

Schematic representation of the geographical railway network used by the Swedish Transport Administration

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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 is imposing larger costs and they have a possibility of inconsistency in accuracy of these 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 is aimed to examine ArcGIS Schematics extension for automatically generating the schematic map from a geographical database that is suitable for railway applications. In addition, it wants to evaluate the data in the current database provided by the Trafikverket for creating the schematic maps as a suitable input for ArcGIS Schematics. The results show that the ArcGIS Schematics extension can automatically creates the schematic map for railway networks, and it makes the situations much easier for Trafikverket that currently they create the schematic maps manually. In addition, the evaluation of current data uses in Trafikverket shows that the 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

Swedish Summary

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 forskning syftar till att undersöka hur ArcGIS Schematics automatiskt kan generera den schematiska kartan från en geografisk databas som är lämplig för järnvägsapplikationer. Dessutom vill den utvärdera om de data som finns i den aktuella databasen som tillhandahålls av Trafikverket kan användas för att skapa schematiska kartor som en lämplig ingång för 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, utvärderingen visar att av de data som används av Trafikverket för närvarande kan matchats med 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.

Terminology

- **Avvikande Huvudspår:** This is a deviant track which is extract 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 the position and location of an object which is linked to the rail network.
- **Normal Huvudspår:** The main track is a track with 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.
- **RefLinkPart Data:** It is a linear transport network element and is described by a sequence of transport links, thus it is the geometric representation of the reference system. Which here, the reference system is a linear reference system for representing the roads and railroads.
- **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 the precise and exact data between varieties of stakeholders. In addition, the efficient Geographical Information Systems (GIS) encourages the railways 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. Since maps combine pictorial and symbolic representation, they are interesting with respect to organizing the included data. Examples of such data are images, annotations, text such as names or descriptions of places, and representation of actual elements in the world by different colors and types. In this study, this map was denoted as a *geographic map*. Examples of the geographical maps are the city or country road or railroad network maps (Berendt, et al., 1998).

Another method for presenting data is schematic maps. In the schematic maps, the distances and directions are not assessed in the same way as in the geographic maps (Berendt, et al., 1998). The schematic maps express only essential and important features, such as connectivity and stops on transportation maps. Therefore, they only have linear cartograms designed 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 representations are studied in this report. One is geographic representation whose main issue is for representing any fields that studies a certain phenomenon on, over, or under the surface of the Earth (Yuan, et al., 2004). One of the important applications of the geographic representation is the geographic representation of the 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 could utilize haptic or audible 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 railways network, 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, or
- Sometimes, the data needs to be improved to better represent the reality.

Recollecting the data about the features in the network would be essential to reuse the geometry data in the system by using their relations. Improvements in the quality of the data geometry or changes of the railroad designations continuously influence on changing and improving data in the database which causes double updating in the system; one for the geographical representations and one for the schematic representation. In practice, this involves consuming more times and costs (Informationsmodeller, 2013).

Currently, one difficulty which encountered by the Trafikverket is that different representations (geographical and schematic) have to be updated separately imposing larger costs and they have a possibility of inconsistency in accuracy of these two representations. This study examines the relevant studies by executing fact-finding on the Internet and interviews with other 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 in this study is to investigate the link between schematic and geographic representations of the railway network. The specific objectives of this study are:

- To examine ArcGIS Schematics extension for automatically generated schematic mapping from a geographical database that is suitable for railway applications.
- To 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.
- Evaluate the current data model at the Trafikverket as a suitable input for ArcGIS Schematics.

1.4. Methodology

Figure 1.1 demonstrates the outline of the whole project. It 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 with other Railroad Administrations in Europe, their experiences of applying ArcGIS Schematics extension are investigated. After that, the current data in Trafikverket as a suitable input data for ArcGIS Schematics extension are tested. After much editing and improvements of the data, a methodology for creating satisfying schematic maps was obtained. This process also identifies possible shortcoming in the current information model at Trafikverket. For verification the final result, the schematic map for two other central stations is created. Finally, according to the obtained results, the identified objectives of this project are evaluated.

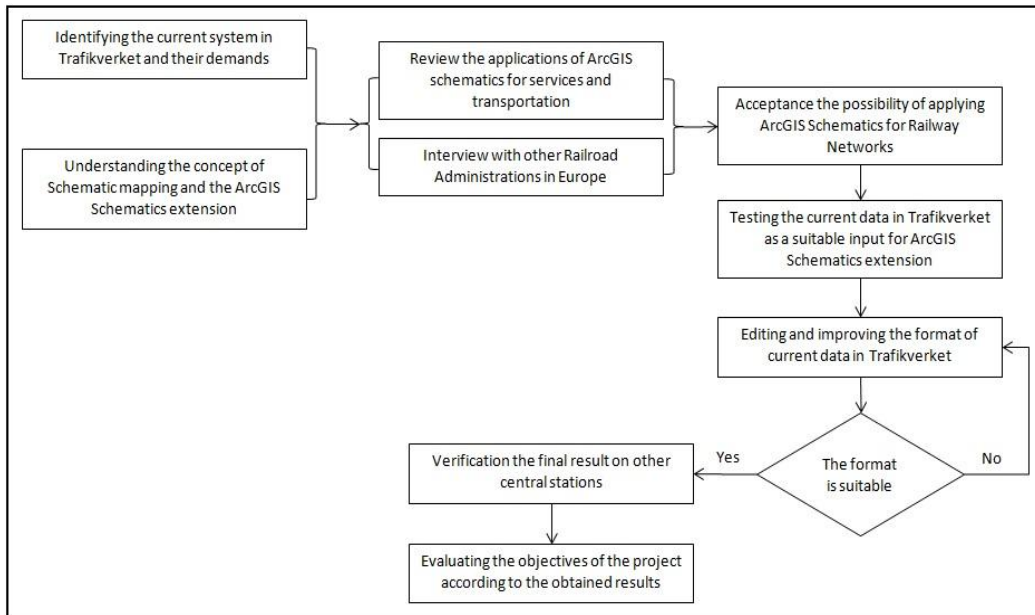


Figure 1-1: The Methodology and outlines of this project

1.5. Scope and Limitations

The scope of this study is the schematic representation of the geographical railway network at Trafikverket, Sweden. This study is started by general information about Trafikverket and railroad information, and schematic mapping. Later, the methods 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. 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 the Trafikverket and Railroad Information is provided. It 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).

In chapter 3, the concept of Schematic mapping is explained. Moreover, different types of schematic diagrams, as well as schematic mapping are introduced. In addition, 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 algorithm and parameters for creating the schematic maps are described. Different elements in the ArcGIS Schematics are also introduced. Hence, the functionality of the applications on the market for schematic representation of a railway network and other related experiences are described.

Chapter 5, the outlook to the other railroad administrations and companies in Europe is highlighted.

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 discussion in chapters 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)

The target of Trafikverket 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. The transport policy goals which they guarantee the socio-economically effective transport supply system for citizens are divided into two subjects: functional goal and consideration goal. The functional goal is about creating the availability for travel and transportation, and the consideration goal is about concerning the safety, environment and health (Sarin, 2014).

The predecessors of the Trafikverket were Vägverket (the Swedish Road Administration) and Banverket (the Swedish Rail Administration); joined in the beginning of 2010. Based on the data and information retrieved in September 2013, Trafikverket has around 6,300 employees. The employees 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).

In 2012, the total annual budget of the Swedish Transport Administration was SEK 51.9 billion, while the major investments were mainly belonged to the railway system. Concerning the public railways, the traffic volume for the passengers was around 97 million train kilometers. For transporting goods, the total traffic volume for railway on state-owned tracks was 42.9 million train kilometers, with the rail transport volume exceeded 21.0 billion ton kilometers in this year (Trafikverket, 2012).

The railway network is a complex and distributed system with a variety of technologies and equipment which function together in order to respond to the demands on capacity and volume, speed, and mobility for transporting the

passengers and goods (Morant, 2014). The railway system is divided into different systems and parts depending on its functionality, such as the track, the rolling stock, the signaling system, the power supply, etc. (Penicka, 2007).

In Trafikverket, a wide network of diverse and combined databases is available which gather information about the railway network. Stakeholders can access these data according to their needs and demands to carry out the 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 the users to see which items compose and design a section of the railroad including the signaling, track components, the power supply, and so forth. By looking for a specific item in this database, it can be seen that what has been installed there and what inspections and checking up have been performed over time. This system is called BanInformationsSystemet (BIS). BIS represents the railway network by the current situation, for example the present. There is no full history, nor is there the option to view online in a future observation date ((Ekström; Gabriellson, 2012). During January each year, the database is archived and therefore by comparing the archived data and information, some important levels of changes can be detected but they are not in detailed (Banverket, 2008).

Since 2013, the Trafikverket has developed and published a new information model which is called Informationsmodell (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 which forming the 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 the BIS system related to geographic and schematic representations.

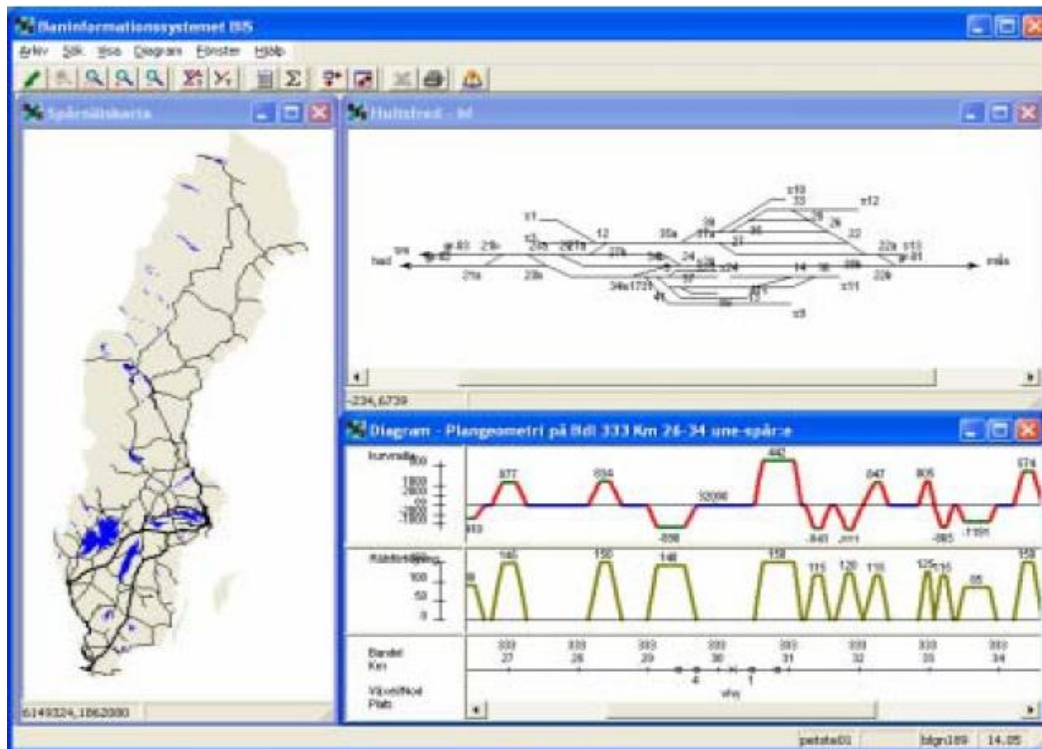
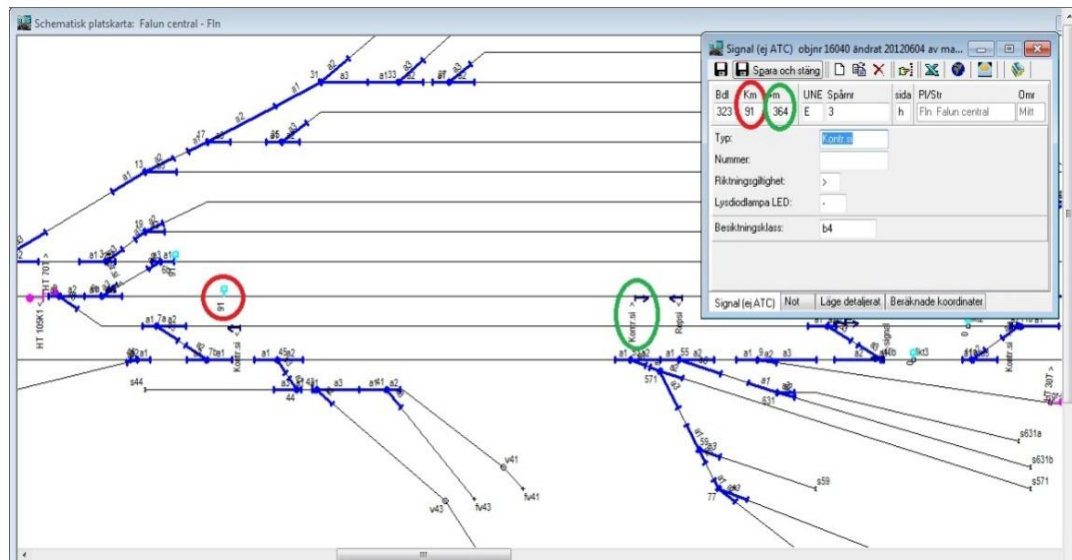


Figure 2-1: The BIS system view

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 while m corresponds to the number of the meters after the kilometertal. The direction corresponds to the length measurement direction. Therefore, the 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 the kilometertal located

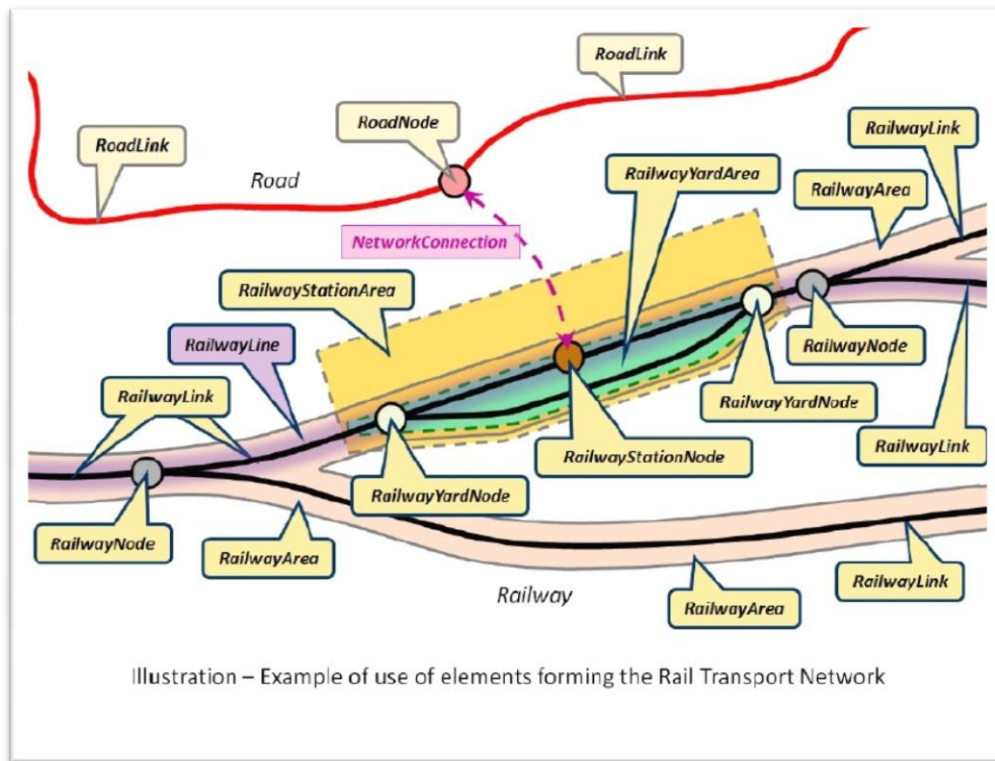
in km 91 (red circle), and an object located 364m after the kilometertal (green circle); thus it can be seen in the property of the object that the location of the object is (km91 + 364m).



**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

The railway network has a basic network structure which includes the topology, network linkage mechanism, 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 the coordinates. Figure 2-3 shows the elements that form the 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.

The node is a point representing a location where the tracks of the vehicles drivability changes as the switches where the track ends. 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.

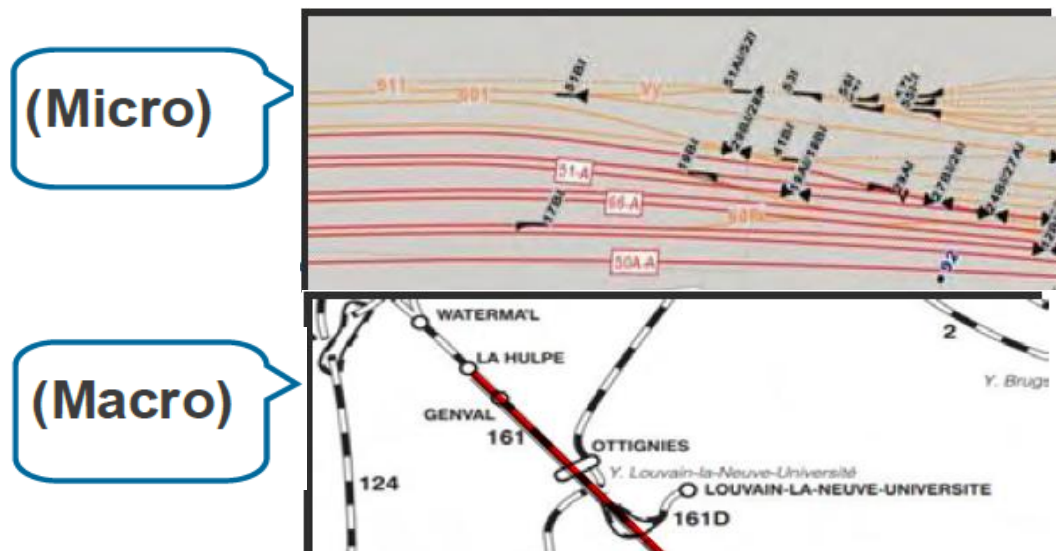


Figure 2-4: Railroad information in micro and macro level in BIS, From (UIC, 2013), p. 21

To describe how the railways are linked in the model, their topology utilizes different parameters such as the node, the track link, the direction, the side, and the connection. 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 the 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 on 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 the link (link mode).

As it was mentioned before, the position statement that is used for the spatial orientation along the track is titled *kilometertal*. The measurements of most items and classifications are reported by kilometertal.

- **Geographical Coordinate System in BIS**

Both the track links and nodes have coordinates in the geodetic reference system SWEREF 99 TM which is the Swedish realization of ETRS89. The connections in the 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 a kilometertal for specifying the locations of the 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 the kilometertal works according to the linear reference system (Ekström; Gabrielsson, 2012).

- **Schematic Representation in BIS**

The schematic maps have a long tradition in railway information systems. The Trafikverket, implemented a geographical representation on micro level, which is covering Sweden nationwide along with a schematic presentation. While in macro level, the semi-geographic macro-representation was created a long time ago. 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. The 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 the kilometal. In addition, it uses the 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 (Informationsmodeller, 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 and data 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, different documents are necessary. For the dated references, the cited version is only valid. Contrarily, for the undated references, the latest version is valid. Most of the ISO standards are approved as the European standards (EN) and then directly it becomes a formal Swedish standard from SIS.

The content and structure for a dataset is identified by the application schema. Its purpose is to setting up and defining a common and correct interpretation of the data. This application is not adjusted by any special hardware or software. The concept schema language in the application schema is the 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).

The 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. 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).

2.3. Report: The Information Model Transport Network - Road and Railway (Informationsmodellern)

The aim of the new information model describes the transport network (road and railways) for supporting the business of the Trafikverket. In this document, the exchange model, components, or the database model have not been described but they are used as the requirements explanation when such models have to be described. This model is mainly used to manage the Trafikverket's external actor's needs.

The extent of the new information model has to take into account the compulsory requirements of the Trafikverket. In addition, it must meet the requirements of the Swedish Standard (SS 637004) in the data exchange with the NVDB part, along with those parts that meet the new requirements of the Trafikverket, such as the intermodal transfer nodes and managing the multiple levels of the network details (Informationsmodellern, 2013).

- The Reference System in the Informationsmodellern

The aim of the transport network as a reference system is defining where appropriately features such as equipment, construction properties, etc. connect to the network, and thus be able to provide the topological relationships such as borders and intersects. 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 the 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, as examples:

- Connecting the features to the reference system.
- Providing the basic data such as the geometry, the track or type of the roads.
- Establishing a transformation between different reference systems, like between the kilometer system and SWEREF99.
- Selecting the geographic collection such as all the 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, the 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 the 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 a future architecture.

The relations between different parts of the informationsmodeller along with the relationship between the transport network (road and rail) as a reference system and the features connected to the network are illustrated in figure 2-5:

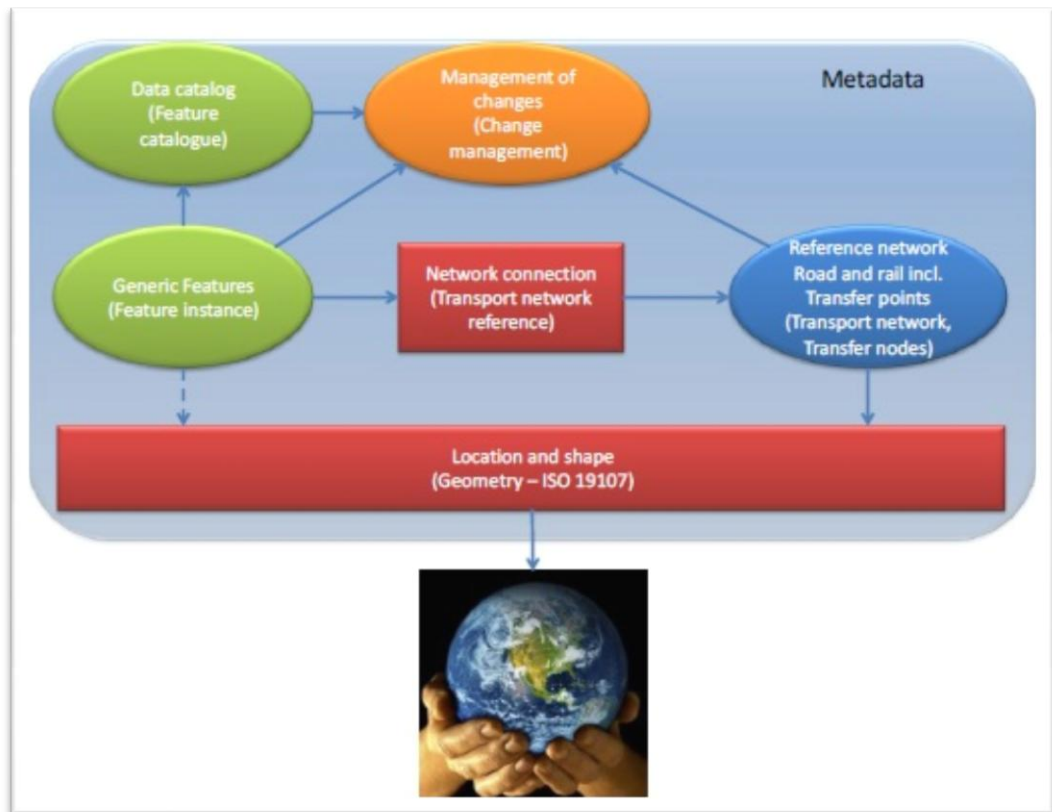


Figure 2-5: Relationship between transport networks, operating data and geography
From: (Informationsmodeller, 2013), p. 8

For describing where the main properties of an actual network are, the reference network is defined. The main properties are:

- The topology for describing the interconnection of the various elements of the network.
- The geometry for describing the location and the shape of different elements of the network in three dimensions.
- The time dimension for describing in what time different elements of the network are presented and existed in reality. Thus, it can be shown in the fourth dimension, the time axis in addition to the spatial axes.

Generic features are defined as anything in a network that has a logical or physical connection to the network. They can be objects such as equipment

related to the road or railroad, events that occur anywhere in the network. The properties that describe the elements of the network are executive partitions and dividers such as the segments in the railway lines and the regulations and rules such as the speed limit.

As regards describing the changes in the data, such as the network connection to the features and the reference network, the change management topic is being raised. The purpose of the change management is to discuss different aspects of change occurrences. Furthermore, it provides the ability of tracing the data and a basis for the exchange of the gradual updates of the data (Informationsmodeller, 2013).

- **Purpose of the Model**

According to the information in the last section, this model should cover the total requirements and supplies for the following areas:

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

Overall, the model would provide a synchronized and harmonized description in the first place of the road and rail networks, out of the same basic model, along with allowing the transitions between different transport networks (Informationsmodeller, 2013).

- **The Railway Transport Network**

The basic model of the 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.

The most significant supplement to the railway networks as a general transport network is the facility to use the kilometetal. In addition, the distances from the

switches which necessitate the trains change their path or travel through these locations are described. Also, 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. The schematic geometry is used mainly for making readable the graphical representations of a complex network, such as the operation station (Informationsmodellern, 2013).

2.4. Current Process for Generating Schematic maps in Trafikverket

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

- The person, who wants to create or edit a schematic map, must get some drawings from the reality or some documents and information about the project from consultants. These documents can be a schematic map on the paper (as word or pdf document), the instruction guidance, or the geographic map. However, for creating the geographic maps after creating the schematic maps, in all these documents, they must have a clear description about the coordinates of the tracks, the switches, the kilometertal, signaling and so on.
- After they gather the documents, they have to create all the nodes and links such as the tracks, the switches, signaling manually in the 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, the BIS could not generate the schematic map itself while the user draws the schematic map according to the position of the station. Then they 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 database is run and the data is exported to the BIS System and the user can apply them.
- The user has to define the new coordinates for all the 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 the new objects.

For creating the schematic maps in BIS, there is not any specific rule or guidelines of how the schematic maps should like. By looking to the 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 distance can be vary from 0 to 100 pixels. In addition, a line can be broken in several points while another line can have no break point. So, personalization view is completely effect on drawing a schematic map in BIS.

Today in Trafikverket, they use schematic maps for the time table, the position of trains (traffic information), and for subways maps. They 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, and for defining the suitable sound distance from the railroads to the houses and for many other different information.

3. Concept of Schematic Mapping

One method for presenting the 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 the 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 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, in which the relationships of the connectivity are highlighted, is provided (Yates; Humphreys, 1998).

3.1. Types of Schematic Diagrams

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

Geo-schematic representation of the data maintains some of their spatial accuracies when presenting the network, but allows independency for modifying some of 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. However, the linear features are exploded, dragged, or changed as required.

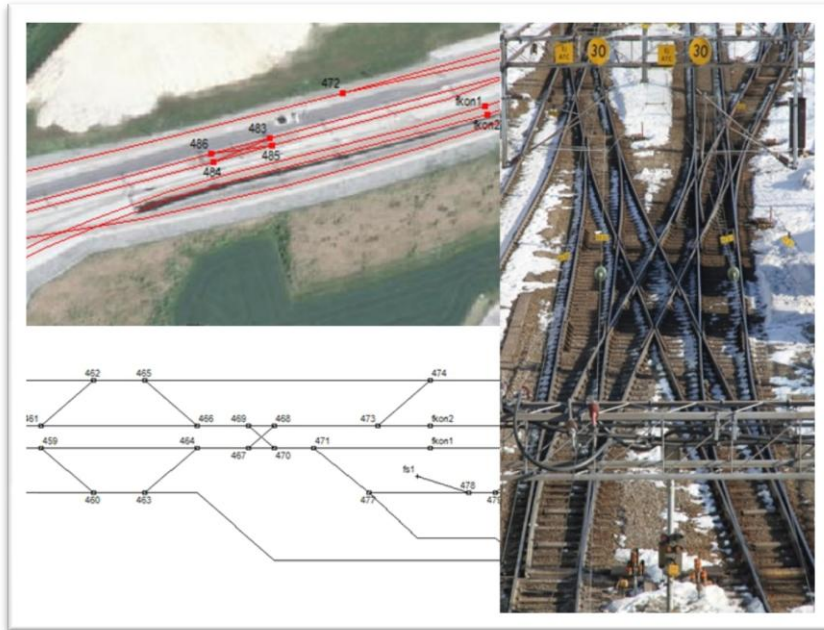


Figure 3-1: Views of the geographic and geo-schematic representations beside the real life of the railway.
From: (Rasmus, 2014), p. 6

Another type of representation is called the purely schematic representation wherein the geographic location of the node is not used for positioning and locating a node in the schematic representation. The nodes are located only because the connectivity and a complete management of their schematic locations are permitted. 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.

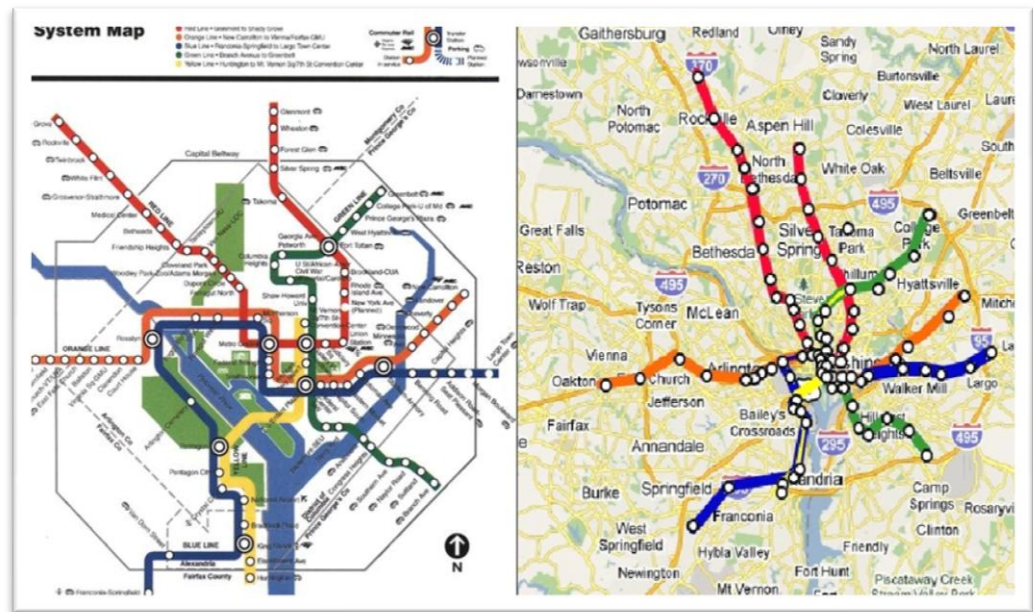


Figure 3-2: Washington Metro Map (Classic and Spatial Map)
From: (WashingtonMetropolitanAreaTransitAuthority, 2006)

3.2. Characteristics of Schematic Maps

The routes on the schematic maps are commonly drawn straight. The lines have different directions with fixed and stylized angles, such as 45°, 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 and agriculture, finance, and homeland security. Consequently, according to the needs, connectivity can perform in different manners (Esri, 2013).

3.3. Related Studies of Schematic Representation

Hochmair (2009) analyzed how detailed network information in the map of public transportation affects the 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. It also provided the same information as in the schematic map (Hochmair, 2009).

Hochmair (2009) argued that in public transportation systems, the schematic maps help the user to direct their attentions on the decision points and routes; henceforth, they can be derived more easily than by using general maps. Finally, Hochmair (2009) assessed the effect of the 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 the cartographic map of the 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 because the 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 the 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 the network data, highlighting that the schematic maps are useful for presenting the routes and finding the ways. In addition, the components used by Ware et al. (2006) for the mobile GIS included a positioning system such as the 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 the mobile GIS applications. They produced prototype software while their results showed that the algorithm they applied was successful in creating schematic maps and 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. Advantages and Disadvantages of Schematic Maps

The advantage of using the schematic representation can be observed when it is applied to 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 a schematic and a 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: while one type is the ordinary geographic city map for finding 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).

The ArcGIS Schematics is a way for automating the 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 the ArcGIS Schematics, it is possible to:

- Automatically generate the schematics 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 which they include the schematic builder, schematic rules, and the automatic layout (figure 4-1). These components can be arranged as a repeatable process for generating the diagrams (Esri, 2014b).

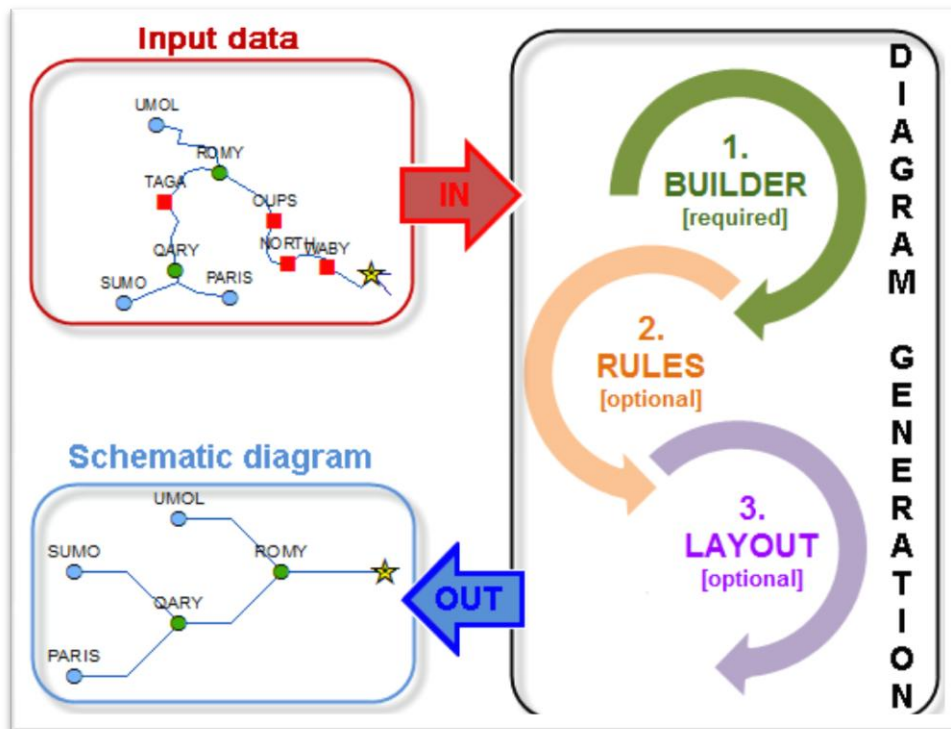


Figure 4-1: The process of generating the Schematic diagram.
From: (Esri, 2014b)

The 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 the schematic diagrams is 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 are applied for clarifying the space between the schematic features. In addition, the 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 a transport network is Relative Main Line Layout. It works with the 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).

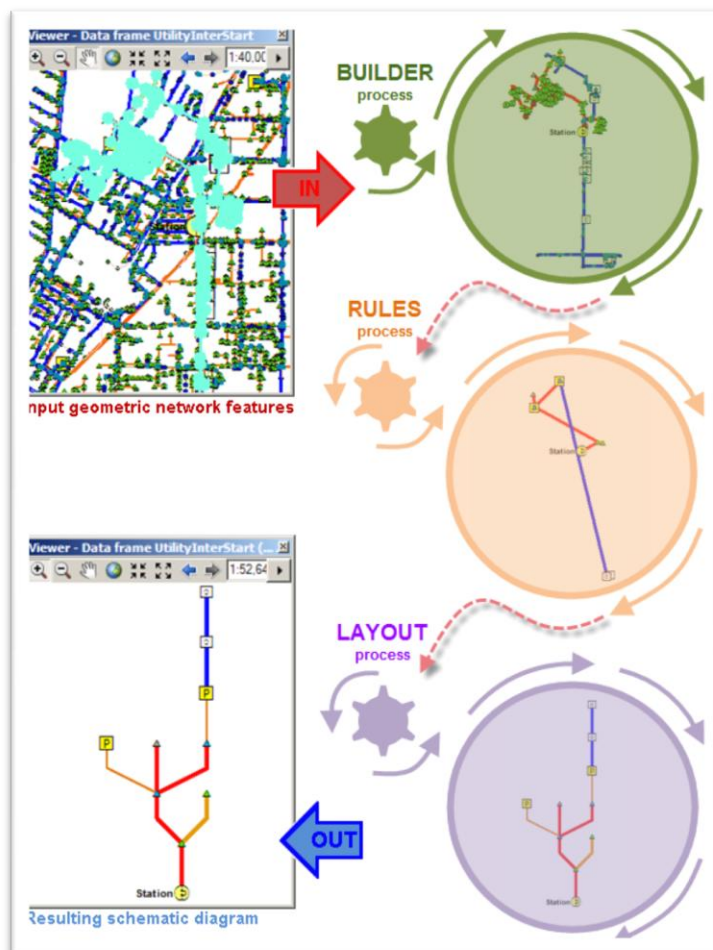


Figure 4-2: The process of generating schematic diagram based on geometric network features.

From: (Esri, 2014b)

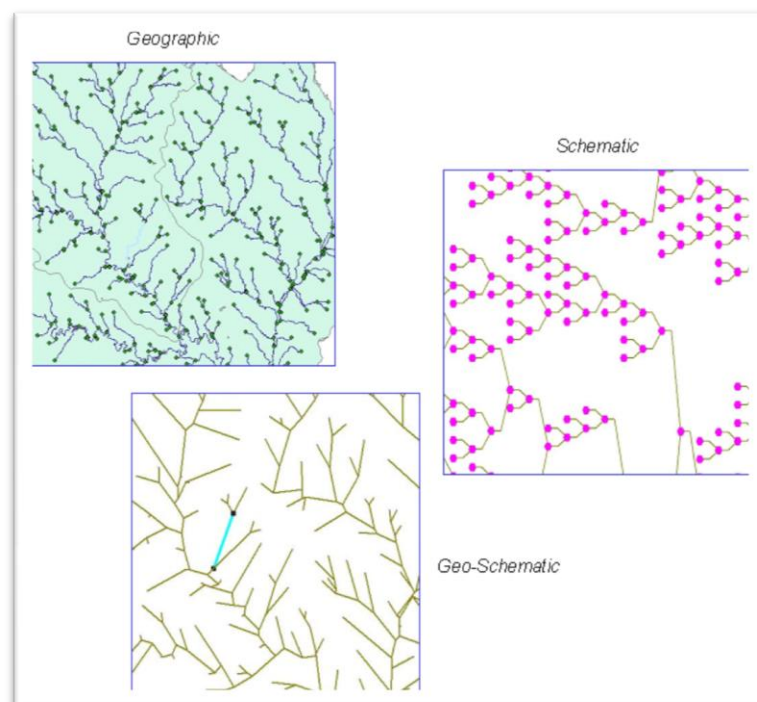
4.4. Important Features of ArcGIS Schematics

- Automatic Diagram Generation

By the ArcGIS Schematics, the geo-schematic and pure-schematic views can be automatically generated from the existing network data. Using the 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 is possible to be seen by the 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 the 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**

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

Since the 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**

The ArcGIS Schematics relates directly with the features in the geo-database and it avoids duplication. Therefore, the results of the 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 properties in the geo-database results in preventing the differences between the schematics and the database to occur while eliminating the demand for an extra database. For easily integrating, editing, and multiple-user accessing, all the information is stored and saved in a geo-database (Esri, 2014a).

- **Customizable Algorithms**

The ArcGIS Schematics has layouts adjusted to several application areas. It means consistent with variety of demands, 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 the diagrams of outside and inside plants. 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, the 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 the 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 the 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 the ArcGIS Schematics is reading networks, repossessing the 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, the 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,

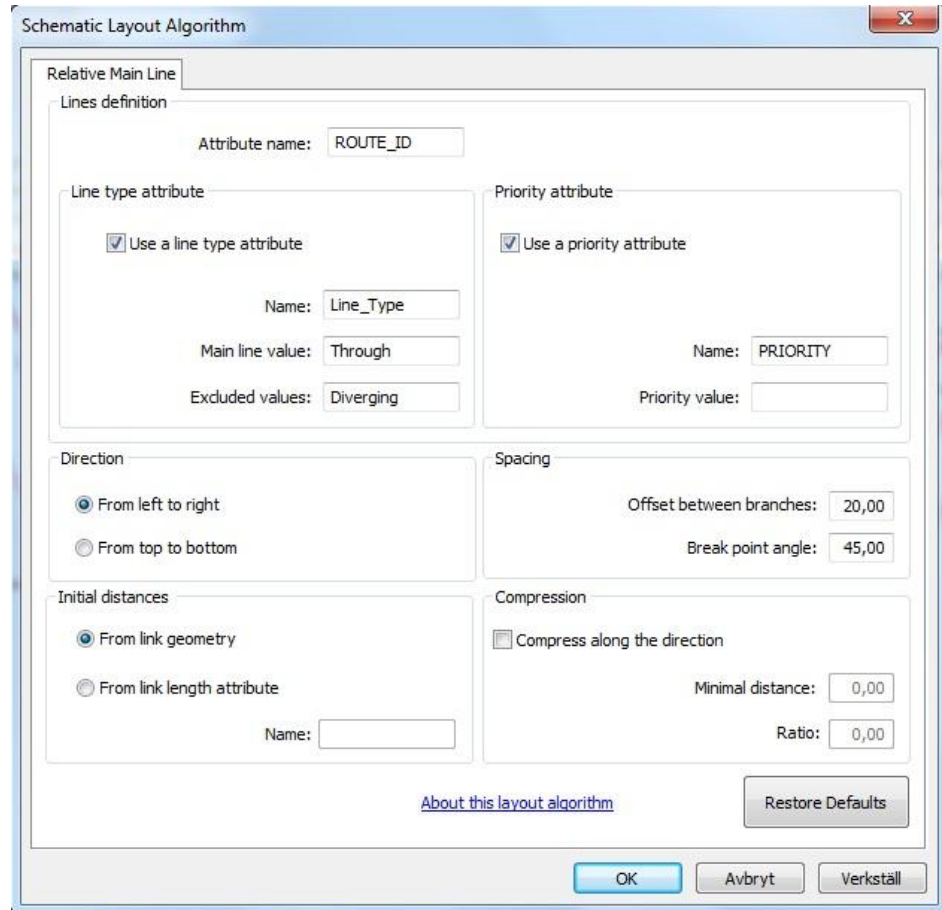


Figure 4-4: The parameter settings in the Relative Main Line Layout Algorithm.

All these setting in Relative Main Line Layout algorithm are constant, and did not chance 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. Applying ArcGIS Schematics for Services and Transportation

Commonly, in transportation administrations systems, one database stores and maintains the features of a geographic information system (GIS) while the other database or a separate set of applications maintains and keeps the schematic representation of those features. However, the data which are

derived in the 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 the 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, the clients and users of the ArcGIS Schematics extension believe that while installing it, special considerations should be given to its data model, especially to the storage and maintenance of the connectivity of features (Esri, 2006b).

4.10. Other Applications of ArcGIS Schematics

It needs to be asserted that there are other experiences on using the 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, the map perspective, and orientation. These problems make reading the map difficult. Having used the format and style of schematic representation of Harry Beck's London

Underground, Field (2009) made visible a network of trails and lifts; therefore, he improved the user's ability to navigate in the mountains (Field, 2009).

Field (2009) captured the route data by the GPS. Afterwards, he applied the data interoperability tools for importing the data into ArcGIS 9.2. The ArcGIS Network Analyst tool was used for defining the topology and creating the network dataset. It could be used in the ArcGIS Schematics extension for generating the geo-angled direction of the 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 reduced 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) in his report was to extract a type of a trail map by applying similar techniques for creating a schematic map (Field, 2009).

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, the Qtel developed their software created on Network Engineer and ArcGIS Schematics, facilitating the network planning and its maintenance. During the project, the ArcGIS Schematics were customized especially for the 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 the ArcGIS Schematic helped the 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 the ArcGIS Schematics extension are asked from them (the questionnaire is available in Appendix 1). After gathering the questionnaires and obtaining their answers, their experiences are listed below:

- **The ProRail Company**

The ProRail in Holland is the 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. The 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 the 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 the ArcGIS Schematics, because the 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 the ArcGIS Schematics for testing them.

ProRail used the ArcGIS Schematics for a pilot to evaluate the ArcGIS Schematics extension. They found some advantages associated with using the 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 the data from the other sources such as the SAP (the Structural Analysis Program).

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

- The outcome is not a feature class and it needs a 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 the 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.

- **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 the RFF only uses the 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, the RFF only uses the ArcGIS Schematics for presenting their schematics map and they believe that one of its benefits is the ability to use the ArcGIS Server. They can directly connect to the server and create their schematic representations easily. They also use the 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 the 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 the Avesta Krylbo central station. Avesta Krylbo station located at Stationsgatan in Krylbo, about 4 kilometers from the Avesta center.

The 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 the 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.

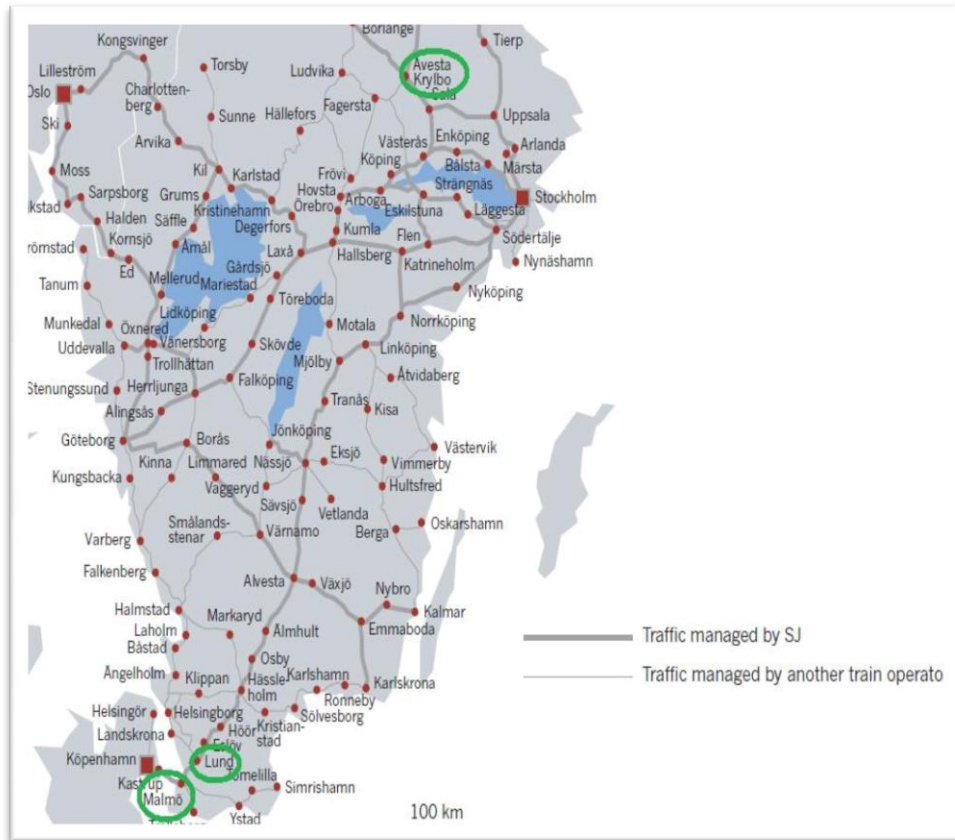


Figure 6-1: The position of Avesta Krylbo, Lund and Malmö central stations in Sweden.

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, different geographic data are retrieved from Trafikverket and tested in ArcGIS Schematics extension. They were:

- 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 the information about the switches.

4- The Spårnummer feature class which has the 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 the locations where the network ends. For describing the manner of traveling between the nodes in the network, the links are defined, each of which 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, at the beginning, 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 the 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 briefed below:

- 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:

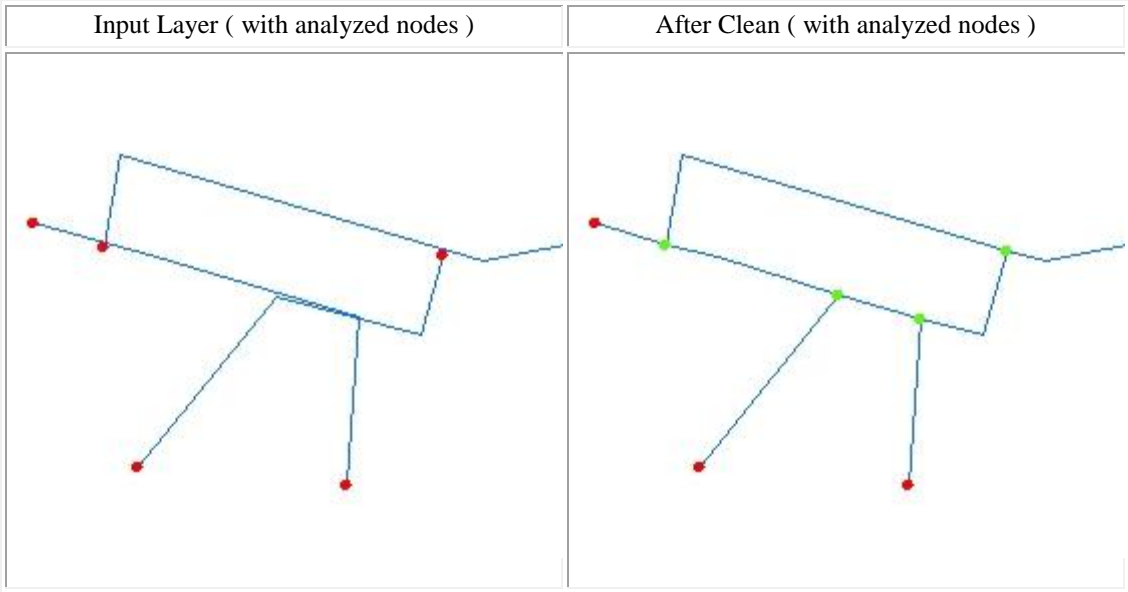


Figure 6-3: Example of TransportLinkSequence
From: (Tchoukanski, 2013)

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).

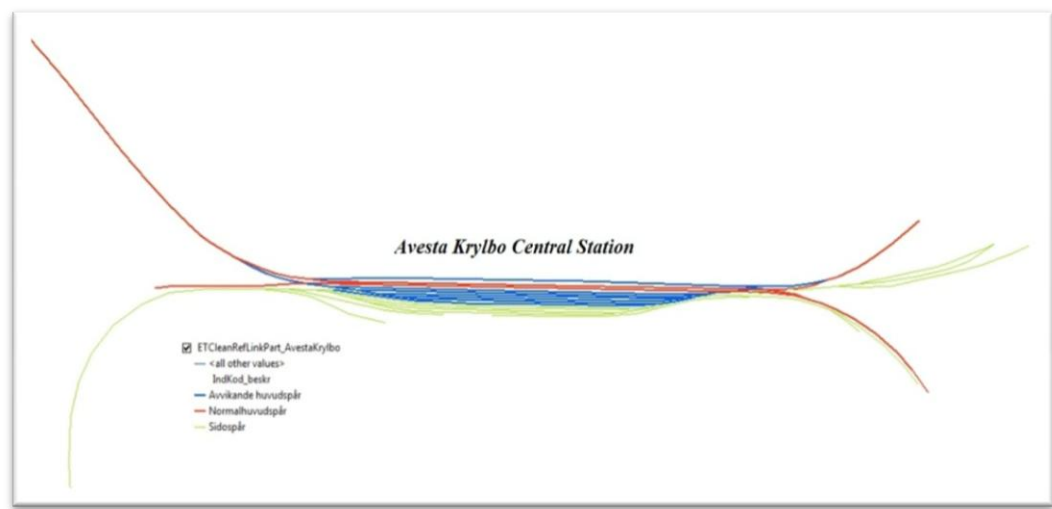


Figure 6-4: The geographic view of the Avesta Krylbo central station with identifying different types of tracks

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 place 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 place of switches between the tracks is empty (figure 6-5).

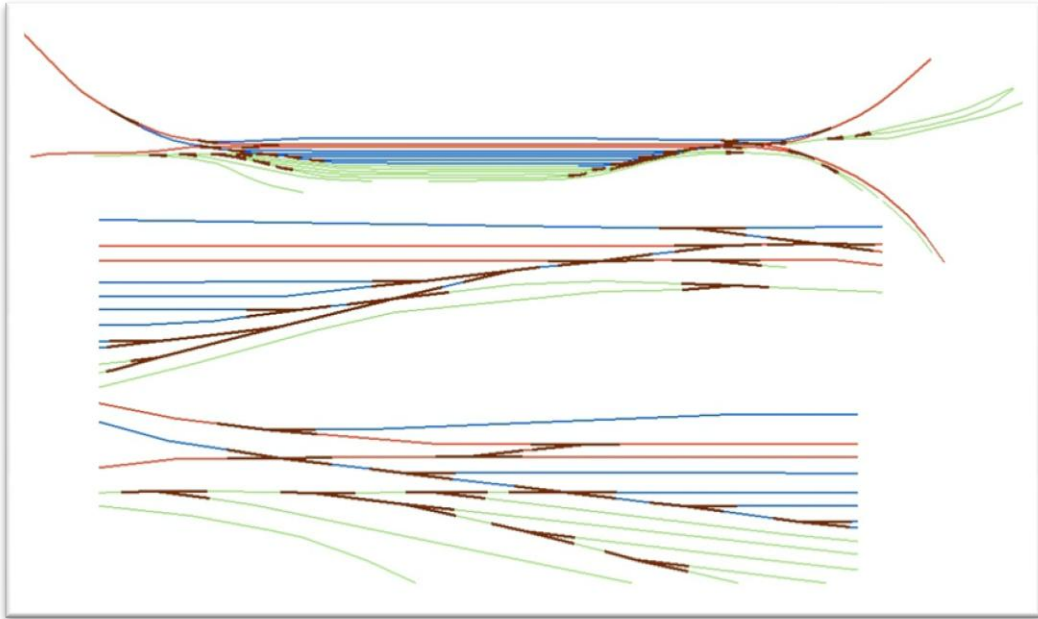


Figure 6-5: The geographic view of the Avesta Krylbo central station with assuming different types of tracks and switches

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 switches with 2 legs. 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).

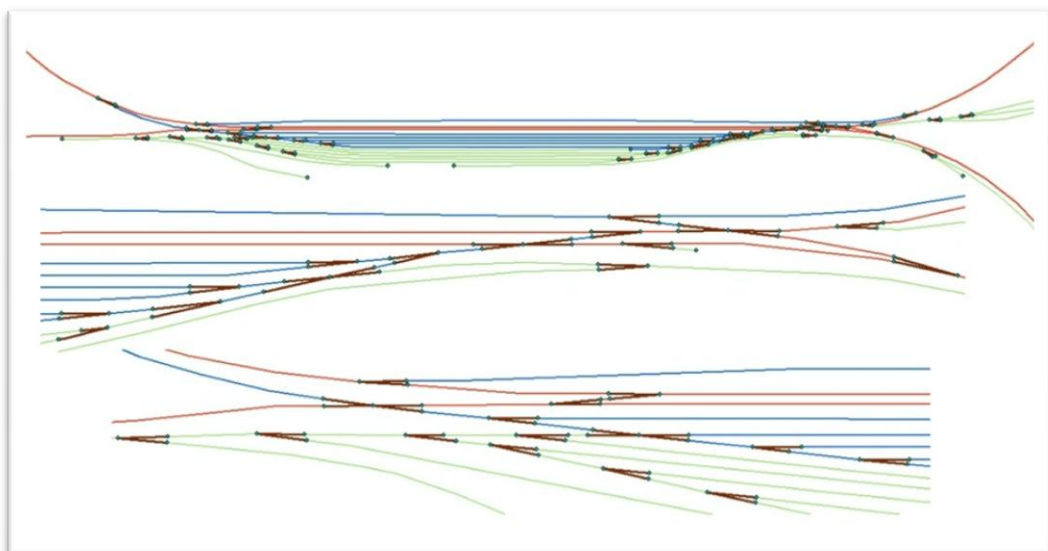


Figure 6-6: The geographic view of the Avesta Krylbo central station with assuming different types of tracks and switches with two legs

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).

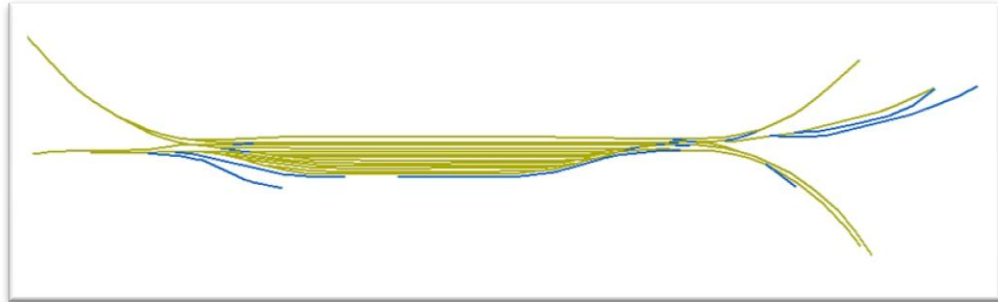


Figure 6-7: The geographic view of the Avesta Krylbo central station with assuming new attribute (`LINE_TYPE` 0 ; 1)

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 place 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 where the places of switches were empty.

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 to change their routes, therefore, they exclude from the main lines or switch legs.

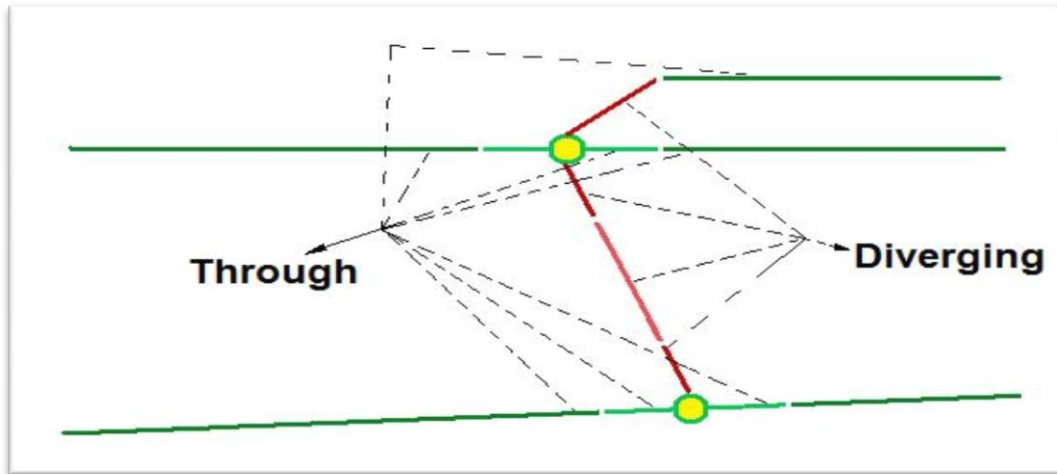


Figure 6-8: The illustration of the Through and Diverging tracks and switch legs

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

- 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 the 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

- Import the feature classes and the geometric network from the intended .mxd file,

In the 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. The complex description of how a schematic map generate in ArcCatalog tab and in ArcMap are explained in Appendix 2.

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. Different 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. Although the BIS do not generate the schematic map automatically and the users would decide how its shape could be; however, it is used as a model for me and tried to get a similar shape to this, because the BIS users fulfill the current requirements on a schematic map.

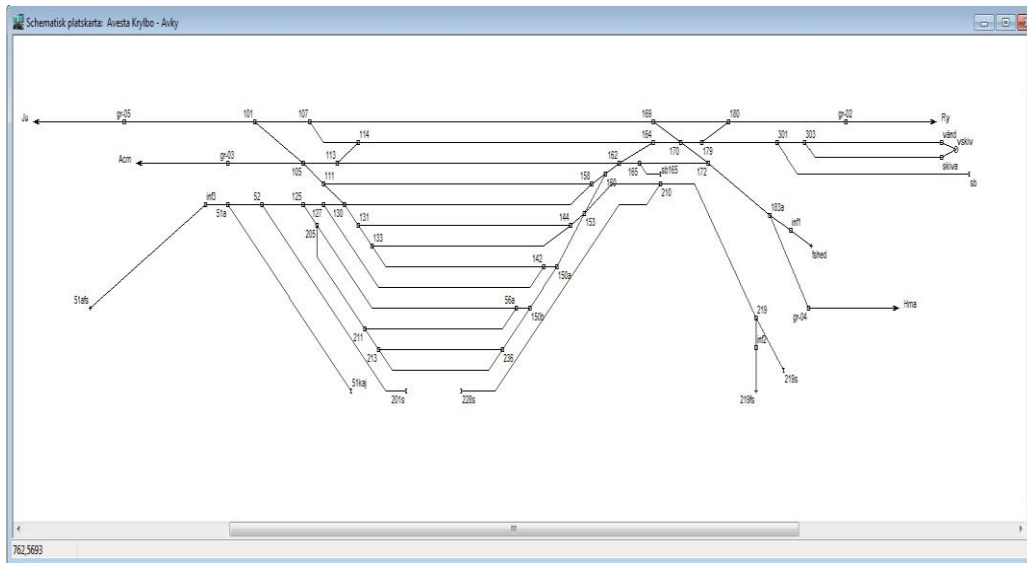


Figure 7-1: The Current Schematic view of the Avesta Krylbo central station at Trafikverket.

As it was mentioned in section 2.4, for creating the schematic maps in BIS, there is not any specific rule. But it can be estimated that the break point angles can be 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 45° were constant for all steps. The values for line type definition were different in each step that they will introduce respectively in the following.

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 the 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 the 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.

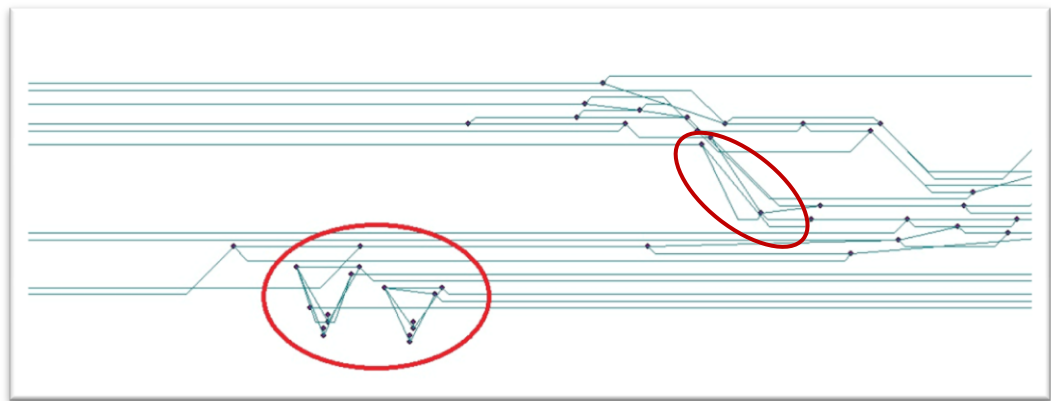


Figure 7-2: The schematic view by applying only the RefLinkPart data

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.

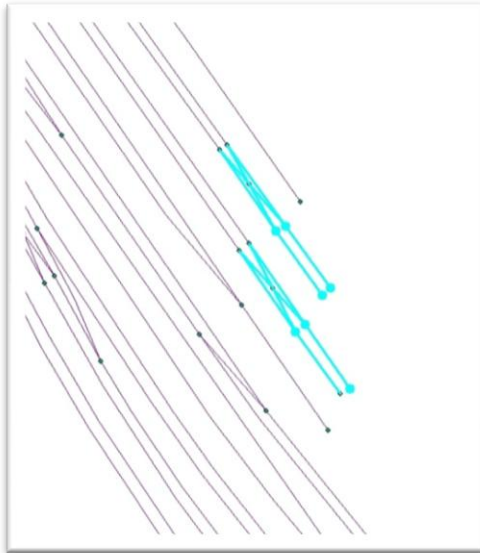


Figure 7-3: The geographic view of some crossings in reality

Stage 2:

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

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

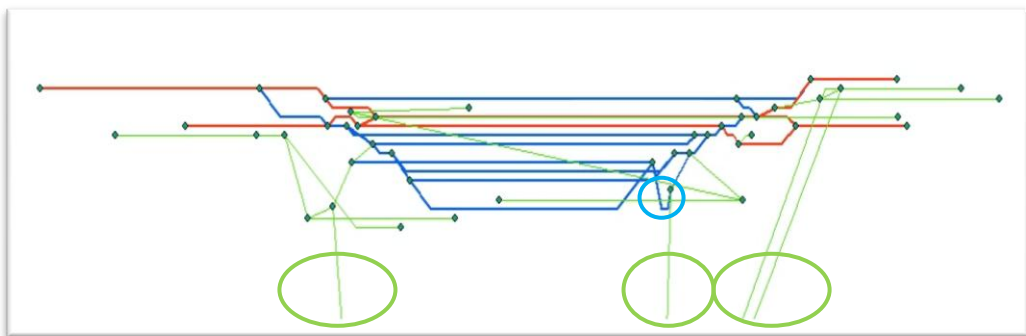


Figure 7-4: The Schematic view of Avesta Krylbo central station with specification of different track classes

The map in figure 7-4 shows that 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 compare 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 bellow:

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

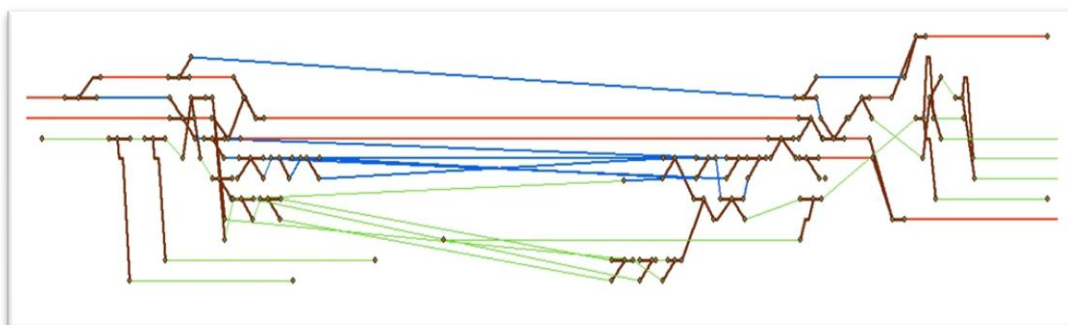


Figure 7-5: The Schematic view of the Avesta Krylbo central station with assuming different types of tracks and switches

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 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.

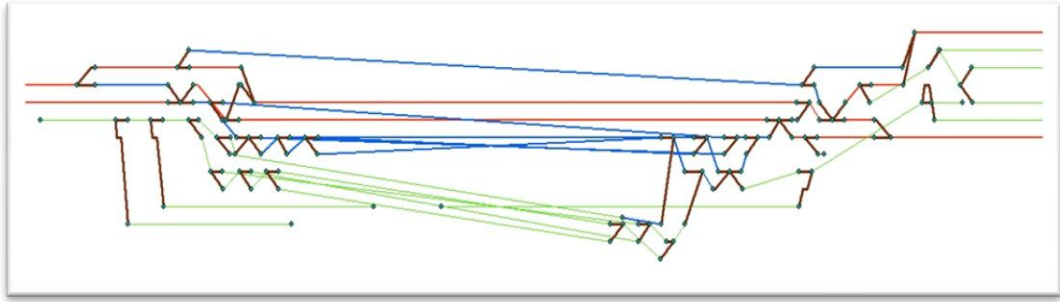


Figure 7-6: The schematic view of the Avesta Krylbo central station with assuming different types of tracks and switches with two legs

Finally, by adding the new feature type (LINE_TYPE) to the attribute of the feature classes, it is needed to be mentioned that the obtained result here was really more transparent and so 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.

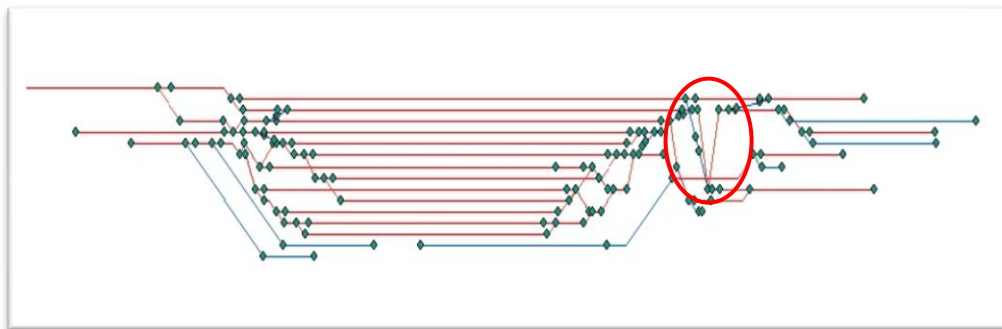


Figure 7-7: The schematic view of the Avesta Krylbo central station with assuming new feature type (LINE_TYPE 0 ; 1)

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.

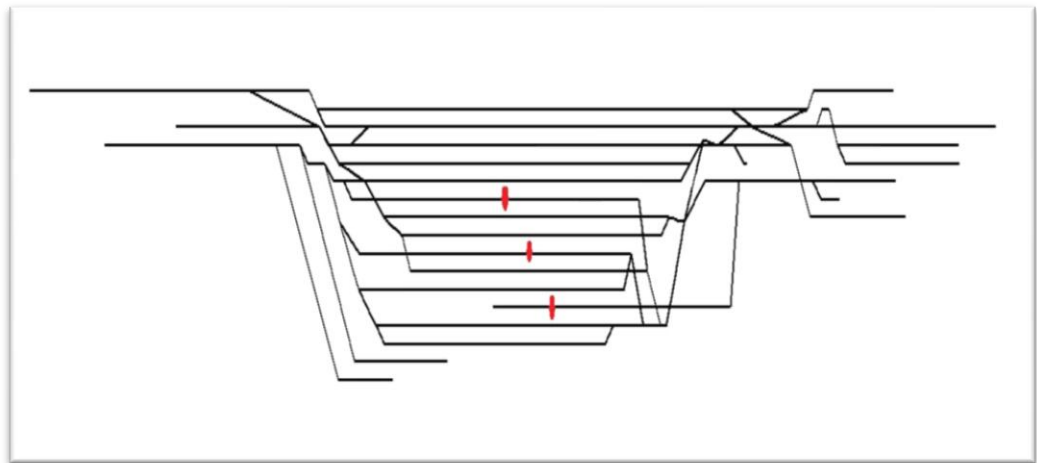


Figure 7-8: The schematic view of the Avesta Krylbo central station with creating the new feature type definition (LINE_TYPE Diverging ; Through)

7.2. Manual Editing

Since the 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 the 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 shape as the Trafikverket's schematic map in BIS was obtained (figure 7-9).

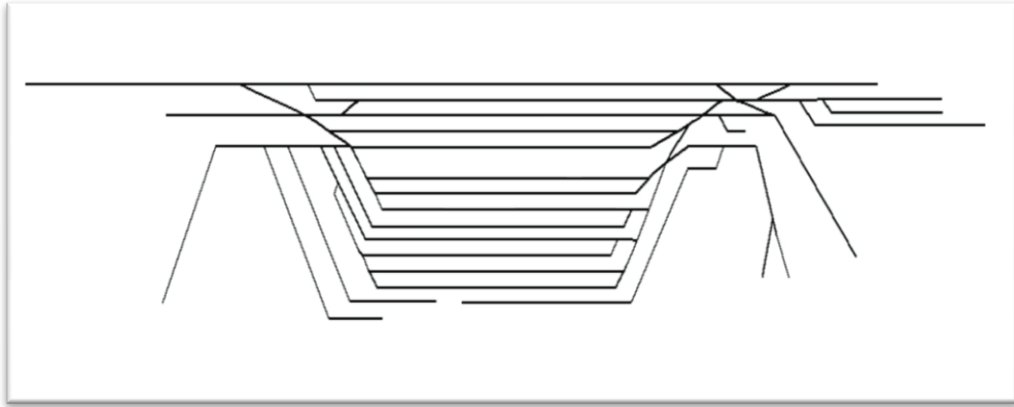


Figure 7-9: The schematic view of the Avesta Krylbo central station after some manual editing

7.3. The Schematic Map for Lund and Malmö Central Stations

At the end, the ArcGIS Schematics extension was tested for two other stations: Lund and Malmö central stations. As mentioned in section 6-1, the Lund central station is a little bit bigger and more complex station than the Avesta Krylbo central station. 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.

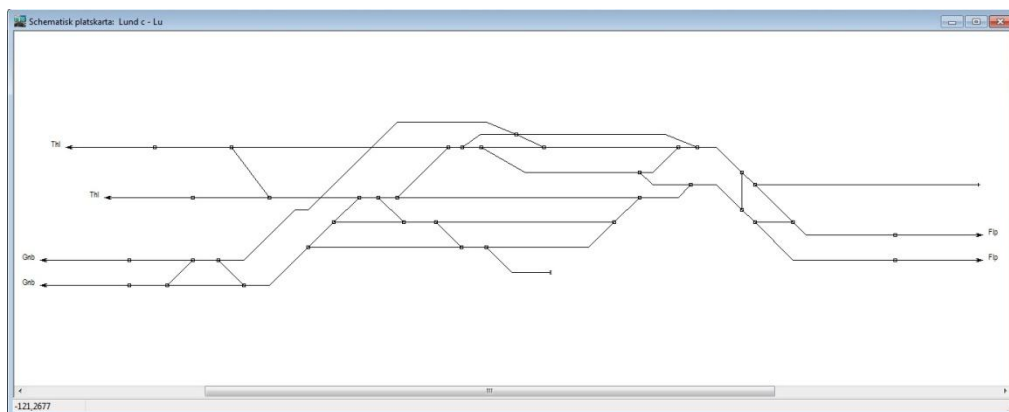


Figure 7-10: The schematic view of the Lund central station in BIS

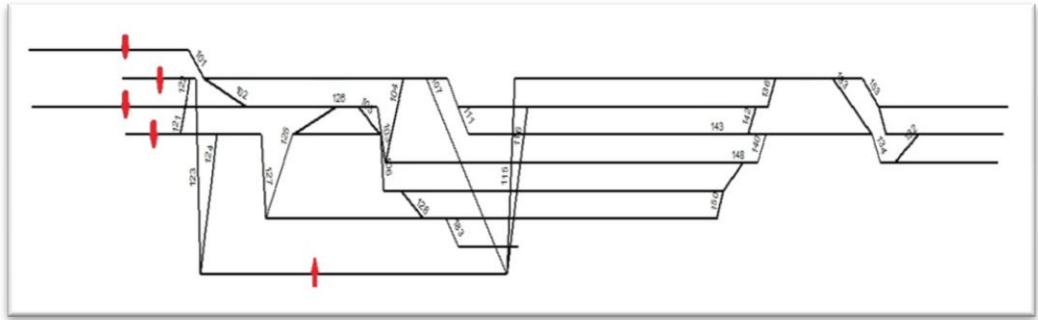


Figure 7-11: The original output of schematic map of the Lund central station from the ArcGIS Schematics

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 true position, the exact schematic map as the schematic map in BIS in Trafikverket was obtained (figure 7-12).

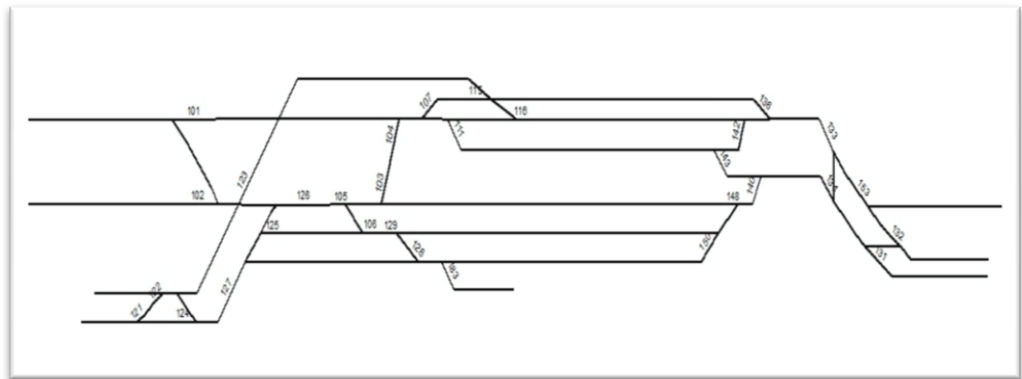


Figure 7-12: The schematic view of the Lund central station after some manual editing

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.

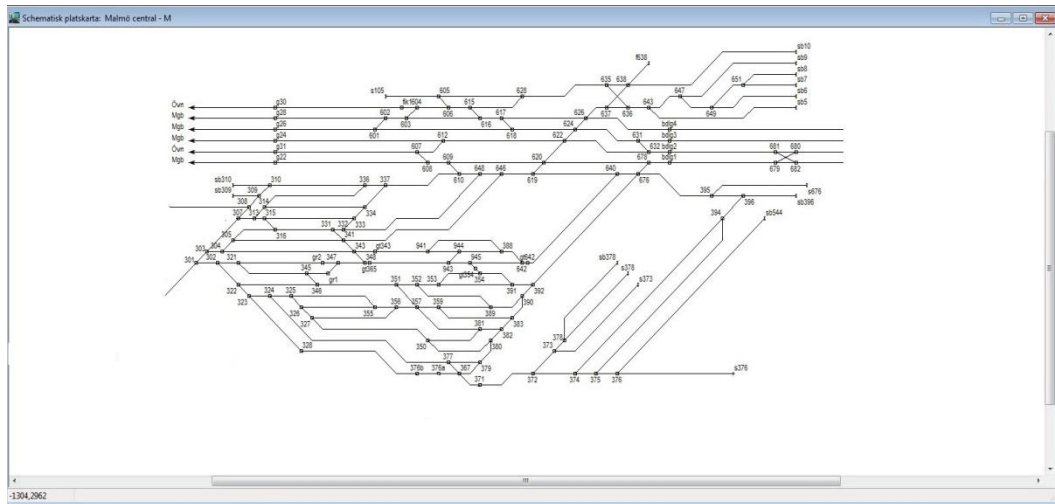


Figure 7-13:- The schematic view of the Malmö central station in BIS

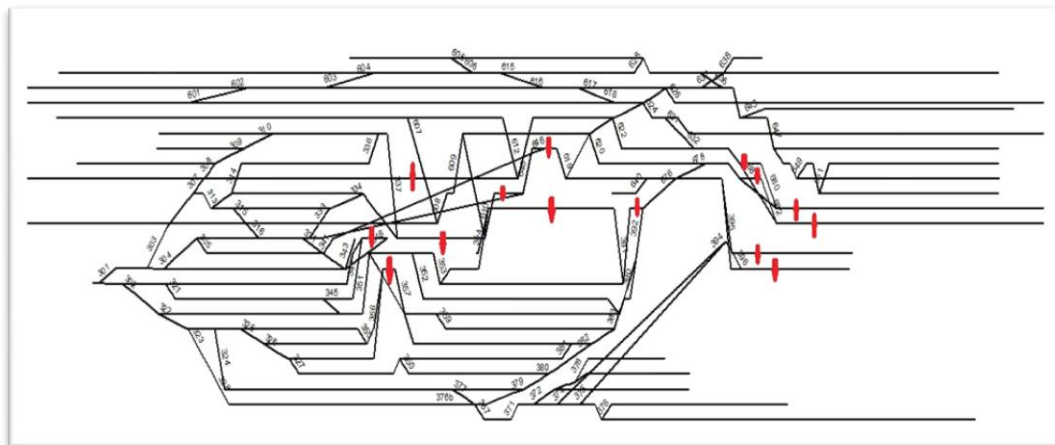


Figure 7-14:- The original output of schematic map of the Malmö central station from ArcGIS Schematics

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 tracks. The result of the original schematic map shows that there is some problem in generating the 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).

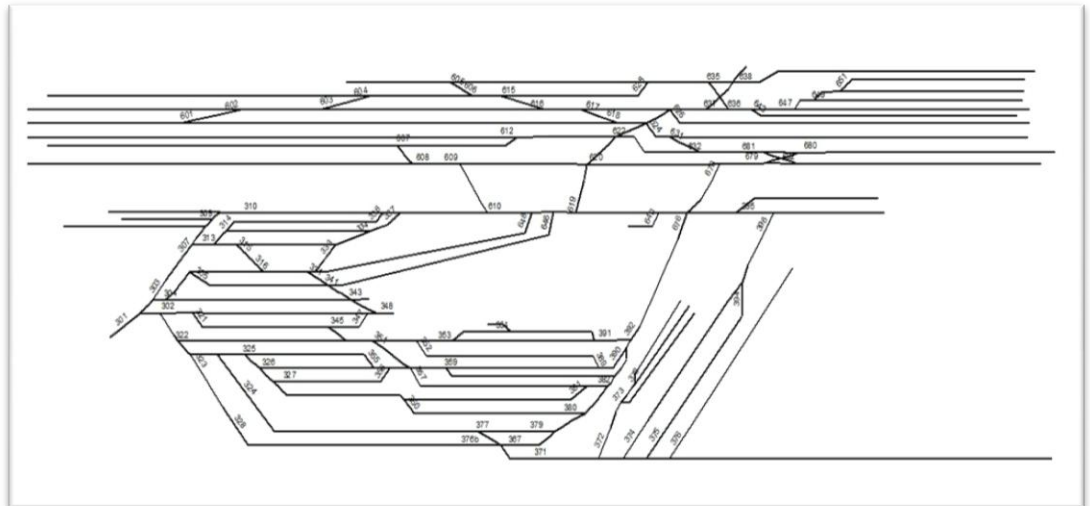


Figure 7-15-: The schematic view of the Malmö central station after some manual editing

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 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 Current and Automatically Generated Schematic Map

Trafikverket currently uses the BIS for creating the schematic map. The users at Trafikverket get some drawing from consultancies, and then they draw it manually in the 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 which is also presented by Trafikverket, uses the same data as is used 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 the 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 Current Data Model Provided by Trafikverket

The main criteria for comparing the creation of the schematic map in BIS and the automatic generation and updating of the schematic map through the ArcGIS Schematics extension are as below:

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

- *Errors*: For generating a schematic map in ArcGIS Schematics and reducing 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.

While there is not any specific rule in the BIS, and personal idea and manual tools for creating the schematic map in BIS increase the probability of errors.

- *The level of generalization*: The high level of generalization and standard parameter setting in ArcGIS Schematics cause the software valid for all kinds of stations. While in BIS it is completely different from one station to another station, and according to their importance and their position it could be varied.

- *Time for creating one schematic map*: For creating or updating automatically the schematic map in example for Lund central station, in ArcGIS Schematics extension, it takes around one hour. Or for Malmö central station, it takes between one and one and half hour. While, creating or updating the schematic map and after that creating the

geographic map in BIS is completely manually and spend too much time (at least one day for drawing the schematic map, the next day for updating the database, and then drawing the geographic map, so around 2 or 3 days is needed).

- *Aesthetic*: Drawing the schematic map in BIS is art and it is completely personalized and the users draw it in the way that it looks nice and completely clear and intelligible. While in ArcGIS Schematics map, some lines (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) do not locate in their true locations and they need to be edited. Therefore, in these places the shapes are not so nice and clear and they need some manual editing.

The criteria for defining the view 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 except the first one in ArcGIS Schematics. In some places that ArcGIS Schematics has problem for truly generation, such as in connection lines between two different routes in Malmö central station, these connected lines across over other lines and intersect them. This event causes the schematic map in ArcGIS Schematics could not be nice. While since the users in BIS draw the schematic map manually and break them in different distances, so the schematic map in BIS is nicer and clearer.

The comparison between the creation of the schematic map in BIS and the generation of the schematic map through the ArcGIS Schematics extension is summarized as table 7-1:

Criteria	Manual work in BIS	Automatic work in ArcGIS Schematics
Manual work	High	Low
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 required improvement of the data at Trafikverket since the special information for creating the schematic map was needed, such as the role of the tracks and switches. The “Line_Type” feature type was needed to add to the attribute table of their data, either the RefLinkPart data or the Spårnummer data. Also, for creating the schematic map, the Spårnummer or RefLinkPart data were could not use only, as they just have information about the tracks. The Spårväxel feature class was also needed to use 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 applying the ArcGIS Schematics extension can be generated.

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.

The second problem in this study was the shape of the connection 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, there are several switches connect to each other without any tracks between them.

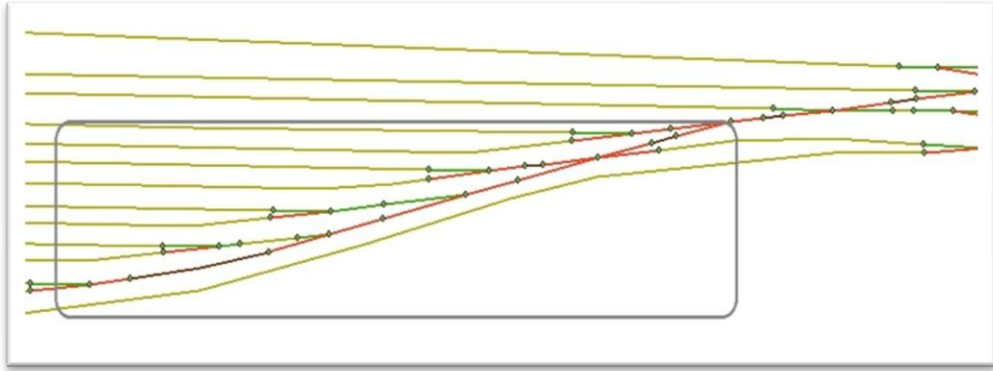


Figure 8-1: The Right side of the geographic view of the Avesta Krylbo central station with a lot of switches connected to each other without any tracks between them.

In this part, there are several small switch legs and nodes (junctions between the switch legs) which are presented but there are not any main lines or 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.

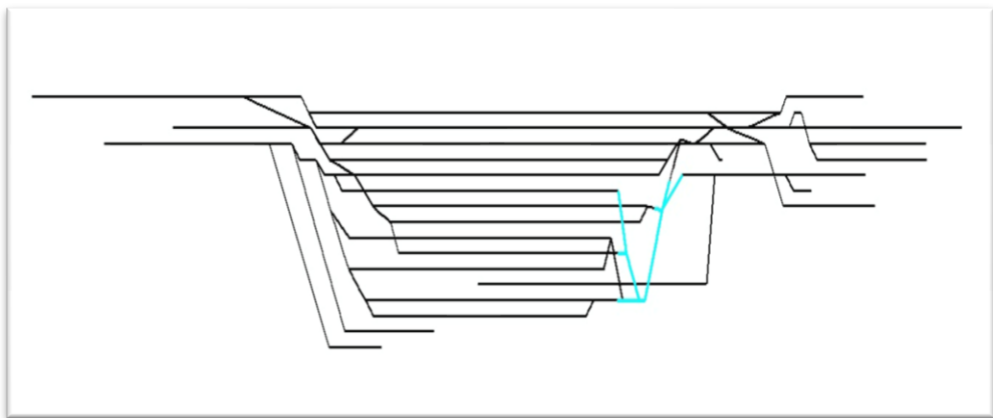


Figure 8-2: The schematic view of the Avesta Krylbo central station with a lot of switches connected to each other without any tracks between them.

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

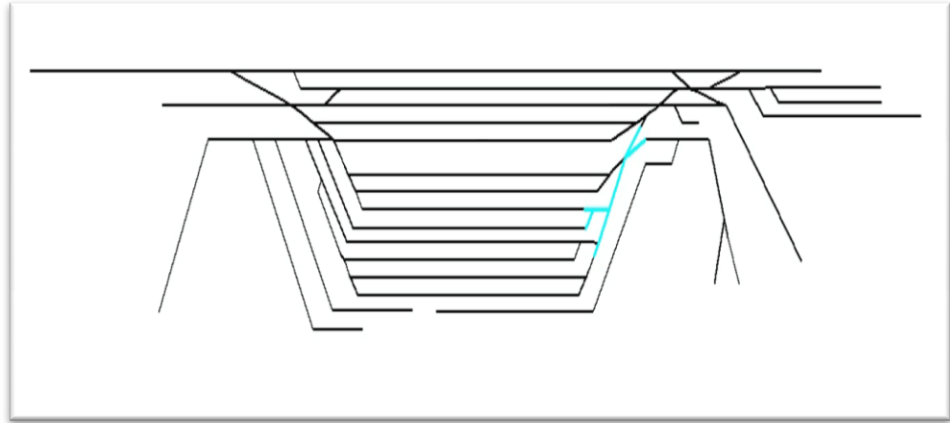


Figure 8-3: The schematic view of the Avesta Krylbo central station with a lot of switches connected to each other without any tracks between them (After manual editing).

Consequently, it can be inferred that it could be the weakness of the software in some special connections, such as in the obtained result in Avesta Krylbo central station that could not distinguish the level of the switches. Therefore, it moved some of the junctions and lines up or down: otherwise, the topology map regarding different connections must be improved, and logical connections represent the reality.

However, the original output of ArcGIS Schematics extension is acceptable for Trafikverket since the time for creating the schematic map and doing some manual editing is so low. 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.

9. Concluding Remarks

9.1. Conclusions

In this study we examine methods for automatically generated schematic map from a geographic database 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 the ArcGIS automatically can be generated, while it was intangible for Trafikverket. Until 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 the situation for automatically creating and updating the schematic map for them more easily.

The second objective of the study was to explore whether the ArcGIS Schematic meets the requirements of the railway network which are provided by the Trafikverket. It is also defined 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 / Diverging) must be added to their model and also their topology maps so that the comparison of the connections to the reality has to be maintained.

The third objective of the study was to compare the results of this study and the information model within other European companies (such as ProRail in Holland and RFF in France).

ProRail has used the ArcGIS Schematics as a pilot. They also tested it for some stations and found that in their current data model, the switch is a part of the Rail branch, which is not sufficient for using the ArcGIS Schematics. Therefore, they need two switch legs as separate objects. It is the same as that was found in this study; at first the RefLinkPart data was tested, in which the switches and tracks were not separate, and did not yield good results.

Therefore, two separate feature classes were used, one for tracks and one for the switches. Moreover, they mentioned that some improvements were 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. It is also found that some improvements regarding the connections in the topology must be applied in order to obtain better and more accurate results.

RFF also applies the ArcGIS Schematics on small parts of their networks and then paste small pieces together to produce a complete schematic map. They think that 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. They believed that the Esri algorithm is very useful for a small part of a network not for a complex network. Finally, they maintain that one of the main problems with using the ArcGIS schematics is that they need to perform manual editing in their process.

In order to have a complete acceptable schematic map for the final users in Trafikverket, some manual editing was needed to be done to have a nice and acceptable map.

At the end, and to fulfill the last objective in the study, the current data in the Trafikverket were evaluated as a suitable input for the ArcGIS Schematics. The BIS and the new information model at Trafikverket apply the RefLinkPart data to their model. Since their data included the information about the network, it could be matched and be considered as suitable input data for the schematic extension. Nonetheless, as it was mentioned in section 7-4, their data just need to revise and a new feature type (Line_Type) add to them. Then it could be used for the ArcGIS Schematics extension. In addition, the geometric network by applying the RefLinkPart data (the tracks information data) and the Spårväxel data (the switches information data) is needed to create. Moreover, maintaining the topology has been so important.

9.2. Suggestions

At the end, for further improving and developing the model and generating the schematic maps, some actions must be taken:

- A new feature type (Line_Type) must be added to the RefLinkPart data as a suitable input for ArcGIS Schematics.
- Another feature class (spårväxel) must be added that it also have the information about the switches separately.
- Since the RefLinkPart data have the information about the tracks and in the whole network it is expanded, Trafikverket has to erase the place 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 in comparison with the reality.

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

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Appendixes

Appendix 1: 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 2: Detail of Creating Schematic Map in ArcCatalog Tab and ArcMap

In ArcCatalog Tab:

- Creating a File Geodataset for each central station by a right-click on the main folder in the Catalog tree and chose the *New > File Geodatabase* from the pop-up menu.
- Creating a New Feature Dataset in each Geodatabase by a right-click on the Geodatabase in the Catalog tree and chose the *New > Feature Dataset* from the pop-up menu.
- After copying the input data (RefLinkPart data+ Spårväxel data) in the Feature Dataset create the Geometric Network by a right-click on the Feature Dataset in the Catalog tree and chose the *New > Geometric Network* from the pop-up menu.
- Also by a right-click on the Geodataset in the Catalog tree and choosing the *New > Schematic dataset* from the pop-up menu, create the Schematic Dataset.
- By a right-click on the Schematic Dataset and choosing the *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 the *New Schematic Diagram Template* from the pop-up menu.
- o Use the Properties tab and wrote a name for the *Name* field (figure App.2.1).

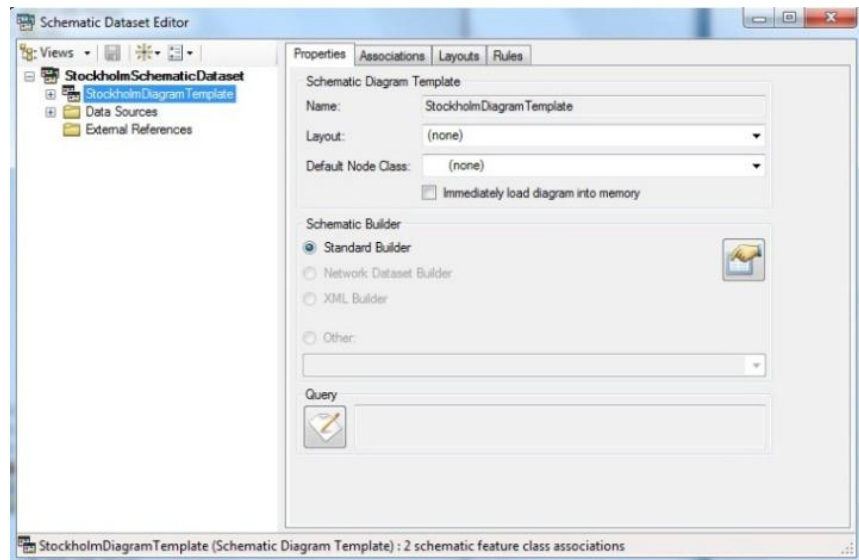


Figure App.2.1: Schematic Dataset Editor Dialog box

- Right-click on the template file and chose Import From Feature Layers from the pop-up menu. Then the *Import From Feature Layers* dialog box was opened.
- By clicking the ellipse button at the end of the *Map or Layer File* input area, the “*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.2.2).

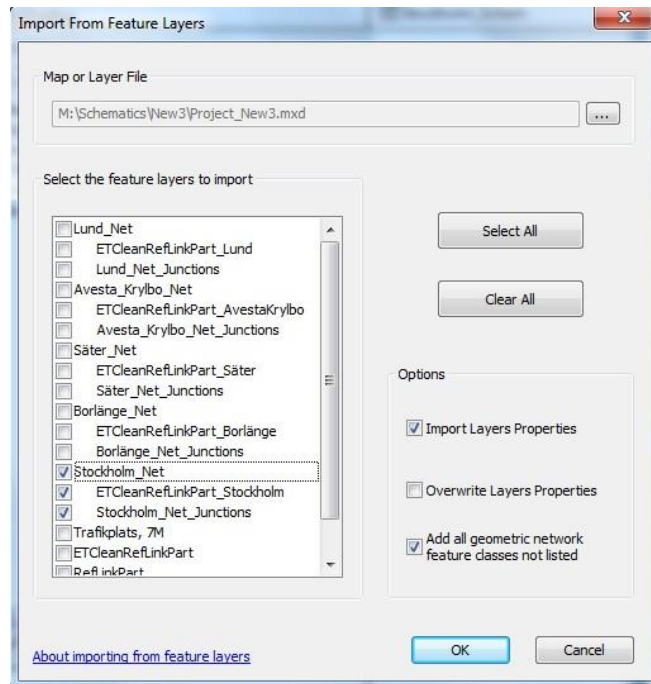


Figure App.2.2: Import From Feature Layers dialog box

By saving the Schematic Dataset Editor Toolbar, a Schematic dataset is configured, and then it was ready to be applied in creating the schematic diagrams in the ArcMap. At this instant, the 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 the ArcMap:

- Select the features that they need the schematic maps are created for them.
- Clicked the *Generate New Schematic Diagram* Button.
The *New Schematic Diagram* dialog box was opened.
- Clicked the 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 the *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 containing the selection set they had just created was selected in the drop-down list (figure App.2.3).

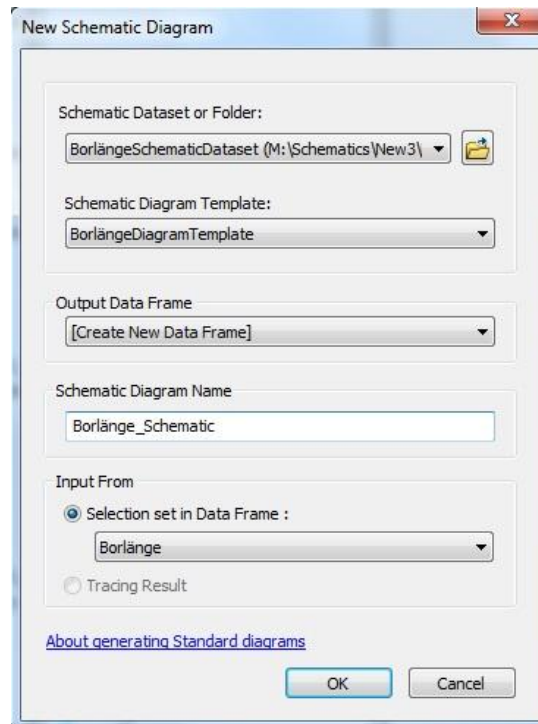


Figure App.2.3: New Schematic Diagram dialog box

By clicking the OK Button, the diagram generation was started and the result of the schematic diagram was displayed.

For changing the layout, at first the Relative Main Line must be selected in Layout Task. Then these setting must be done in the layout task properties (figure App.2.4):

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

- Set other selection according to the demand.

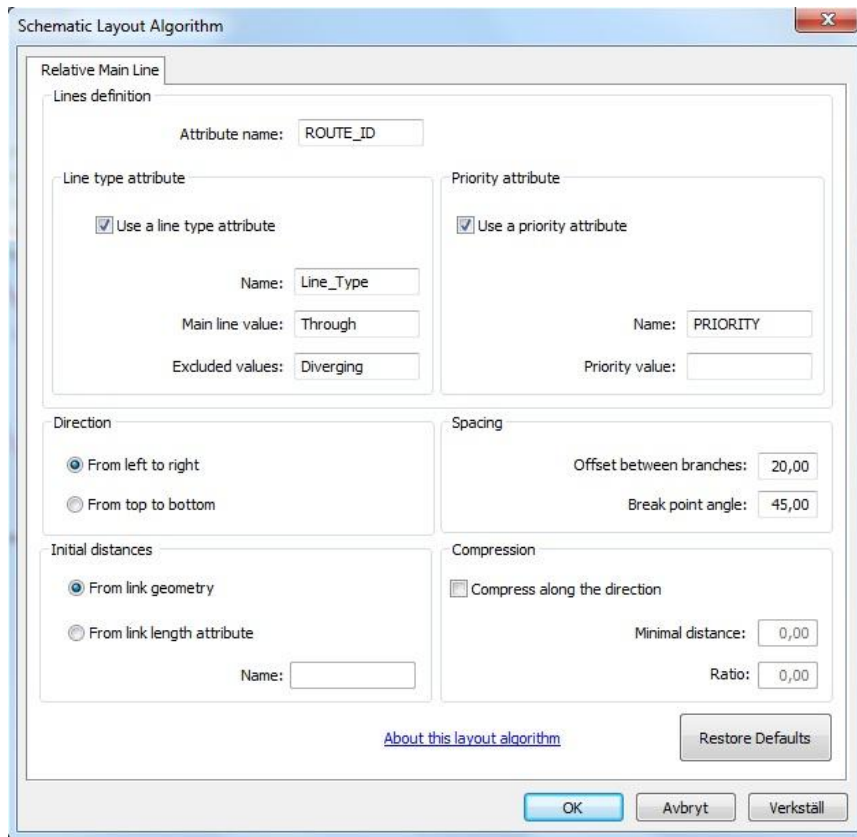




Figure App.2.4: Schematic Layout Algorithm Properties

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

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