MASTER THESIS

Multi-Criteria Decision Support for Transportation Network (Re-)Design at Outbound Logistics, Tata Steel Europe

Lobje Schoon
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Multi-criteria decision support for transportation network (re-)design at Outbound Logistics, Tata Steel Europe

Master thesis for Industrial Engineering & Management,

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Tata Steel Europe
Business Planning & Supply Chain
Outbound Logistics Network Management & Development

Arnold Baas
Matthijs Beukers

University of Twente
Faculty of Behavioural Management and Social Sciences
Industrial Engineering & Management

Leo van der Wegen
Eduardo Lalla

Hot metal flows from the forehearth into a torpedo ladle at the Hisarna pilot plant

Acknowledgements

Since I was young, I saw the magical lights of the Tata Steel plants at the other side of the North Sea Cannel when I visited my family in IJmuiden. It goes decades back when my great grandfather started to work for the steel factory and it stayed until now in the family. This made me extra proud to give a presentation on my elementary school about steel making at Corus, and now – fifteen years later – writing my thesis at Tata Steel Europe.

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IJmuiden, June 2019,

Lobje Schoon

Summary

This research is performed at Tata Steel Europe, a worldwide company that produces, processes and distributes steel. Tata Steel Europe has operations in 26 countries, several plants across Europe and customers in the automotive, construction, engineering and packaging sectors. Delivering these products in their global transportation network is challenging given the 6500 current transportation routes and 2500 network nodes like terminals and harbours. The network management and development department (NMD) manages this network on tactical and strategical level. Distribution chain consultants and logistics analysts are part of this team and aim to design an optimal transportation network. Since the network is continuously subject to change, consultants need to analyse this network from time to time to validate if the current network is still optimal. This process of validation and possible redesign is called a network review.

Current global overcapacity of steel poses a threat to the steel sector's health and prices collapse. This excess capacity creates the need for Tata Steel to differentiate from competition with high quality products and service in order to achieve long-term success. However, Tata Steel lags behind competitors on delivery performance. Customers expect their orders to be correctly delivered on-time. In order to meet these expectations, it is important to create a robust network that is resistant to heavy changes in the network. Yet, it is complex to maintain a robust network due to several challenges: many route possibilities, many modality possibilities, selection of suppliers, continuously changing prices, multiple criteria for a network, dependency of suppliers. Furthermore, the consultants make these decisions individually and no standard process is available.

These aspects increase the complexity of a network review and create a need for uniform support to (re-)design an optimal network. As a result our main research question is:

How can a standardised review of the transportation network improve the competitiveness of Tata Steel Europe?

This question comprises the following two questions:

- *What should a standardised process of the network review look like?*
- *How can an MCDA model that analyses more criteria than only costs, support the network review?*

After considering the current situation, literature and group meetings with NMD employees, we came to several requirements for a network review, possible triggers that drive a network review, and criteria that are important for redesign. This resulted in a recommendation for a new network review process, that consists of eight phases. In this new process, a step is included that evaluates scenarios based on

criteria with an MCDA tool. This MCDA tool is built in Excel VBA and calculates for six criteria (and twelve lower-level criteria) the raw scores, the normalised scores, a final ranking and a sensitivity analysis. Criteria that the tool measures are costs, sustainability, robustness, inventory time, readiness of implementation, and quality aspects.

We tested the tool that we built on data from a network review in West-Germany. This review already started before this research, and ended during this research. Goal of this research was to lower the number of trucks and to search for a more efficient structure of the network. Data from the demand forecast of 2019 was used, together with the expected lead times and the output of network modelling in the optimisation tool. Five scenarios were evaluated: the baseline, a free-run (unconstrained), a barge hub in Duisburg, a rail hub in Hagen, and a no-truck scenario (no trucks on main legs). The barge- and rail hub scored best according to our tool, and the baseline scenario the least. The scenario that was chosen by the consultant, was a combined scenario of the barge hub and the rail hub scenarios. He modelled this scenario again in the optimisation tool and made more restrictions to make it as realistic as possible. This result is called the final scenario. We added this final scenario to our tool to validate the outcomes of our model, which resulted in almost similar scores of the rail hub scenario and the final scenario.

The recommended process gives the outbound logistics department clear guidelines for the tasks and responsibilities in a review. Part of this process is the use of the MCDA tool that provides more insight in the performance of scenarios on softer criteria than only costs and sustainability, like robustness, inventory time, implementation, and quality aspects.

We recommend Tata Steel to implement the process and make formats for the several outputs, to gather best-practices of previous projects, and to develop a review calendar. Furthermore, we recommend to adjust the KPIs of outbound logistics for evaluating the network, and to continuously update the current network in the optimisation tool. For the implementation of the tool, we recommend to ask for more IT information in an RFQ, further examine the calculations of lead times, working capital, and inventory times, connect datasets around the departments, to make more use of the possibilities of the optimisation tool, research the use of new technologies in network redesign, and evaluate the impact of the tool on decision making.

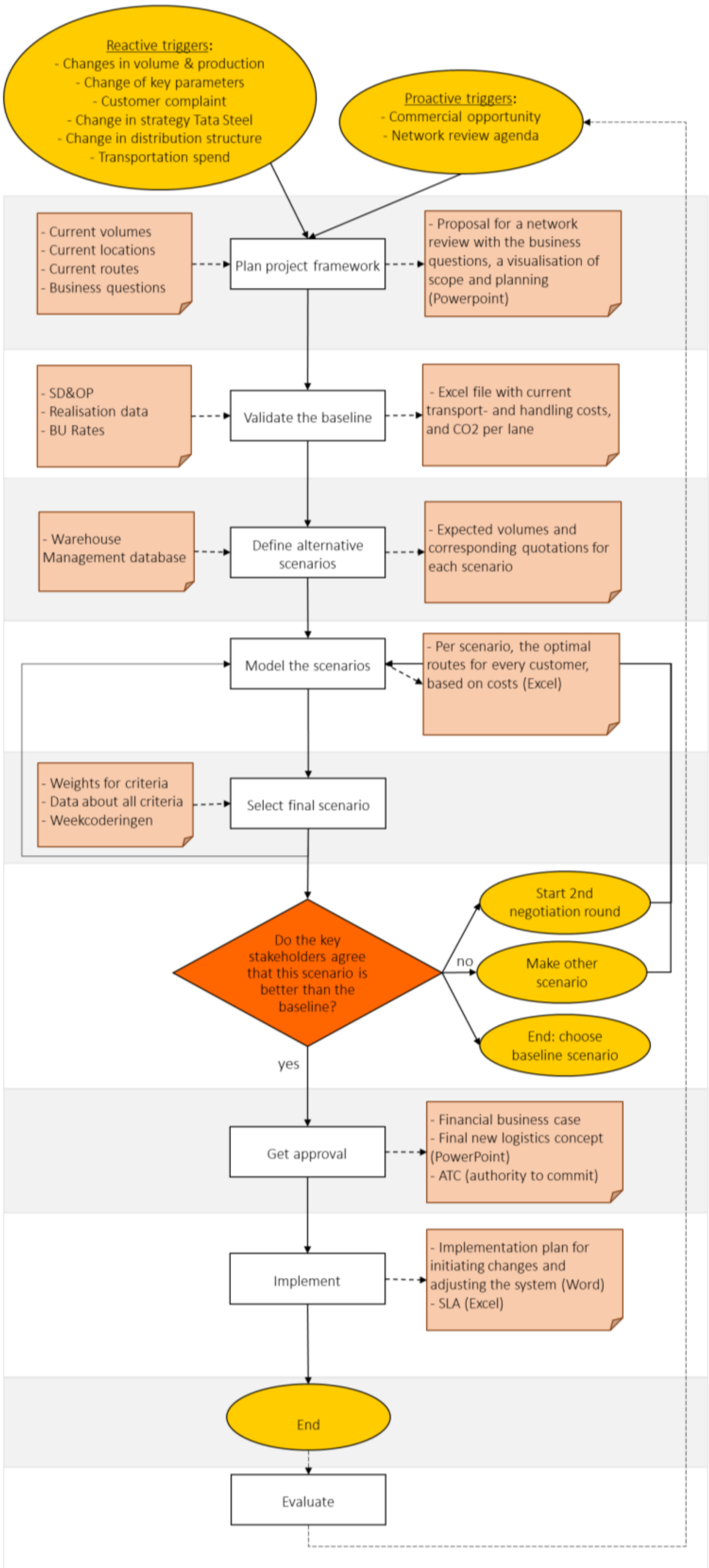
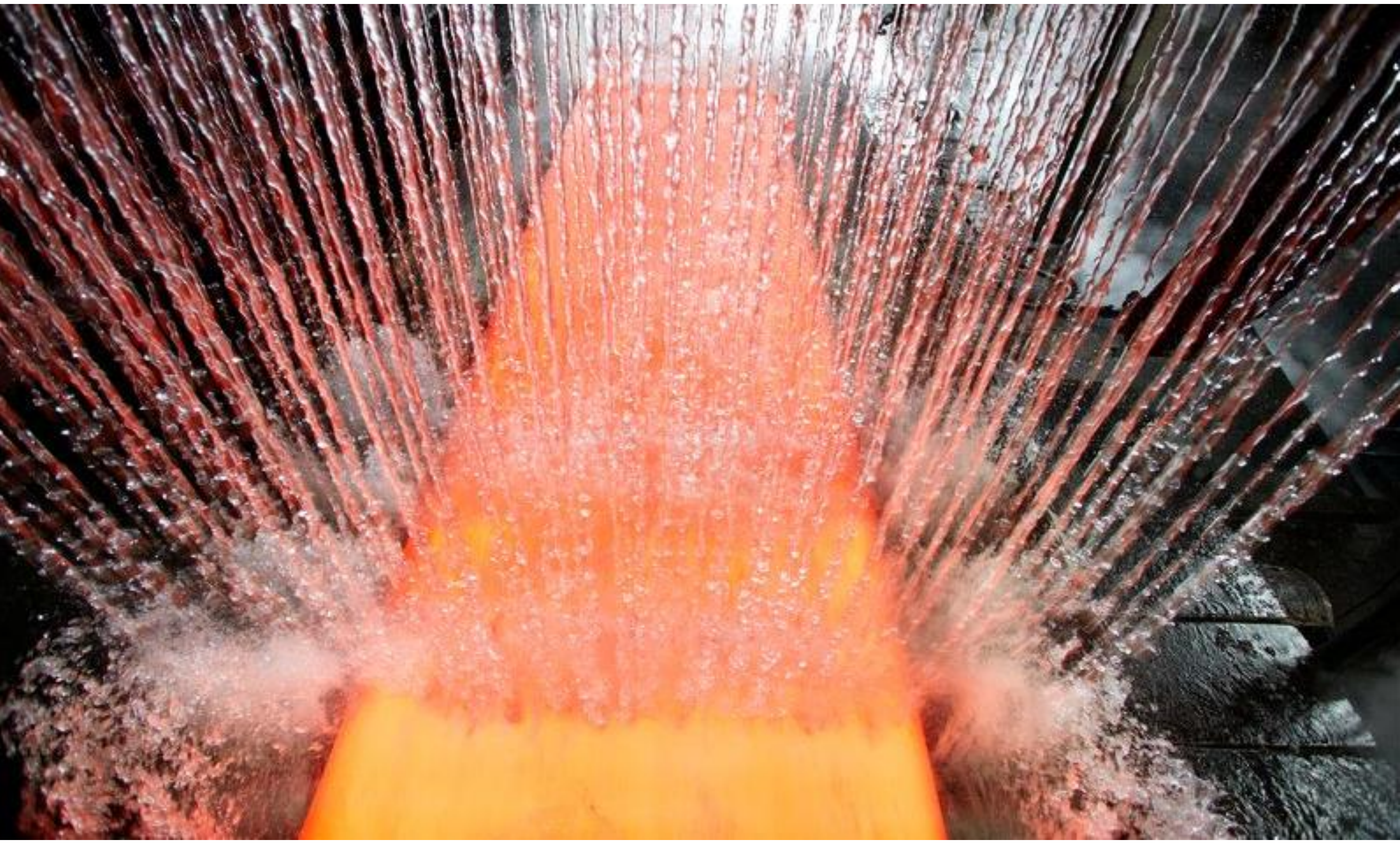


FIGURE A: PROPOSED FLOWCHART FOR A NETWORK REVIEW



Cooling of a strip at the hot mill (warmbandwalserij)

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Glossary of Terms

Terms	Description
(F)MADM	(Fuzzy) Multiple attribute decision making
(F)MODM	(Fuzzy) Multiple objective decision making
AHP	Analytical hierarchy process
ANP	Analytic network process
BU	Business unit
CSR	Customer service representative
CTS	Customer technical service
CVC	Customer value creation
EDI	Electronic data interchange
ELECTRE	Elimination and choice expressing reality
KPI	Key performance indicator
LSP	Logistic service provider
MAUT	Multi-attribute utility theory
MAVT	Multi-attribute value theory
MCDA	Multi-criteria decision analysis
MLE	Mainland Europe
NMD	Network management & development
OSL	On site logistics
PROMOTHEE	Preference ranking organization method for enrichment of evaluations
QTS	Quality and transport safety
S&OP	Sales and operation plan
SC	Supply chain
SD&OP	Sales distribution and operation plan
SKU	Stock keeping unit
SMART	Simple multi-attribute rating technique
TSE	Tata Steel Europe
YTD	Year to Date

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Tata Steel at IJmuiden, the Netherlands

1 Research Definition and Methodology

In this chapter, we present an introduction to the research by giving a short description of the company in Section 1.1, followed by a description of the department of network development & management in Section 1.2. Section 1.3 describes the problems tackled and the scope of this research and Section 1.4 discusses the research questions.

1.1 Tata Steel Europe

The largest steel producer in the Netherlands – previously known as Koninklijke Hoogovens or Corus and now acquired by Tata Steel – celebrated its hundredth birthday in 2018. Tata Steel Europe is part of Tata Steel Group (see Appendix A), which is a worldwide company that produces, processes and distributes steel. Tata Steel in Europe is one of the largest steel producers, it has operations in 26 countries and commercial offices in over 35 countries. Tata Steel Europe has two integrated steelmaking sites in IJmuiden (the Netherlands) and Port Talbot (the UK). In addition, Tata Steel manufacturing plants are across Europe and serve customers in the automotive, construction, engineering and packaging sectors (Tata Steel, 2018).

The site in IJmuiden is the production facility of high-quality hot-rolled, cold-rolled and coated steel. Production starts with raw materials that are used to make pig iron in the blast furnaces. Pig iron is used as input for the steel mill. The produced steel can then be casted (in the hot- and/or cold strip mills), rolled and coated. This process is displayed in Figure 1-1, where the white lines represent the various end products that are shipped to the customers. As one can see in this production scheme, products can be made with different finishing processes. This way, the portfolio of Tata Steel exists of approximately 40,000 stock keeping units (SKUs).

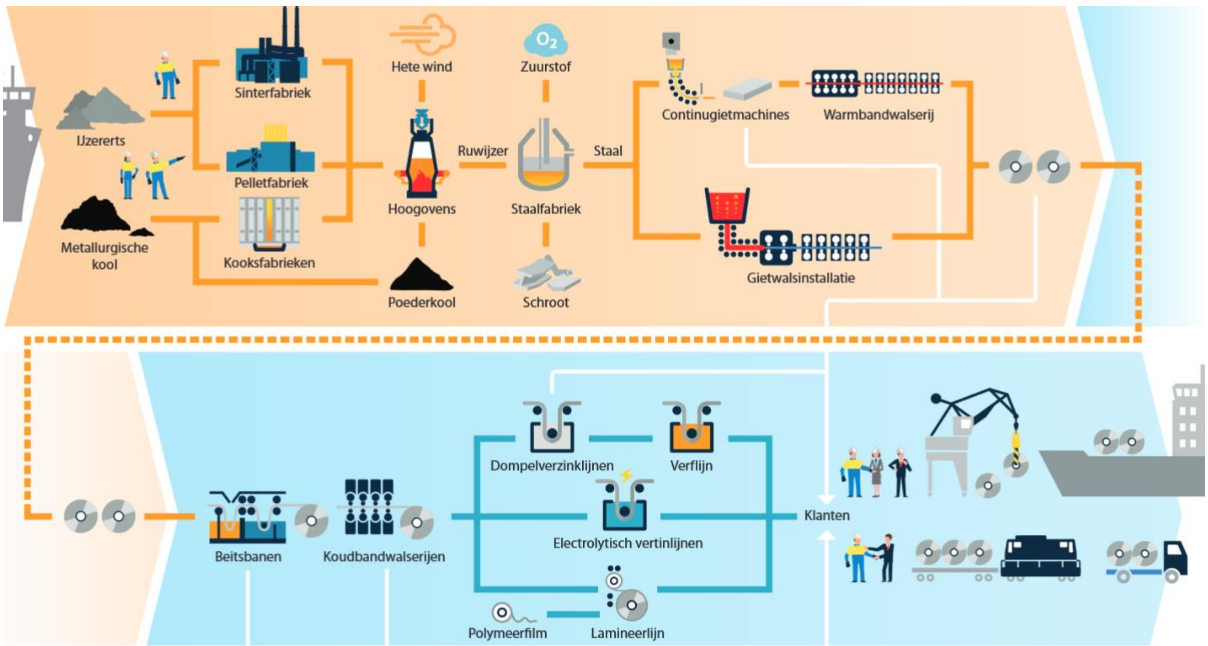


FIGURE 1-1. PROCESS OF MAKING STEEL AT TATA STEEL IJMUIDEN (TATA STEEL, PERSONAL COMMUNICATION, 2018).

Going down the supply chain, the end product eventually needs to be distributed to customers around the globe. To give an idea of how much steel is delivered to these customers, Tata Steel Group, Tata Steel Europe and Tata Steel IJmuiden, respectively transport 28, 18 and 7 million tonnes of steel to their customers (Tata Steel Europe, 2018). Tata Steel IJmuiden has its own port and rail network where this steel can be loaded on vessels, barges, trains and trucks.

The outbound logistics department is responsible for supplying customers, several million tonnes of high-quality steel needs to be delivered correctly and on-time. This is a challenge given the fact that the global transport network exists of more than 6500 transport routes and 2500 network nodes like terminals and harbours. The outbound logistics department works on improvement programs driven by more standardised regulations and with better automation of processes (Tata Steel IJmuiden, 2018). To manage this transport network, the outbound logistics department divided the world into the following regions: Benelux; Central & East Europe; France; Germany, Austria and Switzerland; Mediterranean; NAFTA (Canada, USA and Mexico); Nordics & Poland; Spain & Portugal; United Kingdom; rest of the world.

1.2 Network Management & Development

The department of network management & development (NMD) is part of the outbound logistics department. The ambition of NMD is to manage the network in the above-mentioned regions on tactical and strategical level. In this department are four roles, including distribution chain consultants and logistic analysts, see Appendix A. Distribution chain consultants aim to design an optimal transportation network with help of the logistic analysts.

1.2.1 Tasks of the Logistic Analysts

Logistic analysts get a demand forecast (S&OP) from the sales department, which includes customers, volumes and locations where this volume is planned to be produced. Based on historical data, the logistic analysts then supplement this forecast with an allocation of the demand per location and other parameters like costs, CO2-rates, modalities and locations of hubs. With an optimisation tool, the transport network is then visualised (SD&OP) and is used to make a (bi)annual plan. Distribution chain consultants use these plans for reviewing the transportation network. Sometimes the optimisation tool is also used to optimise certain scenarios and to solve the network design problem using a Branch & Bound algorithm. The process described above is shown in Figure 1-2. In this figure, the information flow is given that logistic analysts need for running the optimisation tool. This starts with the parameters (input) and ends with the optimisation solutions and the (bi)annual plans (output). Examples of a visualisation from the annual plan are presented in Figure 1-3. In the left figure, the expected demand spread from UK and MLE volumes from the annual plan 2018-2019 are shown. The right figure shows the design of the transportation network in France in 2018-2019.

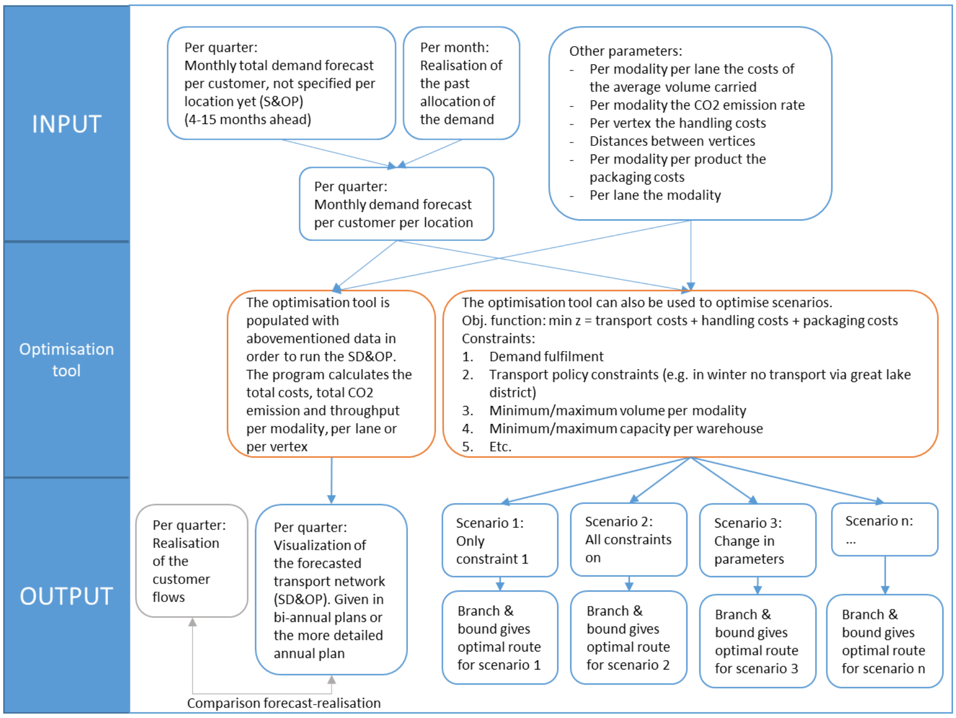


FIGURE 1-2. INFORMATION FLOW THE OPTIMISATION TOOL.

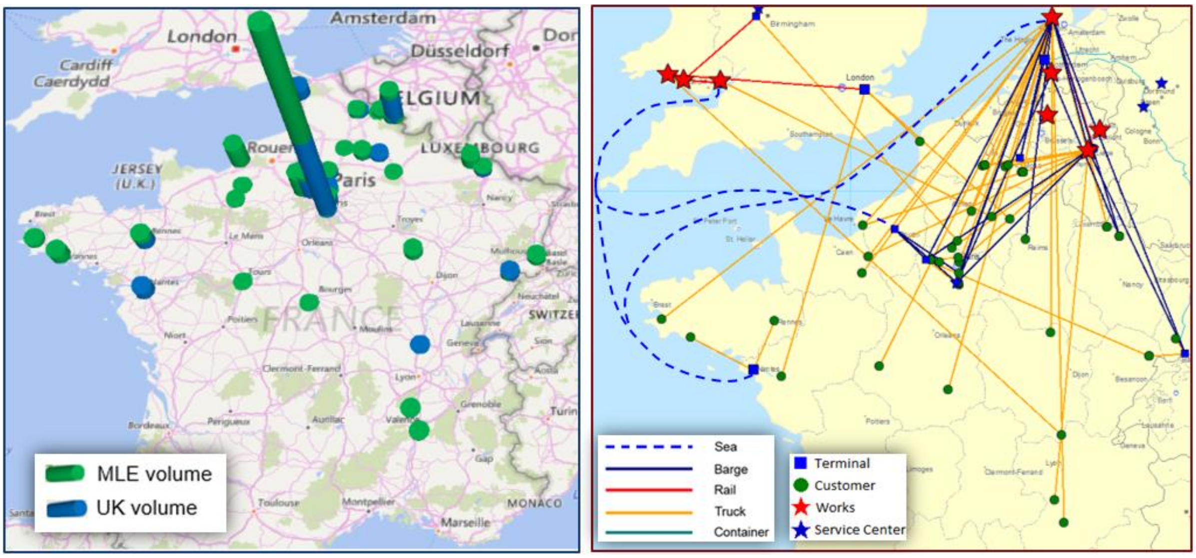


FIGURE 1-3. EXAMPLES OF THE OUTPUT FROM THE ANNUAL PLAN 18/19.

1.2.2 Tasks of the Distribution Chain Consultants

Distribution chain consultants work on all three levels of planning: strategic, tactical and operational. On a strategic level they look on the highest level for development and operation and this can be international, national and regional. This level includes decisions made about the physical structure of the network design, such as hub and terminal locations. Decisions that are made must comply with the company's vision, for example given a possible joint venture[1]. On a tactical level, distribution chain consultants determine an efficient allocation and utilization of existing resources to achieve the best possible performance of the entire system in terms of routes, modalities and carriers. They need to make a trade-off between service level (i.e. lead time) and transportation costs (Trujullo Díaz, et al., 2015) (Schmidt & Wilhelm, 1999). On an operational level the distribution chain consultants solve real time problems.

As said above, consultants make decisions about the network design on a strategic level. This network exists of works (plant locations), terminals, (consignment) warehouses and customers. Products can move between works, from works to customers, from works to intermediate points like terminals and warehouses, from here to other terminals and warehouses and from there to customers. A small example is given in Figure 1-4. In practice, there are three options how a coil is shipped to the customer. Option one is from works directly to a customer. Option two is from works, via a terminal or consignment warehouse to the customer. Option three is from works, via terminal to another warehouse and from there to the customer. These options from works to the customers are the lanes. Each lane can exist of a preleg, mainleg and a subleg. Coils can be transported between points in the network with vessels, barges, rail, truck or airplane. The modality airplane is only chosen for transportation in case a coil needs to be delivered last moment.

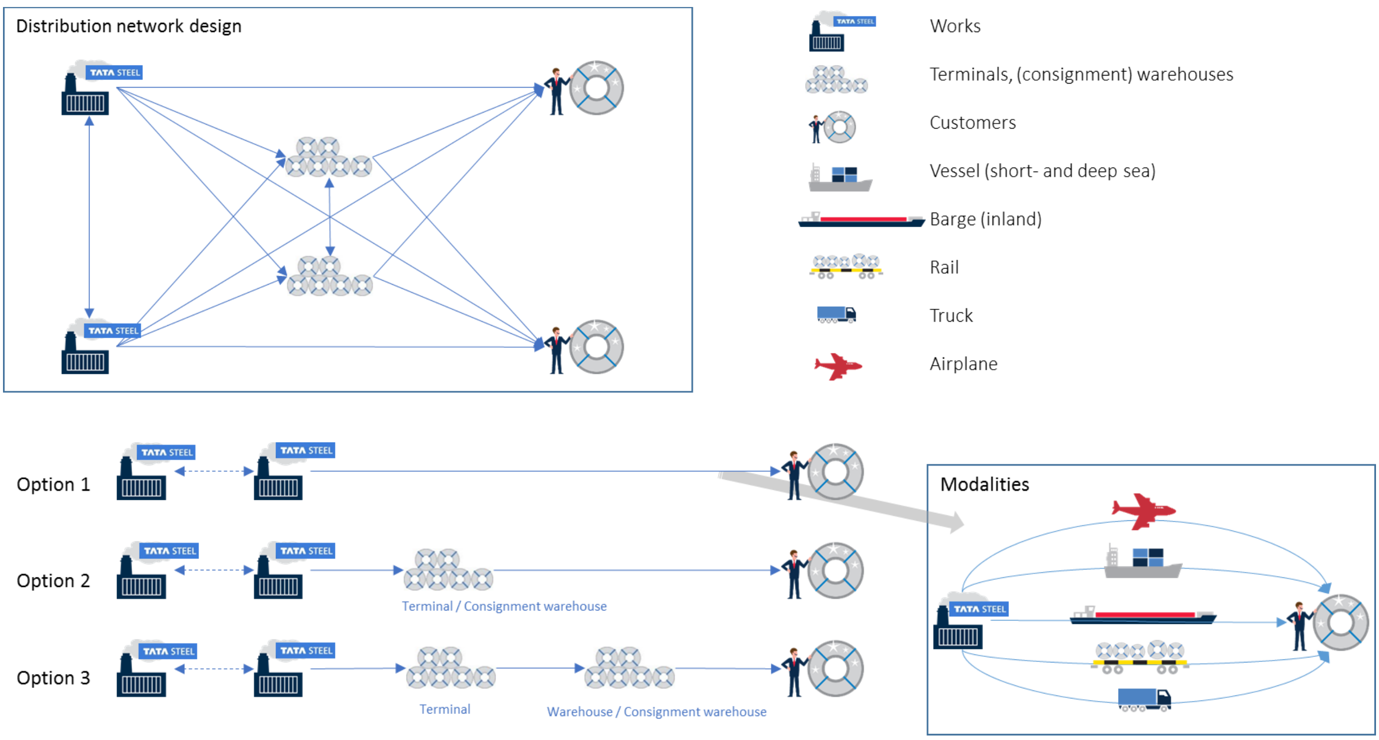


FIGURE 1-4. EXAMPLES OF THE DISTRIBUTION NETWORK DESIGN AT TATA STEEL EUROPE

[1] After this research it became clear that Tata Steel is not proceeding with the joint venture. However, it is still an example of a major change for a company and thus for the logistics network.

Tata Steel contracts logistics service providers to arrange among others transportation and warehousing. An overview of all the activities is shown in Table 1-1.

TABLE 1-1
ACTIVITIES ASSOCIATED WITH LSPS, BASED ON (AGUEZZOUL, 2014)

Activities associated with logistics service providers	
Transportation	Sea ship, barge, rail, truck, container, air, intermodal, shipping, forwarding
Distribution	Merge in transit, order fulfilment, dispatching
Warehousing	Storage, receiving, (de)consolidation
Inventory management	Storage/retrieval management
Packaging	Design, labelling, assembly/packaging, palletizing
Reverse logistics	Pallets flows management, return shipment management

Since the network is continuously subject to change, consultants need to analyse this network from time to time to see if the current network is still optimal or that the network should be optimised. We name this analysis of the transportation network in a certain region, a possible redesign of this network and the implementation of this new network design, a network review. Events that trigger a review are called triggers. Examples of these triggers are:

- *Changes in the customers volumes and production*. When the sales department provides the new demand forecast, a change in volume can lead to a change in the route or modality to this customer. This is related to changes in production. When there is shortage of steel due to changes in production, this has a consequence for the order fulfilment to customers. Other modalities with shorter lead time can be chosen to ship the cargo. On the other hand, when there is a surplus of steel, consultants need to search for warehouses where this can be stocked.
  If volumes change due to production instead of the forecast
- *Changes at logistic service providers (LSPs)*. When a logistic service provider opens a new terminal, the consultant can decide to change the transport network around the new terminal.
- *Changes in transport or handling prices*. If a logistic service provider decides to change the price of a modality, this can lead to a change of service provider.
- *Changes in the route*. When the water level of the rivers is too low or too high, barges can ship less cargo than normal and other modalities need to ship the rest of the cargo to customers. Also strikes and road maintenance can influence the route to customers.

Triggered by one of these changes, the distribution chain consultant can decide to review the current network and possibly change a transportation route or modality.

1.3 Problem Statement

Section 1.3.1 introduces the problem at the outbound logistics department related to this research, in Section 1.3.2 the deliverables of this research are explained, and Section 1.3.3 describes the scope of this research.

1.3.1 Problem Description

The current global overcapacity of steel poses a threat to the sector's health. The developments in the last decade contributed to a collapse in the price of steel (Pooler & Feng, 2017). The excess capacity in global steel industry makes it harder for Tata Steel to sell their steel to customers. Tata Steel needs to differentiate from competition with high quality products and service in order to achieve long-term sustainable success. Tata Steel's customer survey from 2016 confirms that these factors are value drivers for their customers, because both value drivers *product quality* and *delivery performance* have a high impact on customer satisfaction (respectively 67% and 72%). Nevertheless, especially on delivery performance, Tata Steel lags behind competitors (Tata Steel: 7.0 versus competitors: 8.4) (Tata Steel Strip MLE, 2016).

Examples of customer feedback mentioned in this survey:

"Where is my steel?"

"Late delivery"

"Low predictability of orders"

Customers expect their orders to be correct and delivered on-time, despite heavy traffic, weather conditions or production failure. In order to meet these expectations, it is important to establish an infrastructure within which operational transportation decisions regarding scheduling and routing are made. Tata Steel is the biggest shipper in the Netherlands and with nine works in Belgium, the Netherlands and the United Kingdom and 1100 end customers, they are dealing with a complex network. Complexity increases when a choice needs to be made about direct or indirect delivery. With indirect delivery products are changed from modality in a terminal, temporarily stored in warehouses or stored as consignment stock. With direct delivery, the same carrier handles the freight from pickup to delivery.

Next to the complexity of decisions about routes, more challenges occur in strategic network design:

The second challenge is about the choice of modalities. The modalities that Tata Steel uses are sea vessel, barge, rail, and truck. Vessels are used for freight transport over sea while barges are used for inland waters. The modality split of Tata Steel in 2017 is as follows: barges are the most common way of shipping orders (31%), followed by short sea and deep-sea vessels (19% and 19%), train (18%), and truck (13%). Next to unimodal transport, it is also possible to use several different modes of transport, this is called multimodal transport (when freight is transferred) or intermodal transport (where intermodal containers are transferred, with no freight handling). Likewise, the choice between many modalities means that there are many parties to tender.

A third complexity issue lies in the increased specialised products that Tata Steel produces. A customer can order a coil at low volume that is very specific, which makes the risk factor high. If this coil gets damaged on the way and there is no other coil in stock with the same specifications that can replace the damaged coil, the process of making that coil must be started again. This makes it important for orders with a high-risk factor to choose high quality logistic service providers, even though this provider is located further away from the customer. An additional reason to review service providers can be that some customers have higher product quality requirements and therefore require other providers with better transport quality or a route with less transfers between modalities since this reduces the risk that the coil gets damaged.

A fourth complexity is that prices are often changing. Road tolls and market developments are examples of why the transport prices, handling prices and packaging prices are different over time. These changes make it more difficult to choose the correct price to calculate with, to optimise a transportation network.

A fifth challenge comes with multiple criteria that are needed to optimise the network. Next to price, there are other criteria that need to be considered like sustainability and lead times. Tata Steel aims to lower the number of deliveries per truck that depart from the Tata Steel site and to lower the emission of Greenhouse gases caused by logistics (Tata Steel Europe, 2018). A trade-off between multiple criteria is necessary to optimise the logistics network. However, this makes it complicated for the distribution chain consultant to review the network.

Finally, decisions that are made in the network review should contribute to make the network less dependent on one party or one modality. This way, the transportation network is more robust what is needed for a secure supply in order to deliver at all times.

All in all, these issues make it difficult for the distribution chain consultants to review the network:

a) Many options for possible routes between the production site, downstream businesses and end customers. Routes also depend on direct and indirect deliveries.
b) Choosing the right modality for the route. Which modality fits best, and does one choose for unimodal, multimodal or intermodal transportation.

c) Importance of choosing a logistic service provider dependent on the risk factor of the order and higher quality requirements from customers.
d) Prices that are changing for transport, handling and packaging.
e) Decisions should take multiple criteria into account such as costs, emissions of air pollutants and lead times.
f) The transportation network must be robust and not dependent on one party or one modality.

Furthermore, the distribution chain consultants make these decisions individually from each other. This means that each consultant works differently. They evaluate scenarios dissimilar because they use different criteria. This means that certain regions are being reviewed inconsistent, which can lead to different outcomes between consultants.

All these aspects increase the complexity of a transportation network review, creating a need for uniform support for the distribution chain consultants to design an optimal network. A network should be robust (one that takes changes in demand, infrastructure and price into account) and it should be evaluated on costs and on other criteria that are important for Tata Steel.

These problems lead to the following problem statement:

Tata Steel Europe has difficulties to review the transportation network, due to complexity of this network and due to the absence of a standardised review process.

1.3.2 Scope

To tackle the complexity of performing a review of the transport network, the aim of Tata Steel is to design a process and/or tool that supports the network review on a structural basis and in a uniform way.

This research output is two-fold: on the one hand it focusses on making a roadmap with guidelines how to review the transport network and on the other hand it focusses on making a model that supports decision making for optimizing the transport network considering several weighted criteria like costs and quality. This model is based on the discipline of multi-criteria decision making.

This research uses three regions in Germany as case in order to experiment with the multi-criteria decision model. The regions in Germany are chosen, because the distribution chain consultants started with performing an analysis of these three regions: Hagen/Dortmund, Ruhr and Siegerland. The consultants chose for these regions, because the contract with the railway logistics service provider ends and Tata Steel aims to reduce the direct deliveries with truck to zero in these areas and to make more hubs for shipments with barges and rail. Furthermore, there are good conditions to redesign the transport network in these regions, because there are many terminals and many customers located.

The three regions are shown in Figure 1-5 with customers in the area Hagen/Dortmund in colour blue, customers in the Ruhr in red and customers in Siegerland in yellow. Customers that are shown in the colour black are out of scope, because they already have a location that is connected to rail or water.

FIGURE 1-5. THE DESTINATIONS AND CORRESPONDING VOLUMES IN SCOPE OF THIS RESEARCH (DEMAND FORECAST 2019).

This research considers the strategic and tactical level of decision making. The operational level is considered out of scope, because that involves real time planning, which is the responsibility of another department of Tata Steel.

The suppliers of this research are the department of outbound logistics and sales from Tata Steel Europe. They provide data about the forecasted demand, the actual shipments, quality of logistics service providers, key performance indicators and transport prices. Online libraries are other suppliers of this research, they provide relevant articles and books that can be used for the literature study. The internal customers of this research are the departments within the outbound logistics department. They can use the outputs of this study to optimise their processes. These outputs are a flowchart of a standardised network review and a decision support tool. To give more explanation about the data that can be used for this research, an overview is made in Table 1-2 with more detailed information per database.

TABLE 1-2

AVAILABLE DATA FOR THIS RESEARCH

Data	Content	Supplier of this data
Online literature database	Literature	Online libraries, books
S&OP	Monthly forecast for next year: volumes	Sales
SD&OP	Quarterly forecast for next year: customer flow	NMD
Quality logistic service providers	Number of reported damages from logistic service providers	QTS
KPIs outbound logistic	Key performance indicators	Outbound Logistics
Rate database	Rates from the contract with the service providers	Tata Consultancy Services
BU rate database	Business unit rates (average €/ton of a service provider)	Sourcing

1.4 Research Questions

The research goal formulated in the problem statement of Section 1.3.1 is translated into the main research question:

How can a standardised review of the transportation network improve the competitiveness of Tata Steel Europe?

This question comprises the following two questions:

a) *What should a standardised process of the network review look like?*
b) *How can an MCDA model that analyses more criteria than only costs, support the network review?*

To answer the main question, five research questions are derived from the research goal:

Chapter 2: To understand what aspects are important in the process of reviewing the transport network, we discuss the current way of reviewing the transport network. Furthermore, we discuss performance indicators that can be used for a transport network review. The analysis of this current situation is built upon interviews, documentation and observations at Tata Steel. Interviews are performed with distribution chain consultants, logistic analysts, and with managers from NMD, outbound logistics, sourcing and QTS. The type of interviews ranges from semi-structured interviews to acquiring company data with informal conversations. It is possible that different answers will be given during the semi-structured interviews. In that case, a validation of the answers is made by having conversations with both interviewees.

1. *What does the current process of transport network review look like?*

Chapter 3: Considering the current process of reviewing the transport network, a literature study is performed in this chapter. This study focuses on concepts and methods that are known for reviewing a transport network design. We search for alternatives on how to perform a review of the transportation network and methods for multi-criteria decision making and tools. In this literature study, we focus on scientific articles found in online databases and on information found in books.

2. *Following a literature study, which concepts and methods exist for reviewing a transport network?*

Chapter 4: Using knowledge and methods from the previous chapters, we develop an alternative review method. Output of this chapter is a flowchart for a transportation network review. This new process is based on the requirements and preferences from Tata Steel and these are acquired by interviews among the departments of outbound logistics and sales.

3. *What is the desired process of a network review for the outbound logistics department?*
    a) *What are the requirements and preferences from Tata Steel for a uniform review process?*
    b) *What does the new review process looks like?*

Chapter 5: This chapter builds upon Chapters 2, 3 and 4. We focus on developing a tool for decision support that evaluates scenarios on several criteria. We discuss the calculations for the criteria and present an outline of the tool that we make with VBA.

4. How can a decision support tool complement the network review?

Chapter 6: We test the tool that on data from the network review in the regions Ruhr, Hagen-Dortmund and Siegerland. We follow the analysis phases of the new review process and present the results for each criterion. We compare the outcome of the network review with the outcome of this tool and discuss the similarities and differences.

5. What are the results from testing the decision support tool on the West-Germany review?

Chapter 7: We finalise this report with conclusions, limitations, recommendations and suggestions for further research in Chapter 7.

Transportation of packed steel coils on a train at the site of Tata Steel IJmuiden

2 Current Situation

This chapter discusses the current process of a network review to answer the first research question:

What is the current process of transport network review?

In Section 2.1 we present a description about the current triggers for a review and the key performance indicators for the outbound logistics department. In Section 2.2 we describe the output of a transport review and how internal and external stakeholders are involved in this process. This is followed by an explanation of the current process of a network review in Section 2.4. We summarise this chapter in Section 2.5.

2.1 Triggers for a Network Review

In the current situation, consultants start to review a part of the network on an ad hoc basis, when certain events occur. This is also referred to as 'fire-fighting' by the consultants. These events are partly discussed in Section 1.2.2. Resulting from interviews with members from the NMD department, a more complete overview is made and shown in Table 2-1. We use this information for the design of a review process, because it gives us information about when to start a network review.

TABLE 2-1
LIST OF EVENTS THAT TRIGGER A TRANSPORT NETWORK REVIEW

Trigger	Explanation	Impact on transport costs	Impact on quality of steel	Impact on service to customer	Frequency Rare: < 1 Regular: 1-4 Frequent: > 4 (per year)
Changes in customer volumes and in production	A change in the forecasted volume can lead to a change in the route or modality to this customer.	✓		✓	Frequent
Changes at LSPs	Performance on quality, new locations that open or new LSPs.		✓		Frequent
Commercial opportunity	When the sales department sees an opportunity in the market.	✓			Frequent
Price developments	If a logistic service provider decides to change the price of a modality, this can lead to a change of service provider.	✓		✓	Regular
Disruption in the physical route	Strikes and road maintenance, failure crane or nature disasters.	✓		✓	Rare
Customer complaint	About service, quality, costs or pollution.		✓	✓	Frequent
Changes in the strategy of Tata Steel	A change in focus on costs or sustainability, the policy of Tata Steel, and investment projects.	✓		✓	Rare

From the interviews, it is clear that NMD employees would like to add another trigger to this list: 'monitoring of the network performance'. This is in the current situation not measured, but might be possible when clear key performance indicators (KPIs) are used. The KPIs that are currently used by the department of outbound logistics are:

- Health & Safety$_1$: Number of tours being made in warehouses (year to date)
- Health & Safety$_2$: Lost time injuries
- Effect Modality: Number of modality switches
- Costs$_1$: Average cost/ton
- Costs$_2$: Savings from the Future Value Chain project
- Quality$_1$: Number of load tosses across Tata Steel Europe
- Quality$_2$: Number of load shifts across Tata Steel Europe
- Quality$_3$: Monthly received transport related customer complaints (and year to date)
- Productivity$_1$: Actual shipped volume per month (and year to date)
- Productivity$_2$: Planned shipped volume per month (and year to date)
- Productivity$_3$: Forecasted shipped volume from SD&OP reporting month (and year to date)
- Delivery/service: % Lead time adherence according to plan

These KPIs are for the outbound logistics department. The underlying department NMD does not have its own KPIs. It can be noted that these KPIs are not all relevant for a network review. We only consider the relevant KPIs for this research. Another limitation of these KPIs is the vague description. Furthermore, a good KPI should not be open for interpretation and stays relevant to the business over its lifecycle. For example, the KPI *Costs$_2$* is only valid for a temporary project and does not stay relevant for the lifecycle of Tata Steel and *Effect Modality* is open for interpretation since it does not state if this number is per year or per month. At last, KPIs should be measurable and tend to be given in percentages, rankings, ratings or ratios (Smith, 2017). Only the last KPI *Delivery/service* is expressed as a percentage. These limitations are the reason that these KPIs are not further used for this research.

2.2 Output of a Network Review

The output of a network review is a validation of how the network is designed right now or a new logistics concept in which customers and volumes are assigned to modalities and terminals. This logistics concept comes with a business case, which includes calculations of the financial impact. The output is also about initiating the changes by talking to the account teams and adjusting the systems. In a network review, one looks holistically to a bigger picture instead of looking at only one route.

2.3 Stakeholders of a Network Review

Internal customers of a review are the account teams in the sales department. An account team exists of two rings. The first ring consists of the account manager, customer service relations (CSR), customer value creation (CVC) and customer technical service (CTS). The second ring exists of among others, OBL. The difference between first and second ring is the involvement of these parties to the external end customer. The first ring parties meet every week and the second ring parties every quarter. These meetings are important for a regional analysis to gain support for their suggested network change. A proposed new logistics concept must be approved by the sales department and the end customer. Another internal customer of a network review is the outbound logistics department, that includes the departments QTS, operations, sourcing and NMD. These parties need to plan the material and contract the logistic service providers.

Besides the internal customers of the review, we identified other stakeholders from conversations with employees, shown in Table 2-2. We analysed these stakeholders with the help of a power/interest analysis, given in Figure 2-1. This matrix helps to discover where the power of a project is and helps to find the best communication means with stakeholders. Stakeholders that have low influence and low interest in the project are the customs and taxation departments. They must be monitored during the process. Stakeholders that have low influence and high interest in the project must be informed with relevant information. Stakeholders that must be informed are the financial controller, the invoicing department and the on-site logistics department. Stakeholders that have low interest and high influence are the end customers, managers of outbound logistics and the sales department. They must be satisfied during the process. The most important stakeholders, the key stakeholders, are those who have high influence and high interest. In a network review, they are the logistics service providers and employees of the departments QTS, NMD, sourcing and operations who are represented in the project team. We further discuss which stakeholders are involved per step of the review in the next section.

TABLE 2-2
STAKEHOLDER ANALYSIS

	Stakeholder	Strategic importance
Stakeholders at Tata Steel Europe	Outbound Logistics	Responsible for storing, transporting and distributing steel to end customers.
	▪ NMD	Maintains the network.
	▪ Sourcing	Manages the contracts with warehouses and logistic service providers.
	▪ Quality and Transport Safety	Manages the quality safety of the cargo in the modality.
	▪ Operations / Planning	Plans the materials to modality for pre-, main- and after transportation. A sub department that is under development is tactical operations.
	Sales (account teams: account manager, CVC, CTS and CSR)	Delivers customer information. Stays in contact with NMD.
	Taxation	Monitors the tax compliance activities in countries. Give advice to NMD when cargo travels through certain countries.

	Customs	Has contact with customs authorities and gives advice to NMD when cargo travels through several countries outside the EU.
	On Site Logistics	Manages the logistic network on the Tata Steel area. Their scope stops when materials are transferred from Tata Steel to the modality. Then NMD takes it over.
	Financial Controller	Checks the invoices and the savings.
	ATCE (Invoicing)	Sends invoices to customers.
External stakeholders	Logistic service providers For modalities: Truck; Train; Maritime (corporations & shipping companies), terminals, harbours and warehouses	Together they bring cargo from Tata Steel plant to the end customer or store it temporarily. They are in direct contact with Sourcing (strategic/tactical level) and Operations (operational level).

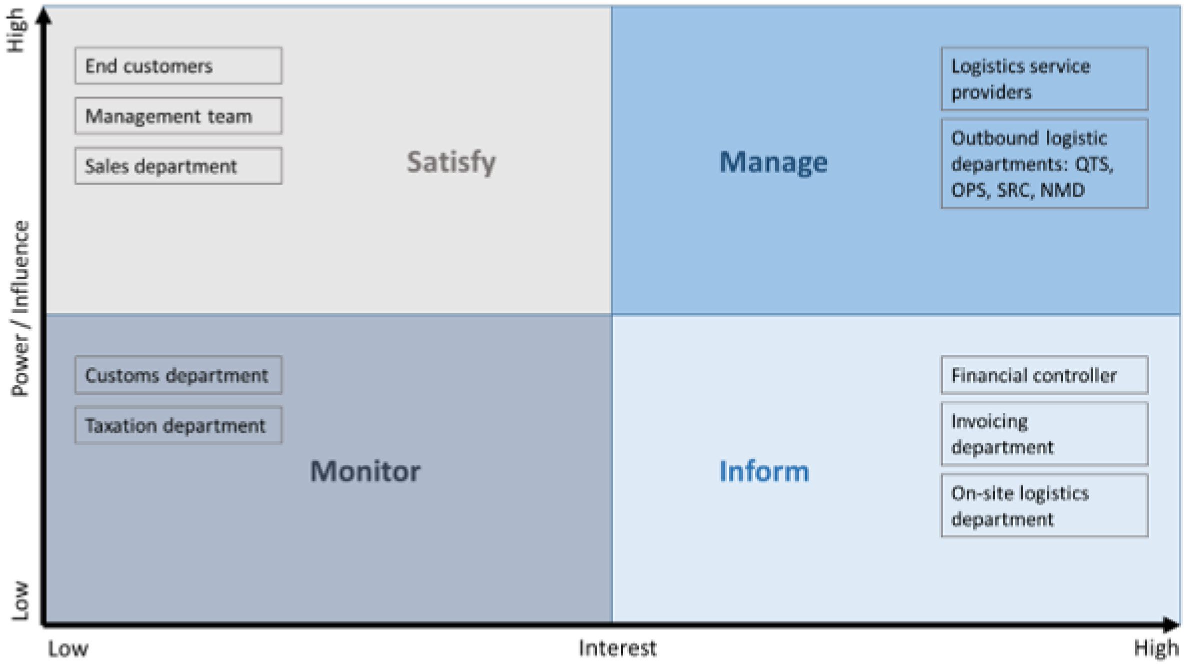


FIGURE 2-1. THE IMPORTANCE OF STAKEHOLDERS.

In the review process, the consultant responsible for the according region is the project manager. The key stakeholders from the departments of sourcing, QTS, NMD and operations form the project team.

2.4 Steps within a Network Review

Through interviews with the consultants, we identified eight steps that they follow while reviewing a region. The steps that are currently taken by a consultant in a network review are:

1. All consultants start with the identification of the current network. This includes defining the scope and timeline. However, the scope and timeline are mostly dependent on the type of trigger.
2. The first scenario is the baseline. This is a validation of the current network and other scenarios need to be compared to this baseline.

3. Alternative scenarios are developed by the consultants based on the size of the trigger, the current developments at Tata Steel, and developments of the LSPs that are in scope. The project leader makes a request for quotation (RFQ) to estimate the prices for certain volumes.
4. When the RFQs have returned, the consultant starts modelling all the scenarios with or without the help of the logistic analyst.
5. Based on the criterion costs, the project leader chooses the best scenario.
6. The chosen scenario is then discussed with the key stakeholders from QTS, planning and sourcing. Possibly, an in-between scenario is optimised again, or a second negotiation round is organised.
7. If the solution is a new logistics concept, this needs to be approved by several stakeholders like the sales department, the financial controller and the outbound logistics department.
8. After an implementation plan is set up, every stakeholder is up to date, and the changes are implemented the network goes live.

Each step is described in more detail below:

1. All consultants start with the identification of the current network. This includes two steps:
    a. The geographical scope of the project determined by the project leader. We observe that a part of the consultants determines this with help of the logistic analyst who provides them information about customer locations and volumes in the optimisation tool. Sometimes, a demand-density visualisation is made to determine the gravity point. An example of the visualisation is given in Figure 1-5 in Section 1.3.1 and Figure 2-2. In the latest, the current works (red), current terminals (blue) and current destinations (green) that are in the scope regarding the case Germany are shown. The exact locations are given in Appendix B. Next to the identification of the current volumes, the project leader has informal conversations with the departments of sourcing (about current contracts in that region), QTS (about quality of LSPs in that region) and planning (about delays in that region). In the end, the consultants summarise all this information and come up with a project proposal.
    b. If the consultant organises a kick-off session, this project proposal serves as the input for this session. Key stakeholders from the sourcing, planning, QTS and NMD departments need to agree to the scope in this session and they discuss developments that occur in that region. They also determine the timeline of the project and the different steps. However, the scope and timeline are often determined by the urgency of the trigger that initiated the network review.

    Stakeholders involved: project manager, project team, (logistic analyst)

FIGURE 2-2. VISUALISATION IS USED TO DETERMINE THE SCOPE OF A NETWORK REVIEW.

2. After the scope is determined, the next step for all the consultants is to make a baseline. This baseline is a scenario of the current routes. If an alternative scenario is chosen in later steps, possible savings can be determined by comparing both scenarios.
    a. This baseline serves as a validation of the current volumes and costs. However, the consultants are uncertain about which volumes they should choose for calculations. There are three options for the consultant and/or analyst to calculate with:
        - Historical volumes (from realisation data)
        - Forecasted volumes (from the S&OP)
        - A mix between historical volumes and forecasted volumes. Here, consultants ask the account teams for more information if there are large discrepancies between realisation- and forecasted data.

        The choice of data is important, because it matters for the comparison. For example, if realisation data is used for the baseline scenario and forecast data for other scenarios. A difference in the optimisation solutions can be the effect of a better network, or of the different data that is used. After this step, the consultant and/or analyst knows the volumes that can be used for further calculations.
    b. The same question rises for the rates that consultants should use for the baseline. It is possible to calculate with:
        - Current rates
        - Rates from the beginning of the financial year
        - Rates that are expected at the beginning of the new financial year.

        Rates are used from the rate database and the business unit (BU) rates database. The rate database includes the rates from the contracts. The BU rate database includes the prices for each LSP dependent on the average volume.

Collaboration between the consultants and the available analysts differ in this step, because not all the consultants trust the outcomes of the optimisation tool. This program needs information costs, volumes and routes as input. However, this information is not always up-to-date, because there is no standard process for the update of routes. Updating basic information in this tool is essential and a prerequisite for further use of the tool.

Visualizations of the baseline for the review in Germany are shown in Figure 2-3 to 2-5. These figures represent the current routes, modalities, works, terminals and customer locations in/to the three regions regarding the case Germany: Hagen/Dortmund, Ruhr and Siegerland.

Stakeholders involved: project manager, (logistic analyst), account teams, financial controller

FIGURE 2-3. BASELINE SCENARIO: THE CURRENT LOGISTICS NETWORK TO HAGEN/DORTMUND

FIGURE 2-4. BASELINE SCENARIO: THE CURRENT LOGISTICS NETWORK TO RUHR

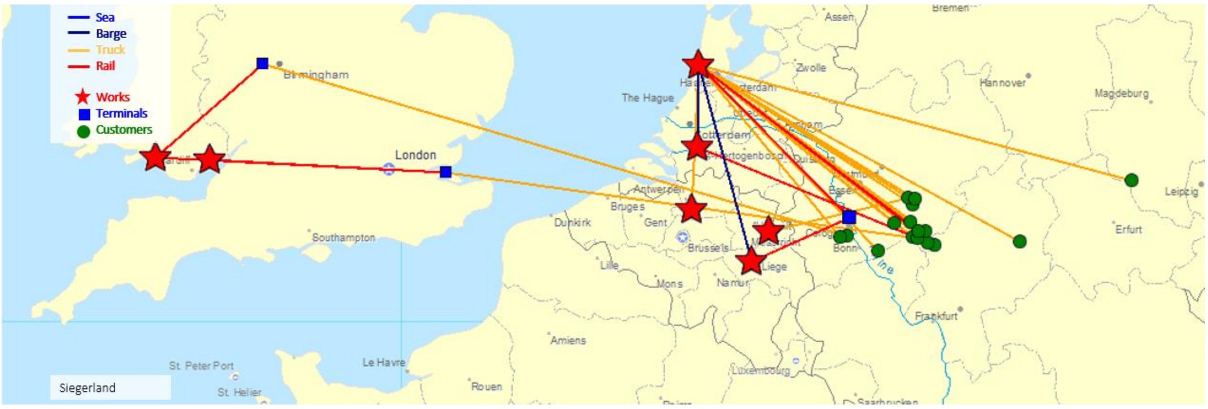


FIGURE 2-5. BASELINE SCENARIO: THE CURRENT LOGISTICS NETWORK TO SIEGERLAND

3. The next step for the project leader is to design other scenarios for the transportation network.
    a. First, there is a search for alternative LSPs or new possibilities with existing LSPs. This is partly desk work: consultants search for known logistic service providers in the region and for possible routes to this region. It is possible to use the warehouse management database for this information. However, it results from interviews that not every consultant and analyst knows this database. Next to desk work, consultants visit the region to see if logistic service providers are still located in that area and if they are capable to accommodate extra volume. It is possible that the account manager from the sales department asks end customers if they know service providers in the region. We observe that also in this step, analysts can support the consultants in the form of a regression analysis, but that this happened in the past one time.
    b. Second, the consultant prepares RFQs to these logistic service providers to estimate what their price will be for certain volumes and services (handling and/or post-transport) in the scenarios. The RFQs are then send to the service providers by the sourcing department.
    c. Third, the analyst prepares the optimisation tool by identifying the lanes for every scenario. This means adding the new routes in the system and potentially do a test run. However, we see again that not every consultant works together with the analyst.

    Stakeholders involved: project manager, (logistic analyst), account manager

4. The next step that all consultants take, is modelling their scenarios after the RFQs are returned and the rates for the volumes are known for every logistic service provider.
    a. One consultant mentioned a free run as a first scenario. A free run is the name of a scenario where there are no restrictions in the optimisation tool. The results can be therefore unrealistic, but can bring new ideas to the table. Although this free run is mentioned in the interviews, this scenario has never been used in a review so far.
    b. For the alternative scenarios, the total costs can be calculated for every scenario. Each scenario has different restrictions. And again, some consultants do this with the help of the logistic analyst and the optimisation tool for optimisation, others only use Excel for calculations without help of the analyst.
    c. If the logistic analyst is involved, he performs a sensitivity analysis regarding a volume change.

    Stakeholders involved: project manager, (logistic analyst)

5. Every solution scores differently on certain criteria. In current practise, the consultant primarily looks at the transportation and handling costs as criterion for the best scenario. The scenario with the lowest cost is chosen. NMD has no further insights in other impacts of scenarios on the supply chain.
   Stakeholders involved: project manager

6. The scenario that is chosen by the project leader, is then discussed with the key stakeholders from the departments QTS, planning, and sourcing. Together, they discuss the feasibility of this scenario. If it is the case that that solution is for example very robust, but financially not the best, they can choose to organise a second negotiation round with the logistics service provider. If this works out, they check whether the network meet the requirements with lower rates. Another possibility is that the scenarios are too extreme, and an in-between scenario is chosen. In that case, the new scenario should be optimised again.
   Stakeholders involved: project manager, project team

7. When the scenario that is chosen by the key stakeholders, is a new logistics concept, this scenario needs to be approved. Consultants work differently regarding the approval of the chosen scenario.
   a. Sometimes consultant work with intermediate steering group meetings, which serve as go/no-go moments. This steering group exist of managers from the outbound logistics department and the sales department.
   b. Depending on the scope of the project, other consultants go to a management team meeting at the end of the review, to propose the new network. In this management team are all the managers from the outbound logistics department involved. If there is a dilemma about the choice of a scenario, then multiple scenarios can be discussed at this meeting. This meeting is a go/no-go moment.
   c. All consultants discuss the chosen scenario with the account teams (and sometimes with the end customer). The account teams and the end customer must agree with the change that is made in the route before it can be implemented.
   d. All consultants must get their chosen scenario approved by the financial controller regarding the costs.

   Stakeholders involved: project leader, management team, financial controller

8. If the change of the network is accepted, all consultants stated that the next step is about designing the system with all the stakeholders. The project leader and these stakeholders plan

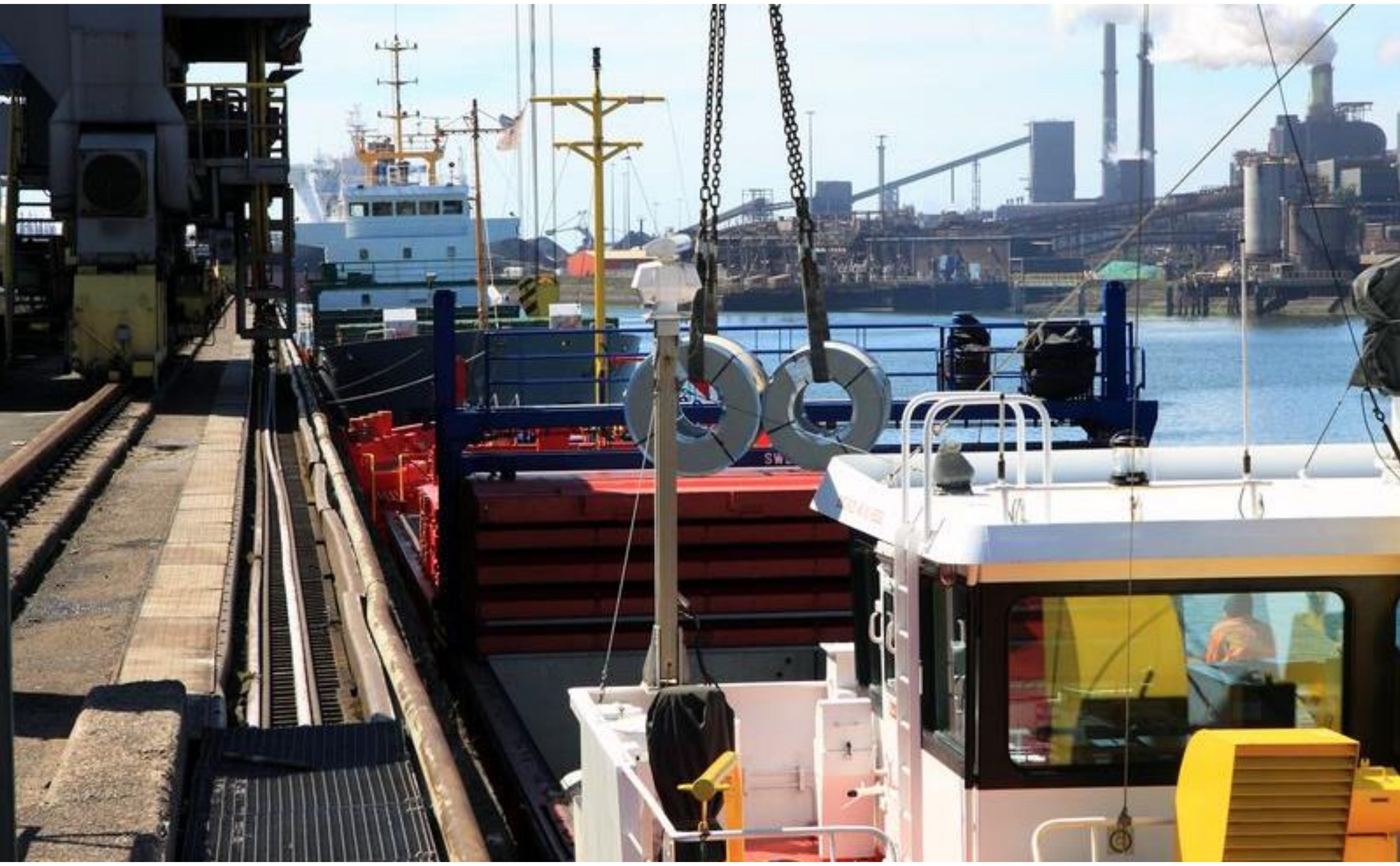
how and when the changes must be implemented. This implementation plan depends on the scale of the project. There is one consultant that also includes the development of a service level agreement with the logistic service provider about practical issues, next to the official contract. After every stakeholder is brought up to date and the changes are implemented, the network goes live.

Stakeholders involved: project leader, sales, QTS, sourcing, NMD, planners, control tower, OSL, supply chain planning, OSL, invoicing, customs, taxation

2.5 Summary

The process of a network review starts when certain triggers occur, so on ad hoc basis. The scope and timeline of the review is also determined by the size of this trigger. Therefore, the review is often a process on micro-level where only one route is under review. There is no clear moment when the goals and business questions of a network review are defined. Consultants have different ways of performing a network review, especially in the interaction with the logistic analyst. The consultants who do not interact with the analyst tend to do calculations themselves in Excel instead of in the optimisation tool, because the data in this program is not always up-to-date. After the change is implemented, there is no evaluation step. Only if there are complaints or other triggers, the network is reviewed again. The consultants work problem driven. If there is something wrong with the network, they are forced to solve this problem. Like a consultant said:

“We don’t perform regular maintenance, but we fix it when it’s broken”.



Loading of coils in a barge at Tata Steel IJmuiden

3 Literature Review

Now that the current process of a review is described, we discuss in this chapter the relevant methods and concepts found in literature. With this, we answer research question 2:

Following a literature study, which concepts and methods exist for reviewing a transport network?

In Section 3.1, we discuss the business drivers, business questions and success factors for a transportation network redesign. In Section 3.1.1., we compare two methods found in literature about the process steps of this network redesign. In Section 3.2, we elaborate on choosing a network design based on multi-criteria decision analysis. We describe the basic terms of in Section 3.3, followed by an analysis of the general steps and an overview of the methods in Section 3.4. We describe two methods for our problem in Section 3.5 and we give a conclusion on the research question in Section 3.6.

3.1 Network (Re)-Design

Network design is the strategic planning process for evaluating alternative structures for a supply chain and selecting the best alternative. It plays a crucial role for companies as they must cope with a variety of challenges in order to secure smooth flows and satisfy customer needs. As explained in Section 1.2.2, network decisions make an impact on all levels of supply chain management: strategic, tactical and operational. Typically driven by the ever-changing market and business conditions, companies face a continuous need to review their existing supply chain configuration while aligning it with the overall business strategy. Depending on the business requirements, companies might consider redesigning their supply chain or designing a new supply chain. Redesign of the network is often due to changing market and business conditions, often in combination with cost pressure and service requirements that require expansion, restructuring, simplification or downsizing of the operations. Also, growth of the company through mergers and acquisitions lead to integrating the acquired operations in the network. A change in key planning parameters triggers companies as well to review their current networks to find out whether they still make sense under the new market conditions. Drivers for the design of a new supply chain are the entry of a new geographic market or a new business field (Capgemini Consulting, 2017). Two consultancy offices (Capgemini and Camelot) have written a report about the strategic and tactical network redesign for businesses. Both reports are similar and describe business drivers, business questions and conduction steps, see Tables 3-1 and 3-2. In this section, we summarise the findings of these reports. It is good to notice that these reports are no official literature, but are written by consultancy firms. However, we think it is important enough to include it in our research since these firms have practical knowledge about the same topic as this research and we cannot find applicable information in literature data banks.

TABLE 3-1
BUSINESS DRIVERS, SEE (CAPGEMINI CONSULTING, 2017) AND (FRANCAS & SIMON, 2011)

Type of network design	Business driver
Redesign of supply chain	Mergers & acquisitions
	Expansion
	Restructuring & simplification
	Downsizing
	Customer shifts
	Major change of key parameters (margins, raw material prices, duties, etc.)
Design of new supply chain	New geographical market entry
	New business field

(Re)-design of the supply chain network must be a solution for achieving the strategic objectives if it does not optimally support the targeted business model. This can be done by answering the key business questions regarding to the supply chain segment. Examples of these business questions are given in Table 3-2.

TABLE 3-2
BUSINESS QUESTIONS, SEE (CAPGEMINI CONSULTING, 2017) AND (FRANCAS & SIMON, 2011)

Segment	Example business questions
Supply network optimization	Optimal number of suppliers?
	Regionalized or global supplier base?
	Single- or multi sourcing and impact on risk management?
Manufacturing network optimization	World factories or regionalized plants?
	Best location for plants: close to customers or close to suppliers?
	In-house manufacturing or outsourcing?
Distribution network optimization	Company-owned or 3PL-operated warehouses?
	Direct or indirect distribution channels to customers?
	Optimal number and location of warehouses?

Decisions in network design must be driven by the company its strategic direction to include the business strategy into the supply chain. According to Camelot, there are four key strategy elements that represent this: costs, service, time and agility (Francas & Simon, 2011). Network design affects the costs aspect through optimizing capital and operational expenditures, the service aspect through customer service levels, the time aspect through lead times and throughput times, and the agility aspect through the flexibility of the network to respond on changing conditions. Since it is not feasible to perform high on each aspect, it is crucial to align the design with the optimal strategy and to make a trade-off between the elements. Balancing between different strategic elements for network design is further discussed in Section 3.2.

3.1.1 The Strategic Network Design Process

Due to constant changes in the business environment, redesigning the network is often not a one-off solution, but should be considered as a cycle, see Figure 3-1.

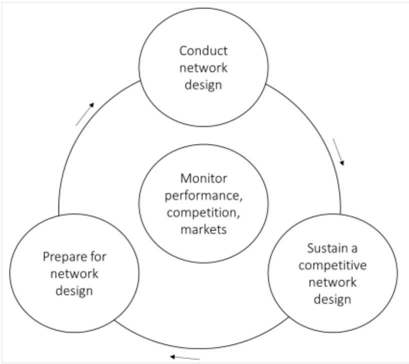


FIGURE 3-1. THE NETWORK DESIGN CYCLE (FRANCAS & SIMON, 2011)

This cycle consists of project preparations, followed by project executions and sustaining a competitive network. When the network design becomes outdated, the cycle starts again. An important part of project preparation is the collection of appropriate data, where the time and resources should not be undervalued. A project approach starts with finding the scope, making suitable business scenarios and finding suitable optimization tools to visualize, evaluate and optimise the scenarios. Project results should be validated continuously. Evaluating the data can also lead to the discovery of quick wins, like inefficient use of certain routes. To sustain the network design, it is important to regularly review and design the supply chain. Results of previous projects should be part of knowledge management since this can provide improvements regarding concepts, modelling and tool approaches. The conduction of the network design is described by both Camelot and Capgemini. Again, these reports are not based on scientific research, but on their practical experiences that provide guidelines for designing the process.

According to Camelot (Francas & Simon, 2011), the conduction of the network design should consist of a structured sequence of planning steps, see Figure 3-2. The first step is to define the objectives and strategy so that trade-offs can be made accurately. The second step includes an analysis of the as-is supply chain, using data to determine the strengths and weaknesses of the current network. The third step composes the generation of scenarios, this includes the use of optimization tools. Scenarios are evaluated in the fourth step where they are validated and prioritized. Both quantitative and qualitative aspects have to be considered while ranking scenarios. The last step is about building the business case and implementation plan, which is done for a few scenarios that scored best. During the process, options may occur to investigate additional or modified scenarios and objectives. This results in possible iterations for analysis, scenario generation, and evaluation (Francas & Simon, 2011).

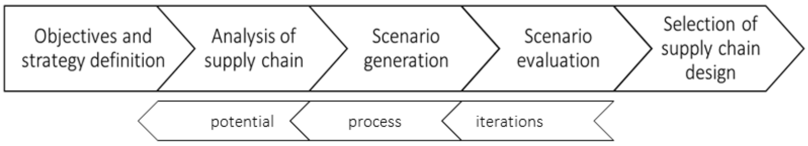


FIGURE 3-2. STEPS FOR CONDUCTION OF A NETWORK DESIGN ACCORDING TO CAMELOT (FRANCAS & SIMON, 2011)

According to Capgemini, the conduction of a network design project should consist of similar steps as Camelot. Yet, formulated differently, see Figure 3-3 (Capgemini Consulting, 2017). This approach consists of two phases and includes an approximated timeline for each step. The first step in this approach is similar to the merged first and second step of Camelot's approach. The foundation for a network analysis is baselining (which is called the as-is situation in the previous approach), after the scope of optimization is determined. Trade-offs must be made for conflicting goals and constraints. The second step of Capgemini's approach is equal to the third step of Camelot's approach: optimization of the network according to the objectives and considering the relevant constraints, using state-of-the-art optimization tools. The third step composes of a what-if analysis: a comparison of the optimization results and the baseline and varying input parameters such as costs and demand to analyse the impact on the business goals. The fourth step of Capgemini's approach is similar to the last step of Camelot's approach, both are about making the business case and implementation plan for the chosen scenario. Difference with the previous approach is that this approach also includes a second phase which is about implementation. It mentions a budget plan, local negotiations with suppliers, service providers or public authorities, and management of the transformation project in time and budget (Capgemini Consulting, 2017).

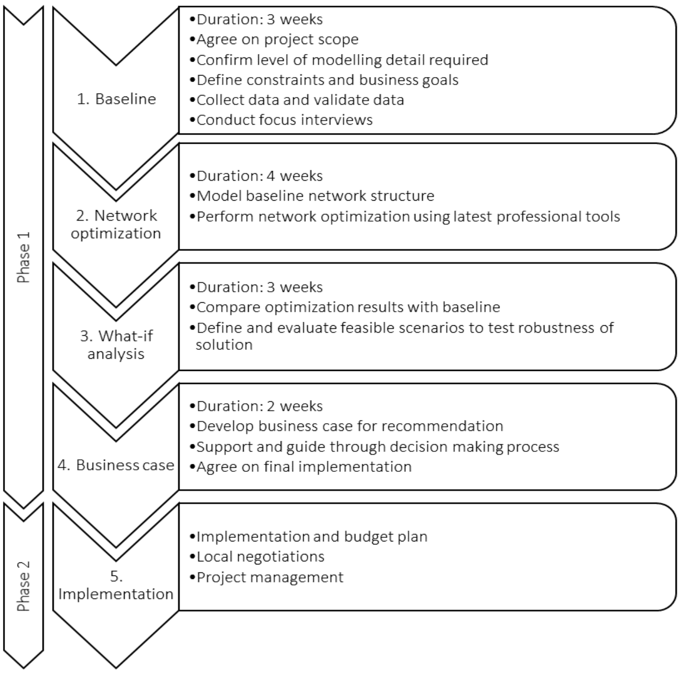
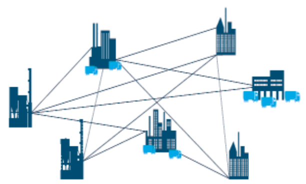
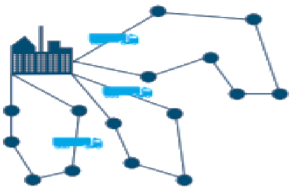
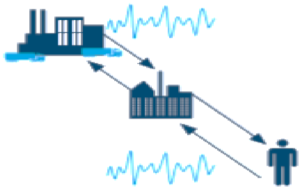
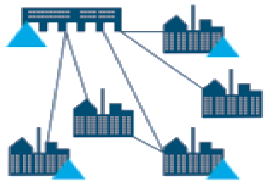


FIGURE 3-3. STEPS FOR CONDUCTION OF A NETWORK DESIGN ACCORDING TO CAPGEMINI (CAPGEMINI CONSULTING, 2017)

After the design of the strategic network is determined, one could consider using tactical optimization tools, simulation approaches and inventory optimization tools. For example, a centralized distribution system should be evaluated on inventory placement and material flows when working capital reduction is an important driver. Simulations can take complexity of the system, dynamics and uncertainties into account and are helpful for understanding the real-life behaviour of the supply chain. As we mentioned in Chapter 1, the NMD team of Tata Steel is responsible for both network optimization and transport optimization.

TABLE 3-3
APPLICATION AREAS FOR SUPPLY CHAIN REDESIGN, BASED ON (FRANCAS & SIMON, 2011)

Driver	• Changing business conditions • Multiple alternatives • Conflicting objectives	• Transportation spend • Changes in distribution structure	• Uncertainty and business dynamics • Process complexity	• Working capital • Changes in network topology
Solution	Network optimization 	Transport optimization 	Simulation 	Inventory optimization 
	Tactical design of supply chain and detailed evaluation of strategic decisions			
Decision	• Optimal size, number, and locations of facilities • Optimal product flows	• Transportation routes • Transport modes • Carrier selection	• Tactical processes • Alignment with network • Risk consideration	• Inventory policies • Inventory placement • Lot sizes

3.2 Multi-Criteria Decision Analysis

As described in the previous section, the (re)-design of a network requires a comparison between the baseline scenario and alternative scenarios, both on quantitative and qualitative factors. Compromises must be made, because an 'ideal' option that fulfils all the business objectives does usually not exist. For support, naive approaches are used such as a simple weighted sum. A disadvantage of this approach is that it assumes linearity of preferences from the person that makes the decision (the decision maker) and quantitative data. Another method is the cost-benefit analysis (CBA), but this approach has the drawback that it only evaluates alternatives on monetary values. An approach that does evaluate multiple dimensions, is the multi-criteria decision analysis (MCDA). MCDA is a discipline that encompasses mathematics, management, informatics, psychology, social science and economics (Ishizaka & Nemery, 2013).

3.2.1 MCDA in Supply Chain Optimization

In supply chain, MCDA is an optimization method because conflicting decisions must be made to design the optimal supply chain. Typical decisions about strategic network design are the number and locations of plants and warehouses and the plant and warehouse capacity levels. A typical tactical decision is the choice of transport modes and the shipment frequency. Supply chain measurements are based on efficiency, responsiveness and disruption risk. Efficiency measures are often focused on minimising costs, examples are:

- Distribution costs
- Inventory holding costs
- Facility operating costs
- Freight transportation costs

Examples of responsiveness measures related to logistics are:

- Reliability and accuracy of fulfilling customer orders
- Delivery time

An effective supply chain also includes mitigating risks in the route. According to (Ravindran, 2016), a factor of disruption risk for network design is:

- Vulnerability of a transportation link

Transportation vulnerability depends on the mode of transportation, the route, the logistics performance and the number of transshipments. The facility's and transportation's vulnerability score are calculated as follows:

$Transportation's\ vulnerability\ score = (Mode * Route * LPI_{Origin} * LPI_{Destination} * Transshipments)^{1/5}$, where the risk score for the criteria are determined using the scores from Table 3-4.

TABLE 3-4
CRITERION RATING GUIDELINE

Vulnerability of a transportation link		
Transportation Mode		
Surface transportation only (truck)	Low	1
Air	Moderate	2
Ship	High	3
Transportation Route Risk Level Risk Score		
Shipping path is in a domestic route or of short duration.	Low	1
Shipping path is within a region or of moderate duration.	Moderate	2
Shipping path is across continents or of long duration.	High	3
Logistics Performance Index/LPI (World Bank)		
LPI of the country is high.	Low	1
LPI of the country is moderate.	Moderate	2
LPI of the country is low.	High	3
Numbers of Transshipments		
The number of transshipments is low.	Low	1
The number of transshipments is moderate.	Moderate	2
The number of transshipments is high.	High	3

Ravindran (2016), gives an example of a multi-criteria optimization model that looks similar to our problem. The model from (Ravindran, 2016) makes the following decisions: (i) supply chain network structure; (ii) production and distribution planning; (iii) transportation selection, including transportation links that must be used to ship items among facilities. These decisions are made to satisfy the objectives: (Z1) maximise profit, (Z2) maximise demand fulfilment, (Z3) minimise delivery time to customer, (Z4) minimise facility disruption risk and (Z5) minimise disruption risk to transportation links. The criteria are shown in Figure 3-4.

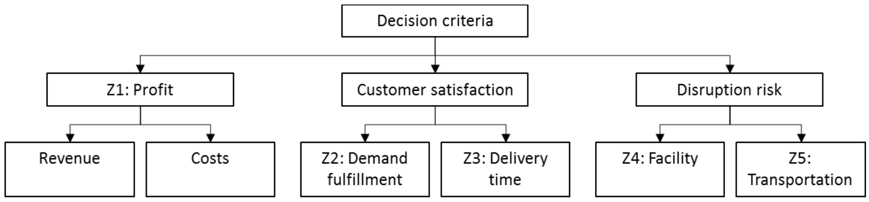


FIGURE 3-4. CRITERIA FOR SUPPLY CHAIN NETWORK DESIGN (RAVINDRAN, 2016)

Efficiency and responsiveness are conflicting criteria, because better responsiveness results often in higher costs. For example, facility costs reduce, and efficiency increases by having fewer distribution centres, but this increases delivery time and reduces responsiveness, this also increases risk by concentrating the distribution risk in fewer facilities. This example shows that criteria for supply chain optimization are often conflicting. Therefore, we cannot optimise on a single criterion, but must use a multiple criteria optimization model to determine the optimal solutions (Ravindran, 2016). Ravindran further elaborates on these criteria by providing the formulas for the objectives and constraints for solving the problem with goal programming, non-preemptive goal programming, and an interactive method.

Although literature is full of single-objective supply chain models and solutions, many authors have also recognized the advantages of considering multiple objectives. However, to our knowledge, none of the literature combines the strategic redesign of the distribution network with the tactical choice of modes and routing to optimise for multiple objectives when all input data is assumed to be known with certainty.

3.3 Basic terms

We define some terms that will be used in the rest of this chapter:

- An objective usually indicates the preferred direction in which we should strive to do better. For example, the minimisation of costs and maximisation of benefits (Keeney & Raiffa, 1976).
- The performance of the objective is measured with criteria, which exists of subcriteria. For example, the criterion *costs*, consists of, among others, the criteria *transportation costs* and *handling costs*. When a criterion is used that is not directly related to the objective, we call this

a proxy criterion. Sometimes the evaluation of criteria requires their decomposition into elementary indicators, which are easier to measure. When the decision maker needs to score an alternative to measure the attractiveness, we refer to this score as the value of the course of action if it does not involve uncertainty (Goodwin & Wright, 1991).

- A decision maker can be his own analyst and does not have to convince anyone of the correctness of his action. However, it is also possible that the decision maker and an analyst work separately from each other. In the latter case, the analyst shows his results and recommendations to the decision maker, who chooses the followed action and must convince others of the correctness of his decision (Keeney & Raiffa, 1976).
- One decision maker can be an individual person or a group of persons with similar preferences (single goal-preference structure). If individuals are characterized by different goal-preference structures, it is a group decision making problem (ElDrandaly, Ahmed, & AbdelAziz, 2009).

3.4 MCDA Tools

Many MCDA methods have been developed over the last twenty years. The methods differ in their properties with respect to the approach of assessing criteria, computation of weights, utilisation of the mathematical algorithm, preference system of the decision makers, level of uncertainty and the ability of stakeholders to participate in the process (De Montis, De Toro, Droste-Franke, Omann, & Stagl, 2000). However, next to all these differences, methods consist of several standard steps. These steps are discussed in Section 3.4.1, followed by classification of the MCDA methods based on their differences in Section 3.4.2.

3.4.1 General procedure MCDA

The standard steps in most MCDA methods are presented in Figure 3-5. Methods start with defining the problem. After the problem is defined, the stakeholders that take part in the process are defined. Identification of the possible alternatives is next. The goal is to choose the best alternative depending on a set of criteria. After the alternatives and criteria are identified, the decision maker translates his preferences into weights for the criteria. To do this, the decision maker needs to have deep expert knowledge on the problem. The previous steps help the decision maker to choose for an MCDA algorithm that fits with the problem, decision maker, alternatives and criteria. After the MCDA algorithm is carried out, the results can be interpreted, which leads to the final decision: the choice of an alternative (Bystrzanowska & Tobiszewski, 2018). During the process it should be possible to go back to a previous step. For example, during interpretation of the results a new alternative occurs. Dependent on the chosen method, it should be possible to go back to either identification of alternatives or application of the MCDA algorithm. We further discuss the first (definition of the problem), the fourth (identification of criteria) and the sixth (selection of MCDA algorithm) steps below.

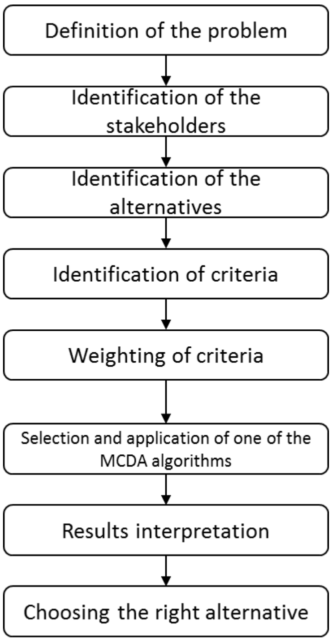


Figure 3-5. General steps for MCDA methods (Bystrzanowska & Tobiszewski, 2018).

As mentioned in the previous paragraph, the first step of most MCDA methods is the identification of the problem. The type of decision problem influences what MCDA algorithm is the best choice. The most common problematics are according to (Roy, 1996) described as:

- The choice problem. The goal is to select the single best option or reduce the group of options to a subset of equivalent or incomparable 'good' options.
- The sorting problem. Options are sorted into ordered and predefined categories. The aim is to then regroup the options with similar behaviours or characteristics.
- The ranking problem. Options are ordered from best to worst by means of scores or pairwise comparisons. The order can be complete or partial if incomparable options are considered.
- The description problem. The aim is to describe options and their consequences in a formalized and systematic manner.

We also give additional information about the fourth step (identification of criteria) because we found in literature that criteria should meet certain requirements. According to Keeney & Raiffa (1993), criteria should have the following requirements:

- Completeness: this is the case when the set of criteria is adequate in indicating the degree to which the overall objective is met.
- Non-redundancy: to avoid double counting of impacts.

- Minimum size: dimension of the problem should be limited to avoid complexity.
- Operational: criteria could be measured and are useful for further analysis.
- Decomposability: aspects of the evaluation process can be simplified by breaking it down into parts. The performance of an alternative on a criterion should be independently judged of its performance on another criterion.

The hypothesis is being made that, while measuring individual aspects, other variables do not change. This hypothesis is crucial, because circumstances and preferences of the actors are not extremely rational and structured (Keeney & Raiffa, 1976).

Regarding the sixth step (selection of an MCDA algorithm), we found in literature requirements for the choice of a mathematical algorithm. The selection of an MCDA method is an important step, since different methods can result in different outcomes. The most important criteria to consider according to (Bystrzanowska & Tobiszewski, 2018) are:

- Validity: finding a method that measures what the decision maker is supposed to measure.
- Appropriateness: finding a method that gives all the information needed to the decision maker and that is compatible with accessible data.
- Finding a method that is trusted by the decision maker, and that is not difficult to use.

3.4.2 MCDA methods

Many MCDA methods are developed over the years to solve the problems described in Section 3.4.1. The most widely used methods according to Ishizaka & Nemery are given in Table 3-5. They divided these methods according to their different approaches. This table differentiates methods on their approach and the type of problem for which the method is used. Ishizaka & Nemery identified three approaches. The first approach is the full aggregation approach, this approach makes it possible to compensate a bad score on one criterion by a good score on another criterion. The second approach is the outranking approach, which is based on pairwise comparisons where a bad score may not be compensated for by a better score. The third approach is the goal, aspiration or reference-level approach. This method defines a goal on each criterion, and then identifies the closest options to the ideal goal (Ishizaka & Nemery, 2013). The different types of problems are explained in Section 3.4.1.

TABLE 3-5
MOST POPULAR MCDA METHODS, CATEGORISED BY PROBLEM TYPE AND APPROACH. BASED ON ISHIZAKA & NEMERY (2013) (MACHARIS & BERNARDINI, 2015).

Approach	Choice Problems	Ranking Problems	Sorting Problems	Description Problems
Full aggregation approach	AHP / ANP MAUT / MAVT SMART / SMARTER MACBETH	AHP / ANP MAUT / MAVT SMART / SMARTER MACBETH	AHPSort UTADIS	

Outranking approach	PROMETHEE ELECTRE I	PROMETHEE ELECTRE III	FlowSort ELECTRE-Tri	GAIA, FS-Gaia
Goal, aspiration or reference-level approach	TOPSIS Goal Programming DEA	TOPSIS DEA		

According to (Hwang & Yoon, 1981), MCDA methods can be classified into two categories: multiple criterion decision making (MADM) and multiple objective decision making (MODM).

- MADM problems have a relatively small number of alternatives. Alternatives are represented in terms of criteria. These problems are assigned to an evaluation with a discrete decision space and a predetermined set of potential actions normally considering information from the DM. Methods based on this type of problem are: scoring methods, multi-attribute value function (MAVT), multi-attribute utility functions (MAUT), SMART, AHP, and outranking methods.
- MODM problems have a very large number of feasible alternatives. Each alternative is defined implicitly in terms of the decision variables and evaluated by means of objective functions. It handles problems that consider a continuous decision space, usually related to design and planning. Methods based on these problems are: MAVT, MAUT, SMART and goal programming (ElDrandaly, Ahmed, & AbdelAziz, 2009).

3.5 Selection of an MCDA Method

As can be seen in Section 3.4, different MCDA techniques suit different kinds of decision problems. Choosing the right MCDA technique is critical to the success and failure of the model. However, choosing the suitable decision method is an exhaustive, thorough, and nearly impossible procedure that must take into consideration all the decision process dimensions, the decision maker's role, the extensive number and variety of methods and the information available. (Mota, Campos, & Neves-Silva, 2013).

Based on the current situation described in Chapter 2, we identified our problem as a choice problem with a limited number of alternatives (an MADM problem). This means we can apply the methods AHP, MAUT, SMART and MACBETH. We assume that all relevant information about the decision situation is known, what means that our problem is deterministic, thereby we cannot use the MAUT method. Since our alternatives have quantitative and qualitative characteristics, we also cannot use the MACBETH method. The decision maker is the project manager and/or project team. Weights that the decision makers assign to criteria can be cardinal (shows quantity) or ordinal (shows position). The solution technique should be a full aggregation approach, because it should be possible to compensate a bad score with another good score.

Based on these requirements and the classifications of MCDA methods in Section 3.4, we choose to further focus on the AHP and SMART methods. To choose the most appropriate method to our problem, we first describe these methods in Sections 3.5.1 and 3.5.2.

3.5.1 Analytical Hierarchy Process

The analytic hierarchy process (AHP) method converts subjective assessments of relative importance into a set of weights. This method uses the pairwise comparisons along with a semantic and ratio scale to assess the preference of the decision maker (relative measurement scale) (Tzeng & Huang, 2011). There are two additional steps that can be added to this method: a consistency check and a sensitivity analysis. This is optional, but recommended to check the robustness of results (Ishizaka & Nemery, 2013). According to Tzeng & Huang, this process follows four steps that can be summarized as follows:

Step 1 – Decompose the problem into a hierarchy of interrelated elements;

Example: Assume we have to buy a plane ticket to Montreal. We can choose between 3 tickets: one with Air Canada, and others with British Airways or Calm Air. The tickets differ on 3 criteria: costs, reputation of the airline, and flying conditions. These criteria can be substituted in 4 lower-level criteria: ticket price, reputation of the airline company, number of transfers and distance of the destination airport in Montreal to the hotel. We present the hierarchy tree in Figure 3-6. We chose to use only four lower-level criteria since this makes the examples short and clear, but we could have more criteria (for example extra costs for luggage or seat choice).

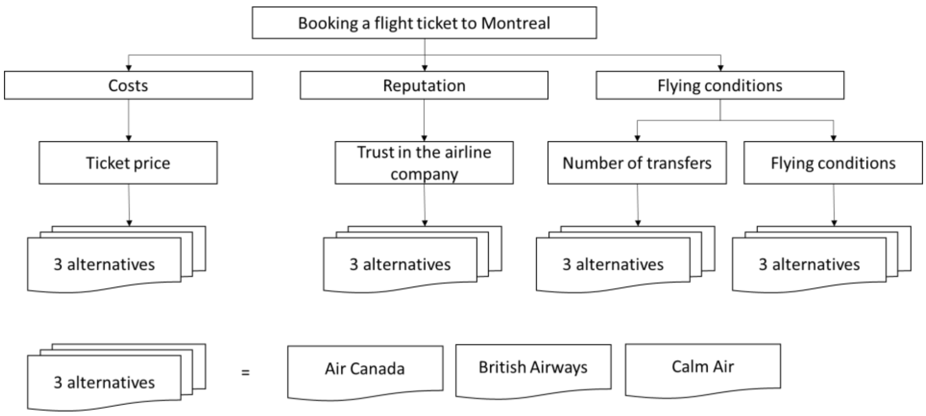


FIGURE 3-6. THE HIERARCHICAL STRUCTURE OF THE AHP (TZENG & HUANG, 2011)

Step 2 – Compare the comparative weight between the criteria of the decision elements to form the reciprocal matrix;

The decision maker compares criteria on their importance in pairwise comparisons. These comparisons are judged on a nine-point rating scale, with each number having the interpretation shown in Table 3-6. These comparisons must be made to make a reciprocal matrix, which is needed to derive the relative weights (Winston, 2003). Half of this matrix is made by the comparisons and the other half is reciprocal: $a_{ij} = {}^{1}/_{a_{ji}}$.

TABLE 3-6
INTERPRETATION OF ENTRIES IN A PAIRWISE COMPARISONS MATRIX FOR AHP (WINSTON, 2003)

Intensity	1	3	5	7	9	2, 4, 6, 8
Interpretation	Objective i and j are of equal importance	Objective i is of moderate more important than j	Objective i is strongly more important than j	Objective i is of very strongly more important than j	Objective i is absolutely more important than j	Intermediate values

Example: For our example we need to make ((N-1)(N)/2 = (4-1)(4)/2=) 6 pairwise comparisons to determine the matrix for criteria and for every alternative ((N-1)(N)/2 = (3-1)(3)/2=) 3 pairwise comparisons. This gives in total (6+4*3 =) 18 pairwise comparisons for 4 criteria and 3 alternatives. Table 3-7 shows the performance of the alternatives on the four criteria. Table 3-8 shows the pairwise comparisons.

TABLE 3-7
EXAMPLE OF RAW SCORES

Values	Ticket price (€)	Reputation	Transfers (#)	Closeness to airport (km)
Air Canada	400	Average	6	50
British Airways	300	Negative	5	60
Calm Air	500	Positive	1	100

TABLE 3-8
PAIRWISE COMPARISONS

n	A	B	More important	Degree of importance
	For all alternatives			
1	Ticket price	Reputation	A	7
2	Ticket price	Transfers	A	3
3	Ticket price	Closeness	A	3
4	Reputation	Transfers	B	7
5	Reputation	Closeness	B	5
6	Transfers	Closeness	A	3
	For criterion: ticket price			
7	Air Canada	British Airways	B	3
8	Air Canada	Calm Air	A	3
9	British Airways	Calm Air	A	7
	For criterion: reputation			
10	Air Canada	British Airways	A	3

11	Air Canada	Calm Air	B	3
12	British Airways	Calm Air	B	9
	For criterion: transfers			
13	Air Canada	British Airways	B	1
14	Air Canada	Calm Air	B	7
15	British Airways	Calm Air	B	9
	For criterion: closeness airport			
16	Air Canada	British Airways	A	3
17	Air Canada	Calm Air	A	7
18	British Airways	Calm Air	A	5

Step 3 – Synthesize the individual subjective judgment and obtain the relative weights;

If the decision maker would be perfectly consistent, then we can obtain the weights w_i from the only nontrivial solution to:

$Aw = nw$, where *A* = consistent pairwise comparison matrix, *w* = column vector [w_1, w_2, … w_n], *n* = number of objectives and $\sum w_i = 1$

However, we do not know *A* and *w*. To obtain the weights, we replace matrix *A* with the pairwise comparison matrix $\tilde{A}$, *n* by the unknown λ and *w* by $\tilde{w}$:

$\tilde{A}\tilde{w} = \lambda\tilde{w}$, where $\sum \tilde{w_i} = 1$

Any value λ satisfying this equation is called an eigenvalue and $\tilde{w}$ is its associated eigenvector. The nontrivial eigenvalue is called the maximum eigenvalue λ_{max}. We expect λ_{max} to be close to *n* and $\tilde{w}$ to be close to *w*.

This approach is possible for slightly inconsistent matrices. Since the perceptions are subjective, it is important to ensure consistency of perceptions and accuracy of weights. This includes the consistency index (C.I.) with equation $C.I. = \frac{\lambda_{max} - n}{n-1}$ and the consistency ratio (C.R.) with equation $C.R. = \frac{C.I.}{R.I.}$. The random consistency index (R.I.), is the average value from a sample of 500 randomly filled matrices, see Table 3-9. Compared to the average of this sample, the AHP allows up to a 10% inconsistency. If the inconsistency is too high, a new matrix should be made (Ishizaka & Nemery, 2013) (Tzeng & Huang, 2011) (Winston, 2003).

TABLE 3-9
RANDOM INDICES FROM (SAATY, 1977)

n	2	3	4	5	6	7	8	9	10
RI	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Example: First, we determine for every criterion and alternative the maximum eigenvalue. After this, we check the consistency ratio, this must be lower than 10%. At last, we calculate the eigenvectors and by normalizing them, we find the ranking and the according weights.

Comparison of the four characteristics of a ticket:

We use two methods to obtain the criteria weights, the eigenvalue method and an approximation method.

The eigenvalue method: We first find the eigenvalues of the matrix. To do this, we find the values of λ which satisfy the characteristic equation of the matrix A, namely those values of λ for which det(A-λI)=0, where I is the 4x4 identity matrix.

$$determinant(A - \lambda I) = \begin{bmatrix} 1 & 7 & 3 & 3 \\ 1/7 & 1 & 1/7 & 1/5 \\ 1/3 & 7 & 1 & 3 \\ 1/3 & 5 & 1/3 & 1 \end{bmatrix} - \begin{bmatrix} \lambda & 0 & 0 & 0 \\ 0 & \lambda & 0 & 0 \\ 0 & 0 & \lambda & 0 \\ 0 & 0 & 0 & \lambda \end{bmatrix} = \lambda^4 - 4\lambda^3 - \frac{136\lambda}{35} - \frac{256}{315}$$

We now find that det(A- λI)=0, gives two eigenvalues:

$$\lambda^4 - 4\lambda^3 - \frac{136\lambda}{35} - \frac{256}{315} = 0: \quad \lambda = 0.20044 \; and \; \lambda = 4.22811$$

The maximum eigenvalue, consistency index and consistency ratio are therefore:

$$Maximum\ eigenvalue\ (\lambda_{max}) = 4.22811$$

$$Consistency\ index\ (CI) = \frac{4.22811 - 4}{4 - 1} = 0.076$$

$$Consistency\ ratio\ (CR) = \frac{CI}{RI\ for\ n = 4} = \frac{0.076}{0.9} = 0.084$$

The consistency ratio is lower than 0.1, which means the comparison is consistent enough. We calculated the eigenvectors for the eigenvalue of 4.22811 and normalised them to obtain the weights. These weights are shown in Table 3-10. The criterion ticket price is the most important for the decision maker (weight of 51%) and reputation the least important (weight of 5%).

TABLE 3-10

EIGENVECTORS OF THE COMPARISON MATRIX FOR THE CORRESPONDING EIGENVALUE (4.22811)

	Eigenvector	Normalized weight	Rank
Ticket price	3.3477	51.06%	1
Reputation	0.2948	4.50%	4
Transfers	1.9143	29.20%	2
Closeness	1.0000	15.25%	3

An approximation method: This is a more practical calculation of the weights. According to Winston (2003), this can be done with a two-step procedure:

1) Make a new matrix A_{norm} that normalised the entries of matrix A in which the sum of the entries per column is 1. This yields for our matrix:

$$A_{norm} = \begin{bmatrix} 0.5526 & 0.3500 & 0.6702 & 0.4167 \\ 0.0789 & 0.0500 & 0.0319 & 0.0278 \\ 0.1842 & 0.3500 & 0.2234 & 0.4167 \\ 0.1842 & 0.2500 & 0.0745 & 0.1389 \end{bmatrix}$$

2) Estimate the eigenvectors w_i as the average of the entries in row i of A_{norm}. This yields for our matrix:

$$w_{max} = \begin{bmatrix} \frac{1}{4} * (0.5526 + 0.3500 + 0.6702 + 0.4167) \\ \frac{1}{4} * (0.0789 + 0.0500 + 0.0319 + 0.0278) \\ \frac{1}{4} * (0.1842 + 0.3500 + 0.2234 + 0.4167) \\ \frac{1}{4} * (0.1842 + 0.2500 + 0.0745 + 0.1389) \end{bmatrix} = \begin{bmatrix} 0.4974 \\ 0.0472 \\ 0.2936 \\ 0.1619 \end{bmatrix}$$

As one can see, these weights (relatively 49.74%, 4.72%, 29.36% and 16.19%) are close to the normalised weights that we calculated with the eigenvalue method, given in Table 3-10.

Comparison of the alternative tickets with respect to the four characteristics:

For the comparison matrices of the alternatives we follow the same procedure as we did before:

$$Comparison\ matrix\ (ticket\ price): \begin{bmatrix} 1 & 1/3 & 3 \\ 3 & 1 & 7 \\ 1/3 & 1/7 & 1 \end{bmatrix}$$

$$Comparison\ matrix\ (feeling): \begin{bmatrix} 1 & 3 & 1/3 \\ 1/3 & 1 & 1/9 \\ 3 & 9 & 1 \end{bmatrix}$$

$$Comparison\ matrix\ (number\ of\ transfers): \begin{bmatrix} 1 & 1 & 1/7 \\ 1 & 1 & 1/9 \\ 7 & 9 & 1 \end{bmatrix}$$

$$Comparison\ matrix\ (Closeness): \begin{bmatrix} 1 & 3 & 7 \\ 1/3 & 1 & 5 \\ 1/7 & 1/5 & 1 \end{bmatrix}$$

TABLE 3-11

CONSISTENCY CHECK FOR THE COMPARISON MATRICES OF THE TICKETS WITH RESPECT TO THE CHARACTERISTICS

	Ticket price	Reputation	Transfers	Closeness
λmax	3.0070	3.0000	3.0070	3.0649
CI	0.0035	0.0000	0.0035	0.0324

RI	0.5800	0.5800	0.5800	0.5800
CR	0.0061	0.0000	0.0061	0.0559

TABLE 3-12
EIGENVALUES AND EIGENVECTORS OF THE COMPARISON MATRICES OF THE TICKETS WITH RESPECT TO THE CHARACTERISTICS

	Ticket price (λmax = 3.0070)		Reputation (λmax = 3.0000)		Nr. Transfers (λmax = 3.0070)		Closeness airport-city (λmax = 3.0649)	
	Eigenvector	*Normalized eigenvector*	*Eigenvector*	*Normalized eigenvector*	*Eigenvector*	*Normalized eigenvector*	*Eigenvector*	*Normalized eigenvector*
Air Canada	2.7589	24%	0.3333	23%	0.1314	10%	9.0246	65%
British Airways	7.6117	67%	0.1111	8%	0.1208	10%	3.8783	28%
Calm Air	1.0000	9%	1.0000	69%	1.0000	80%	1.0000	7%

Step 4 – Aggregate the relative weights of the elements to determine the best alternatives.

After we generated the weights for criteria and the impact of these criteria on the alternatives, we make a priority matrix. Here, the rows denote the alternatives and the columns denotes the priority vector for a certain decision factor. The alternative with the highest priority is the most optimal choice.

Example: multiplying the weights and the normalized eigenvector of the criteria gives a relative weight for each alternative. The alternative with the highest weight is the ticket from British Airways, followed by the Calm Air and Air Canada, see Table 3-13.

TABLE 3-13
EXAMPLE OF PRIORITY TABLE

Alternatives	Priority: Sum (weight criterion * impact criterion on alternative)	Rank
Air Canada	(0.51*0.24) + (0.04*0.23) + (0.29*0.10) + (0.15*0.65) = 0.26	3
British Airways	(0.51*0.67) + (0.04*0.08) + (0.29*0.10) + (0.15*0.28) = 0.42	1
Calm Air	(0.51*0.09) + (0.04*0.69) + (0.29*0.80) + (0.15*0.07) = 0.32	2

An additional step is the sensitivity analysis, where input data is modified to determine the impact on the results. The results are robust when the ranking does not change after varying the weight of the criteria (Ishizaka & Nemery, 2013).

Example: Given our example, we observed that a change in weight of the criterion ticket price, gives a change in the ranking, see Figure 3-7. Before a change in ranking occurs, this requires a change of 17.6 percent (from 0.51 to 0.42, then Calm Air is most important) or from 25.5 percent (from 0.51 to 0.64, then Calm Air is the least important alternative).

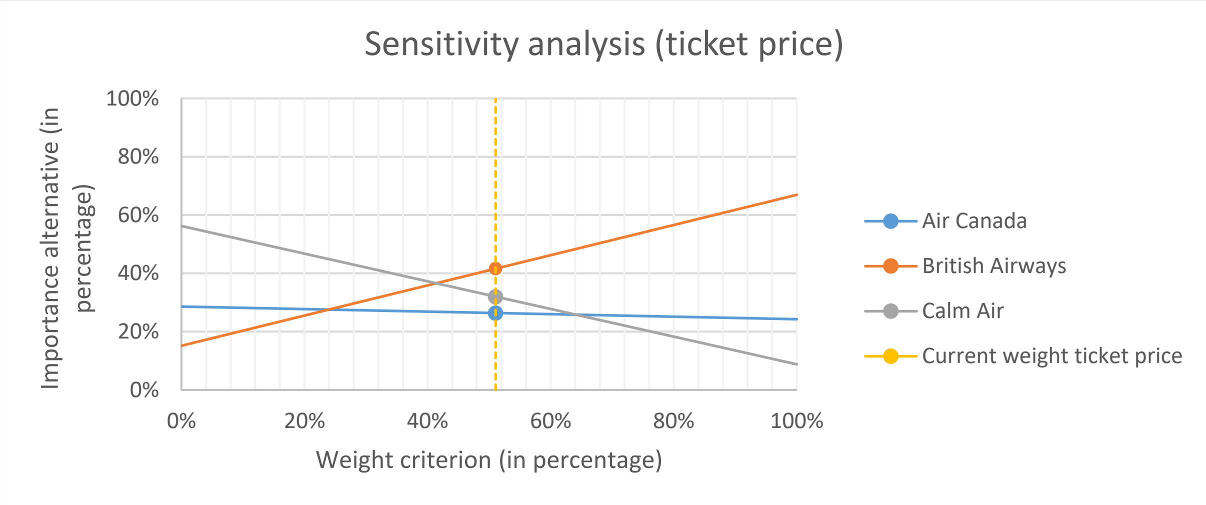


FIGURE 3-7. EXAMPLE OF SENSITIVITY ANALYSIS AHP

3.5.2 SMART

The simple multi-criteria rating technique (SMART), is the simplest form of multi-criteria utility theory (MAUT) and it requires the assumption of preferential independence, which we briefly explained before as decomposability at Section 3.4.1. (Velasquez & Hester, 2013). We explain the concept of preferential independency with an example:

Example: Assume we have two criteria (*ticket price* and *number of transfers*) and two alternatives. If we prefer a ticket of €300 over a ticket of €400 regardless of the number of transfers, and we prefer less transfers regardless of the price, then our preference of price and number of transfers are mutually independent from each other. In other words, changes in the rank order of preferences of *ticket price*, does not change the preference order of the *number of transfers*.

The SMART method is widely adapted because of its transparency, simplicity and relative speed by which the model can be applied (Goodwin & Wright, 1991). The steps of this method are:

Step 1 – Identify the decision maker (or decision makers).

Step 2 – Identify the alternative courses of action.

Step 3 – Identify the criteria which are relevant to the decision problem.

Criteria may be vague and therefore they may need to be broken down into more specific criteria. A value tree can be useful in this step.

Step 4 – For each criterion, measure how well the options perform.

The next step is to find out how well the different alternatives perform on each criterion in the value tree. There are two approaches used to measure the performance: direct rating and value functions.

Direct rating: Scores on criteria can be more difficult to measure when it is hard to find quantifiable variables. The decision maker is asked to rank alternatives from most preferred to least preferred. The most preferred alternative gets 100 points, the least preferred alternative 0. Next, the decision maker compares the intervals between the points on the interval scale to rate the other alternatives in such a way that the space between the values represent the strength of preference for one alternative over another in terms of the criterion (Goodwin & Wright, 1991).

Value functions: This approach is used for criteria that can be represented by easily quantified variables. We start with measuring the relative strength of preference of the decision maker for the alternatives. After we determine the least preferred and the most preferred option, we find the points that fall in-between those points with a value function. One method to elicit a value function is bisection. With bisection we first determine the point halfway, and after this, the quarter points. We can derive a value function when we know these five points (Goodwin & Wright, 1991).

Example: Based on the example of (Goodwin & Wright, 1991), we have again the following raw scores:

TABLE 3-14
EXAMPLE OF RAW SCORES

Values	Ticket price (€)	Reputation	Transfers (#)	Closeness to airport (km)
Air Canada	400	Average	6	50
British Airways	300	Negative	5	60
Calm Air	500	Positive	1	100

<u>Direct Rating</u>

Image has no quantifiable variables that represent this criterion. The ranking is as follows:

(1) Calm Air
(2) Air Canada
(3) British Airways

The best scoring alternative is Calm Air, we give this a value of 100, and British Airways a value of 0. An improvement in *reputation* between British Airways and Calm Air is perceived 1.5 times as preferable as the improvement between Air Canada and Calm Air. This gives Air Canada a normalised score of 60.

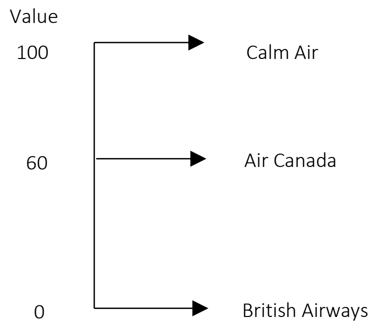


FIGURE 3-8. VALUE SCALE FOR CRITERION 'REPUTATION'

Value Function

The criteria price, transfers and closeness remain to be scored. We assume that the decision maker finds a difference at the beginning of the scale for number of transfers more important than the same difference at the end of the scale. This means that an improvement of 6 transfers to 5 transfers is more important to the decision maker than an improvement of 2 transfers to 1 transfer. For closeness of the airport to the city, the decision maker finds the improvement equally important. This gives the graphs:

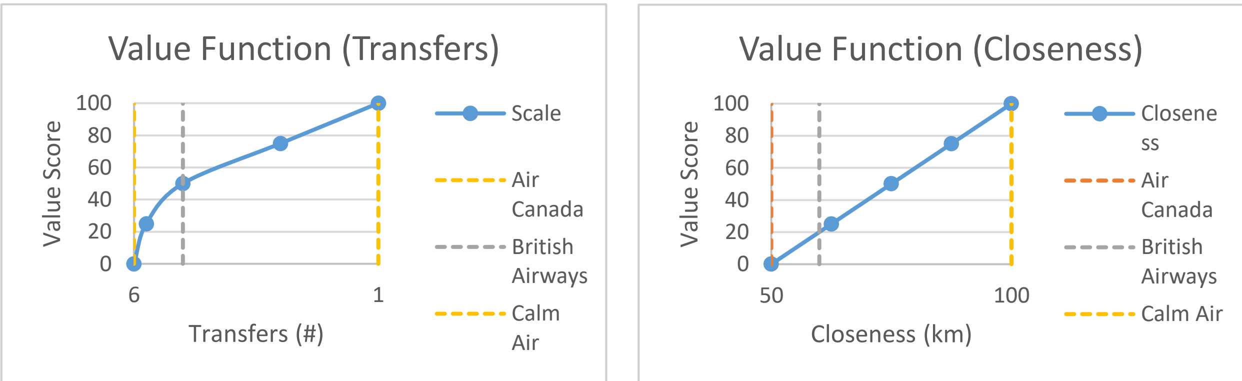


FIGURE 3-9. EXAMPLES VALUE FUNCTIONS

Based on both graphs, we determine the value scores, which are given in Table 3-15. In this example, we follow the method of Goodwin & Wright (1991) and we make a trade-off between the costs and benefits at a later stage in our analysis since the comparison can be difficult to make for the decision maker. The owner already knows the ticket prices, and we focus first on the benefits.

TABLE 3-15

EXAMPLE OF NORMALISED SCORES

	Air Canada	British Airways	Calm Air
Reputation	60	0	100
Transfers	0	50	100
Closeness	0	20	100

Step 5 – Determine the weight for each criterion.

The decision maker attaches weights to each of the criteria that reflect their importance. Different methods exist to choose the weights, but the most common is the use of swing weights. These weights are derived asking the decision maker to compare a change from the least-preferred to the most-preferred value on one criterion to a similar change in another criterion. It is conventional to normalise them so that they add up to 100.

Example: Consider the lowest-level attributes on the benefits branch of the value tree (Figure 3-6). The decision maker imagines an imaginary ticket with all the criteria at their least preferred levels. This is a ticket with the most transfers, the largest distance between airport and city and the worst reputation. The first criterion that he would put to its highest level is the number of transfers. The criterion that he would choose next is 'number of transfers', and at last 'reputation'. Now we can give 'number of transfers' a weight of 100 points. Then, the decision maker is asked to compare a swing from the ticket with the most distant airport to the ticket with the closest airport, with a swing from the ticket with most transfers to the ticket with the least transfers. He decides that the swing in 'closeness' is 80% as important as a swing in 'transfers'.

TABLE 3-16
EXAMPLE RELATIVE WEIGHTS

Criteria	Criterion	Rank	Original swing weights	Normalized weights
Flying conditions	Transfers	1	100	50%
	Closeness	2	80	40%
Reputation	Reputation	3	20	10%

Step 6 – Take a weighted average of the values assigned to each alternative.

Now that we have the performance on each criterion and the weights, we can compare the values allocated to one criterion with the values allocated to the others. To do this, Goodwin & Wright use the additive model. According to this model, they multiply each value by the weight attached to that criterion. The resulting products are then summed and divided by 100. The outcome is the overall value for each alternative.

Example: The normalised scores for our example are given in Table 3-17.

TABLE 3-17
EXAMPLE NORMALISED SCORES

Criterion (aggregated weights)	Lower-level criteria	Normalized Weights	Air Canada	British Airways	Calm Air
Reputation (10%)	Reputation	10%	60	0	100
Flying conditions (90%)	Transfers	50%	0	50	100
	Closeness	40%	0	20	100
Aggregated value			6	33	100

Overall value	0.06	0.33	1.00

Step 7 – Make a provisional decision

The alternative with the highest overall value should be the one the decision maker should choose. However, when the decision maker experiences difficulties in assigning weights to criteria, he can make plot with on one axis the overall values of the alternatives and on the other axis the criterion that is difficult to weight. The non-dominated alternatives lie on the efficient frontier and are worth considering. The choice between these alternatives depends on the relative weight the decision maker attaches to the criteria.

Example: Like we mentioned in the fourth step, we need to trade off the benefits against the costs. This trade-off gives a frontier line that connects British Airways and Calm Air. The decision maker should choose between those two.

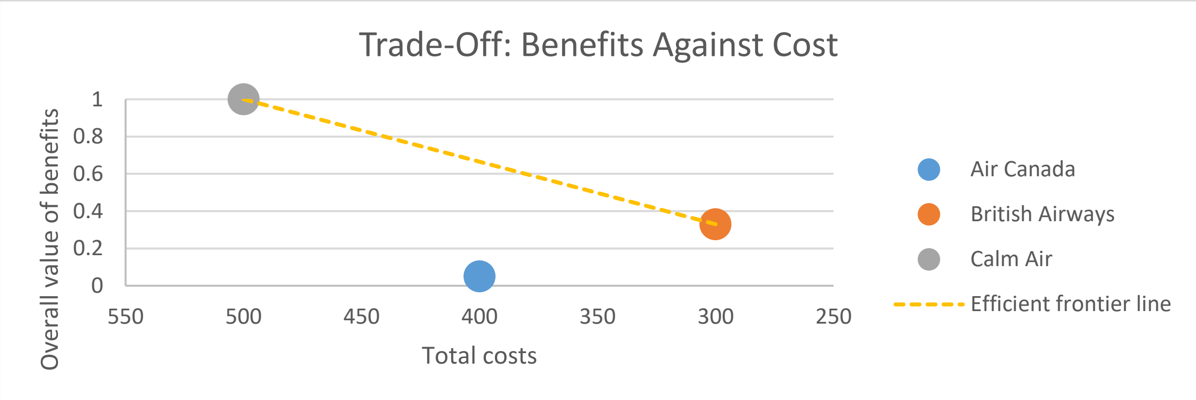


FIGURE 3-10. EXAMPLE TRADE-OFF BENEFITS AND COSTS

The choice between British Airways and Calm Air depends on the relative weight the decision maker gives to costs and benefits. If he is more concerned about costs, he should choose British Airways, otherwise Calm Air. Another way of choosing is to calculate the costs per benefit point. From B to A is an increase of €200 for the ticket price and 66.7 benefit points, so €3 for one-point. Then, we select a lower-level criterion that the decision maker finds easy to evaluate in monetary terms. For our case, this is 'closeness' and he would pay €80 for a change from a ticket that has the most distance to the airport to one with the closest distance, so €80 euro increase for 100 points. However, the weight is 40%. An increase of 100 points on the distance scale would increase the aggregated value of benefits by 40 points. This means that the decision maker is willing to pay €80 for 40 points, or €2 per point. This implies he should choose for a ticket from British Airways.

Step 8 – Perform sensitivity analysis.

Before making a firm recommendation, the decision maker should explore the effect of changes. A sensitivity analysis is used to test the robustness of the choice of an alternative. It shows how the value of alternatives varies with changes in the weight placed on another alternative. A sensitivity analysis contributes to the decision maker's understanding of the problem. Often, only large changes are needed before one alternative becomes more attractive than another.

Example: To see what influence the weights of benefits have on the outcome of the overall value of the benefits is determined in a sensitivity analysis. With our example, the weight on flying conditions (60%) needs to go under 40% to effect the ranking. If that is the case, not Air Canada would have the lowest value of benefits, but British Airways.

Another MCDA method that is similar to SMART is SMART Exploiting Ranks (SMARTER). SMARTER is used when the decision maker has difficulties assigning swing weights to alternatives or to find an appropriate scale. Weights are assigned by using a certain approach and value functions are assumed to be linear. When the decision maker thinks that an increase in the top end of the scale would be more or less useful than an increase in the lower end of the scale, bisection can be used instead of the linear approximation to obtain the value function (Goodwin & Wright, 1991) (Edwards & Barron, 1994) (Barfod & Leleur, 2014).

3.5.3 Comparison AHP and SMART

As we stated in Section 3.4.2., both AHP and SMART are full aggregation approaches for ranking problems with deterministic data. The example shows that the results from the AHP and SMART methods are the same, see Table 3-18.

TABLE 3-18
COMPARISON RESULTS AHP AND SMART

	AHP		SMART		
	Results	Rank	Value benefit	Costs	Rank
Air Canada	0.26	3	0.06	400	3
British Airways	0.42	1	0.33	300	1
Calm Air	0.32	2	1	500	2

Yet, in the AHP procedure, the decision maker is asked to judge two alternatives under a criterion and to express his preference between them. In the SMART method, he is asked to rank the alternatives under a criterion and to assign weights based on his judgement. Thus, the decision maker keeps a more holistic view with SMART, where in AHP his judgement is more fragmented.

A strength of the AHP is its flexibility, its intuitive appeal to the decision makers and its ability to check inconsistencies (Ramanathan, 2001). The pairwise comparison form of data input is straightforward and convenient (Macharis, Springael, De Brucker, & Verbeke, 2004). However, the comparisons can take a lot of time depending of the number of alternatives and criteria. As we saw in our example, three alternatives and four characteristics gave already 18 comparisons. If we would add another characteristic, this would already increase to 25 comparisons. Another drawback of the AHP method is rank reversal phenomenon, which can occur after:

1. Addition or deletion of alternatives
2. Inversion of the scale, for inconsistent matrices of rank n > 3 (Ishizaka & Nemery, 2013)

Example: An example of rank reversal due to addition or deletion of alternatives: When the AHP outcome is a rank of, for example, four alternatives and before making the decision, the decision maker discovers that there exists a fifth alternative, he may repeat the AHP. However, the new ranking can change the ranking of alternatives as well. This can mean that the ranking of our previous example: British Airways > Calm Air > Air Canada gives after introduction of another alternative, a new AHP ranking: Calm Air > Delta > British Airways > Air Canada. Then, we see that Calm Air is better than British Airways, while in the previous ranking British Airways was better than Calm Air.

As we described in the beginning of Section 3.5.2., the strength of SMART is its simplicity to use and its allowance for any type of weight assignment technique, for example with use of SMARTER. Its ease of use helps in situations where there is little information available and access to decision-makers is easy to obtain, but this also has the drawback that it does not capture all the detail and complexities of the real problem (Velasquez & Hester, 2013) (Goodwin & Wright, 1991). For our problem access to decision makers is easy to obtain and it seems not necessary to capture all the details. Another advantage is that a change in the number of alternatives will not change the decision scores of the original alternatives, which is useful when new alternatives are added. A weakness of the SMART method is that it tends to oversimplify the problem when the top few alternatives are very similar.

Since SMART takes less effort and time for the decision maker when the number of alternatives and criteria increase than AHP, and rank reversal can be avoided, we choose to use SMART for scenario evaluation.

3.6 Conclusions

Network design is the strategic planning process for evaluating alternative structures for a supply chain and selecting the best alternative. Depending on the business requirements, companies might consider to re-design their supply chain or designing a new supply chain. Business drivers for re-design of the network are mergers & acquisitions, changing market and business conditions in combination with costs pressure and service requirements that require expansion, restructuring, simplification or downsizing of the operations, and a change of parameters. (Re)-design of the supply chain network must be a solution for achieving the strategic objectives if it does not optimally support the targeted business model. Four key strategy elements that represent the strategic direction are: costs, service, time and agility. Since it is not feasible to perform high on each aspect, it is crucial to align the design with the optimal strategy and to make a trade-off between the elements.

An approach that evaluates multiple elements, is multi-criteria decision analysis (MCDA). Typical MCDA decisions about strategic network design are the number and locations of plants and warehouses and the plant and warehouse capacity levels. A typical tactical decision is the choice of modes and how frequently to ship them. Supply chain measurements are based on efficiency, responsiveness and disruption risk. General steps of an MCDA method are problem definition, identification of stakeholders, alternatives and criteria, selection of the algorithm, interpretation of results and the final choice. The MCDA method that fits most to our problem are AHP and SMART. Both methods are similar, but different in the procedure for the decision maker. A drawback of AHP is the rank reversal phenomenon, which can occur in a network review. As described in Section 3.1.1., Camelot advises that network design should rely on a process that includes potential process iterations. After scenario evaluation, it should be possible to add a new scenario to the ranking. If we would choose AHP, we must start all calculations again whereas with SMART we could simply add the scores for the new scenario. We choose to use SMART since it takes less effort and time for the decision maker than AHP and rank reversal can be avoided.

Distribution of steel per truck

4 Recommendation for a Network Review Process

In this chapter, we give answer to the third research question:

What is the desired process of a network review according to outbound logistics?

a) *What are the requirements and preferences from Tata Steel for a uniform review process?*
b) *What does the new review process looks like?*

We present the requirements and preferences from the NMD department for a standardised process together with a discussion about triggers and criteria in Section 4.1. Based on these requirements, information from Chapter 2, desk research, internal document analysis, observations and interviews with employees from outbound logistics, we developed a flow chart of how a transportation network review should be in Section 4.2. We give a conclusion on this chapter in Section 4.3.

4.1 Development of New Network Review Process

We give our recommendation of a new process in the next section, but before this we summarise the data gathering methods and the results from Chapters 2 and 3 that contribute to the development of this new process, and the identified triggers and criteria.

4.1.1 The Process

We designed the new process of a network review based on multiple data gathering methods. We held group meetings with consultants, analysts, the department manager and the quality manager outbound supply chain. Before these group meetings, we held individual discussions with the NMD members. The current process, as described in Chapter 2, was the input for the individual meetings. We walked through every step and discussed what should be added or removed from the current process. Based on the outcomes of every individual meeting, we discussed the differences and changes that we made in the group meetings. We also found on intranet an old review process, this process was outdated, because it did not involve the use of optimization tools. However, it did include a useful list of stakeholders per step. Through desk research, we found three companies that have a similar review process. Two of these companies are Camelot and Capgemini, described in Chapter 3. Furthermore, NMD meets once a year with the global network design department of Heineken to exchange information and experiences about network design related projects. Next to the previous data gathering methods, we also did observations during the network review of West-Germany. An overview of all the data gathering methods is given in Table 4-1.

TABLE 4-1
DATA GATHERING METHODS FOR PROCESS STEPS

	Data gathering method	Content
Review process	Individual and group meetings (semi-structured)	With NMD employees: consultants, analysts, department manager, quality manager outbound supply chain and the financial controller
	Observations	Observations of the review for West-Germany (Siegerland, Ruhr and Hagen/Dortmund)
	Desk research	Processes from other companies (Heineken, Capgemini and Camelot)
	Internal document analysis	Old network review process (2015)

In Chapter 2, we examined the ways of performing a network review amongst the four distribution chain consultants. We summarise the differences that we found because this serves as input for group meetings as NMD. We found activities to be different between their review methods:

- Determination of the scope and timeline of the project.
- Consultants work together with different groups: steering team, management team and project team.
- Parameters costs and volume are used differently for calculating the baseline. For both parameters, some use current data and other expected data.
- Run of a sensitivity analysis.
- A free run scenario as alternative. This is a scenario where the optimisation has no restrictions. The output is not realistic, but can bring new ideas to the table.
- Inclusion of a service level agreement (SLA) with the logistics service provider.

In Chapter 3, we found through desk research an advice of Camelot and Capgemini for the process of strategic network design. Combined with information that NMD received from Heineken about their review process, this gives the following global steps for a network review, which we use as input for the group meetings at NMD:

1. Definition of objectives & network strategy
    a. Plan kick-off (agree on scope, confirm level of modelling, define constraints and business goals)
2. Analysis of baseline
    a. Collect and validate data
3. Scenario generation
    a. Optimise network according to objectives and considering relevant constraints
    b. Use of optimization tools
4. Scenario evaluation

   a. Compare optimization results and baseline
   b. Run a sensitivity analysis for input parameters such as costs and demand to analyse the impact on the business goals
5. Selection of supply chain design
   a. Make the business case
   b. Make an implementation plan for the chosen scenario
6. Implementation
   a. Make a budget plan
   b. Negotiate with suppliers, service providers and public authorities
   c. Manage the transformation project in time and budget

The output from Chapters 2 and 3, served as input for two group meetings held with the distribution chain consultants, the logistics analysts, the quality manager and the NMD manager. An example of a point of discussion in the group meetings, was about the use of current or expected cost rates and volumes in calculations for the baseline and for the optimization. The outcomes of these discussions are described in Step 2 of Section 4.2. During two group meetings, the following requirements for a network review were mentioned:

- A network review should not be executed on an ad hoc basis only, but also on a structural basis. As described in Section 2.1, NMD wants to prevent to go in a 'fire-fighting' modus. This means that next to the reactive triggers, we should include proactive factors like a review agenda.
- For triggers with a small effect, only a smaller version of the network review is necessary, or the task can be done by the operations department.
- The four distribution chain consultants must have one process of performing the review.
- The logistic analysts should be involved in the review. The optimisation tool must be integrated into the process.
- The solution should not focus on costs only, but on multiple criteria.
- The review should be based on one business question.
- The search for alternative LSPs should be partly desk work and partly field work.
- The process flow must include input and output that is needed for every step. A link to the formats and needed document need to be included.
- Stakeholders who are responsible or who should be informed for each step must be identified.
- NMD wishes to include KPIs to measure the performance of the network. This can lead again to a network review.

Based on outcomes from the meetings and Chapter 2, further outcomes of these meetings were the addition of the steps: determining the scope, a sensitivity analysis, a free run scenario and an SLA in the review process.

Based on outcomes from the meetings and Chapter 3, we decide to split the step 'scenario generation' from the combined steps of Heineken, Camelot and Capgemini. We do this to limit the size because it should consist of both desk- and field work according to the requirements.

Taking the requirements, the developed process by Camelot, Capgemini and Heineken, the stakeholders from the outdated process, and observations into account, we come to a new design of the process that we recommend to Tata Steel, presented in Section 4.2.

4.1.2 Identification of Possible Triggers

We identified possible triggers that will cause the network review to start reactively, through meetings with NMD members and desk research, see Table 4-2.

TABLE 4-2
DATA GATHERING METHODS FOR OBTAINING TRIGGERS

	Data gathering method	Content
Triggers	Individual and group meetings (semi-structured)	With NMD employees: consultants, analysts, department manager, quality manager outbound supply chain
	Desk research	Business drivers from other companies (Camelot and Capgemini)

Resulting from a group meeting with all NMD members, we made a list of possible triggers. Since we found out that this list is infinite, we decided to structure them into categories. Since this list exists of 15 categories and some are overlapping, we had individual meetings with the consultants to structure them into even less categories. The first list of triggers is given in Appendix D. As described in Chapter 3, we also found business drivers that Camelot and Capgemini defined for strategic and tactical network design. We compared the lists and came to a combination of them. The changes that we made are also given in Appendix D. The eventual category list for a network review is then:

- Changes in customer volumes and production
- Commercial opportunity
- Change of key parameters
- Customer complaints
- Changes in the strategy of Tata Steel
- Change in distribution structure
- Transportation spend

4.1.3 Identification of Criteria

As we described in Chapter 1, strategic network design is a complex process partly because multiple objectives play an important role in decision making for logistics concepts. In current practice, NMD only has insight into expected transportation and handling costs, and CO2 emissions, based on a forecast. However, NMD want to have more insights in scenario effects on the supply chain, so we identify these criteria through individual meetings and results from our literature study. Meetings are held with the manager outbound logistics, manager NMD, manager sourcing, manager operations, distribution chain consultants and the logistics analysist.

TABLE 4-3
DATA GATHERING METHODS FOR OBTAINING CRITERIA FOR REDESIGNING THE NETWORK

	Data gathering method	Content
Criteria	Individual meetings	With outbound logistics employees: consultants, analysts, NMD manager, sourcing manager, operational manager, quality and safety manager
	Literature research	Criteria about strategic network design and routing

In Chapter 2, we concluded that possible criteria are based on the following supply chain measures: efficiency measures are ‘distribution costs’, ‘inventory holding costs’, ‘facility operating costs’, and ‘freight transportation costs’. Responsiveness measures are ‘reliability and accuracy of fulfilling customer order’ and ‘delivery time’. Factors of disruption risk are ‘vulnerability of a facility’ and ‘vulnerability of a transportation link’.

Based on meetings at Tata Steel, we concluded that a network design for Tata Steel should: minimise costs, maximise sustainability, maximise delivery service, maximise readiness for implementation, maximise robustness, maximise quality and minimise inventory time(see Table 4-4).

Based on these criteria and objectives in network design we identified the following criteria: ‘costs’, ‘delivery service’, ‘quality’, ‘readiness for implementation’, ‘sustainability’, ‘inventory time’ and ‘robustness’. The criterion ‘costs’ includes transportation costs, handling costs and costs for working capital. The criterion ‘delivery service’ includes delivery time and frequency. ‘Quality’ exists of a performance score of the LSP, risk of disruption in the network, and quality rates of the used warehouses. The criterion ‘readiness for implementation’ encompasses IT connectedness and the ratio of existing routes. The criterion ‘sustainability’ exists of CO_2 emissions and nuisance in the neighbourhood of Tata Steel IJmuiden caused by trucks leaving the site. ‘Inventory on site’ is the time that steel stays in inventory, which means the time between production and transportation. A higher flow is better for inventory and working capital, but results in more inventory in external warehouses, which results in more costs. As last, the criterion ‘robustness’ includes the dependency on suppliers and modalities. These criteria should fulfil the requirements for criteria that we mentioned in Chapter

3 and this evaluation is given in Chapter 5, together with the final set of the criteria and the operationalisation.

TABLE 4-4
CRITERIA FOR REDESIGNING THE NETWORK

Criteria		Subcriteria	
1	Costs	1a	Transportation costs
		1b	Handling costs
		1c	Impact lead time on working capital costs
2	Delivery service	2a	Delivery frequency
		2b	Delivery time (lead time)
3	Quality	3a	Expected supplier performance
		3b	Risk of disruption of a transportation link
		3c	Quality of used warehouses
4	Readiness for implementation	4a	IT connectedness
		4b	Ratio flow through existing lanes
5	Sustainability	5a	CO2 emissions
		5b	Nuisance caused by trucks in neighbourhood Tata Steel IJmuiden
6	Robustness	6a	Supplier dependency
		6b	Modality dependency
7	Inventory time	7	Inventory time at MLE works

4.2 Steps of a Network Review

Based on information from the previous chapters and Section 4.1.1, we recommend a new standardized process of a network review, that is displayed in Figure 4-1 and that includes the following steps:

1. Organise a kick-off phase where the scope, planning and key stakeholders are determined.
2. Validate the baseline scenario to compare other scenarios later in the process.
3. Design alternative scenarios and search for alternative LSPs behind the desk and in the field.
4. Prepare the optimisation tool with the collected data and possible routes to model the alternative scenarios. This includes one unconstrained scenario (for example, the assignment of volumes over warehouses is not restricted) and a sensitivity analysis.
5. Use the output of the optimisation tool as the input for the multi-criteria decision model and select the best scenario based on multiple criteria.
6. Discuss the best scenario with the key stakeholders to validate if this scenario is indeed better than the baseline scenario. If this is not the case, then the process stops and the current network stays unchanged.
7. Get approval from the account manager, the financial controller and dependent on the scope also from the manager of outbound logistics.
8. Implement the new logistics concept and adjust the systems.
9. Monitor the new network design in this region with KPIs to measure its performance on lead time adherence and transportation spend.

Another preference of NMD was to identify the stakeholders that are responsible or accountable for that step and stakeholders who must be consulted before, or informed after that step. This is shown next to the flow chart in Figure 4-1, where R stands for responsible, A for accountable, C for consulted and I for informed. With this method we complemented the power/interest matrix given in Section 2.2.

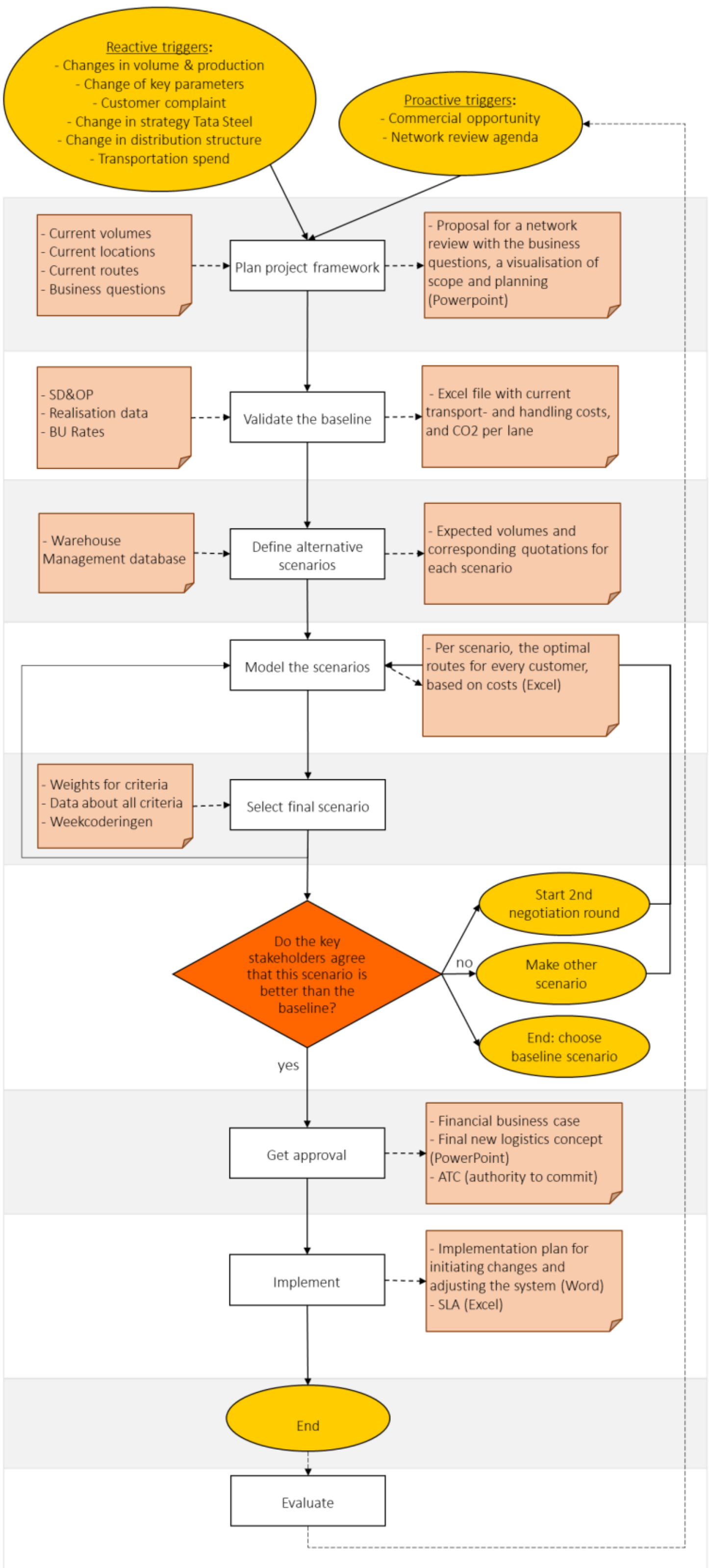
We give a more detailed overview of the steps below and in Figure 4-1 on the next page.

It is possible that the review starts reactive when it is a reaction on a trigger, thus on ad hoc basis. Since NMD only wants to focus on triggers that have potential severe impact and on triggers that have effects on the long horizon, we made a matrix that evaluates if a network review should be started for this trigger. The review can also start proactive when it is not a reaction on a trigger, but for example, because the network in that region should be reviewed every year and no triggers occurred in the previous year.

1. The first phase of a review is the kick-off phase. The distribution chain consultant and logistic analyst are responsible. They must identify the business question for the analysis. This business question depends on the trigger and determines the scope and size of the project. The consultant organizes a session to consult the key stakeholders from the departments of sourcing, operations and QTS. These stakeholders can provide extra information about developments in that region and after this the business questions, scope and planning can be adjusted. The output of this phase is a PowerPoint presentation with all relevant information included about the business questions, scope and planning.

2. Now the scope is known, the baseline scenario is made in the optimisation tool by the logistic analyst. This is a scenario with the current routes, but with the volumes from the forecast. The financial controller needs to be informed about the rates that the analyst will use for modelling. This includes:
    - The current BU rates plus the expected increase or decrease need to be considered for calculations in the baseline scenario.
    - The expected volumes need to be considered for calculations in the baseline scenario. This volume is a mix of realized volume and forecasted volume (of the SD&OP). When a large difference is observed, the consultant asks the account manager if this difference is truly expected. If yes, the forecast volume is chosen. If not, the realized volume is chosen.

   The financial controller needs to validate the calculations for the baseline before other scenarios are compared to the baseline later in the review.



Stakeholders involved[2]: Distribution chain consultant	Logistic analyst	Financial controller	Accountmanager	Employees from SRC, OPS, QTS	OSL & invoicing & supply chain planning	Definition of the activity
R	C			C		• Analyse current logistics network • Determine scope • Determine planning / milestones • Determine the key stakeholders from SRC, OPS and QTS • Allign baseline with key stakeholders in kick-off: discuss developments in region, and perhaps adjust scope and planning
C	R	I				• Make the baseline scenario • Run baseline in SC Guru • Validate the baseline with the financial controller
R				C		• Desk work: search for alternative LSPs • Make alternative scenarios • Field work: validate alternative scenarios with LSPs • Adjust alternative scenarios • Sourcing: send requests for quotations (RFQs) to LSPs
	R					• Prepare SC Guru with routes from the scenarios • Add extra additional routes that are not in scenarios but may be relevant • Validate the prepared routes • Run an unconstrained & alternative scenarios in SC Guru • Run a sensitivity analysis in SC Guru
R	C					• Run VBA multi-criteria decision tool • Select best scenario • Adjust this scenario with more constraints to make it more realistic (i.e. no customer can be delivered with ≥ 1 modality) and calculate costs and CO2 emission in Guru.
R				C		• Discuss best scenario with key stakeholders
R		I	I			• Validate business case with financial controller • Dependent on size scope: validate final scenario with management team by an ATC and final proposal • Communicate final scenario to relevant accountmanagers
R			C	I	I	• Meet with all stakeholders • Make an implementation plan for adjusting the following systems: orderbooking / packaging / agreements dispatch / distribution agreements / transport lead times (weekcodering) • Draw up an SLA with the sourcing department and LSPs • If a new route is implemented: management of change • Savings registration process
				C		• This end point is the starting point for the sales and sourcing departments to start their processes.
	R					• Monitor KPIs: lead time adherence, transportation costs

FIGURE 4-1. THE DESIRED PROCESS OF A FULL TRANSPORTATION NETWORK REVIEW ACCORDING TO NMD EMPLOYEES

[2] Stakeholder involvement: R: responsible, A: accountable, C: to consult, I: to inform

3. The consultant searches for alternative LSPs to design alternative scenarios. Next to desk work, this is done with field work. The consultant visits LSPs that are in scope to assess their equipment and to see if the LSP can facilitate the volume according to the scenarios. A PowerPoint presentation with the scenarios is the output of this phase and is sent to the sourcing department. Sourcing then makes an RFQ to send to the LSP for asking their prices.

4. Before the logistic analyst runs alternative scenarios in the optimisation tool, the program needs to be prepared with all the routes and parameters. Next to the lanes that are already known in the model, other lanes that are relevant must be included. This way the optimization model has more options for routing. All lanes should then be validated together with the distribution chain consultant. When the optimisation tool is prepared with relevant data of the scenarios, the program runs a scenario with no restrictions and the alternative scenarios that are made in phase 3. For example, normally modelling would have the restriction that no customer can be delivered with more than two modalities from different terminals, but in this scenario this is possible. A sensitivity analysis is performed to measure the impact of different volumes and different rates on the outcome of the optimisation. The output of this step encompasses the optimal routes in the network based on total transportation costs and handling costs for each scenario.

5. This output and data from other datasets are the input for the multi-criteria decision model, which evaluates the scenarios on multiple criteria. The criteria focus on the aspects of sustainability, quality, costs, robustness, delivery service, inventory impact and readiness of implementation (see Table 4-4). We explain these criteria in Chapter 5, where we also discuss the results of the multi-criteria decision model. The distribution chain consultant runs the model and chooses appropriate weights for the criteria.

   The scenario that scores best according to the multi-criteria decision model is selected. All the lanes from this scenario are validated by the consultant. He can decide to not fully agree on a route change for certain lanes, but to remain the same lane as the baseline. This can be for the following reasons:

   - If a customer is delivered by more than one modality.
   - The optimisation tool would always choose the cheapest option, even if it differs only a little bit in costs, but is much more polluting. Then the consultant can decide to not follow the optimisation tool's advice.
   - If the new network gives more inventory on site than the baseline scenario.

It is not efficient for the consultant to validate each lane in a network for each scenario, which is why only one scenario is selected as the final scenario at the end of the process. If this scenario is a new alternative because it exists out of other scenarios, the reconfiguration costs are calculated again in the optimisation tool.

6. A go/no-go decision is then made by the key stakeholders. If they agree with this scenario, then the next phase is initiated. If they do not agree with this final scenario, it is possible to start a second negotiation round to get better rates, to make another scenario and start again with modeling, or to stop the review and stay with the current situation.

7. If it is decided that an alternative scenario is better than the baseline, this scenario must be approved by the management of outbound logistics, the financial controller and the account managers of the customers whose routes need to be changed.

8. The consultant makes an implementation plan after all important stakeholders have approved the new logistics concept. The consultant makes a service level agreement with the LSP to make agreements clear (which are not in the formal contract) about the tasks and responsibilities of the LSP. The operations department monitors this agreement after the conduction of the review.

After the new logistics concept is implemented in the network and the systems are adjusted, the review stops and the distribution chain consultant writes a final project summary document. Through the KPIs 'lead time adherence', and 'transportation costs', which are described in Chapter 2, the network performance is measured to ensure efficiency and which can be a trigger for a new network review.

4.3 Conclusions

A network review must start reactively when it is a reaction on triggers, or proactively. For a proactive start, NMD must make a review agenda for every region. The desired process of a network review exists of the following phases: a kick-off phase where business questions are defined so that there is a clear focus in the review. Then a scenario must be made for the current situation and alternative scenarios as well. When data is collected, the logistic analyst prepares the program and after this, it can model all the scenarios including an unconstrained scenario and a sensitivity analysis. The choice of the best scenario depends not only on costs, but also depends on other criteria that we describe in Chapter 5. The scenario that scores best on a combination of these criteria is then adjusted to make it even more realistic. This final scenario is discussed with the key stakeholders from outbound logistics and must then be approved by management, the financial controller and the sales department unless that scenario is the baseline. If a new logistics concept must be implemented, a plan is made to adjust the systems and the new concept is initiated. The performance of the new network should be monitored through ensure efficiency.

A distribution centre filled with coils in Neuss, Germany

5 Development of the MCDA Tool

As described in Chapter 1, consultants must make trade-offs for the (re-)design of the logistics network. These trade-offs must be made on different aspects of the supply chain, as described in Section 4.1.3. NMD has irrespective of the optimisation tool, no other tool for gaining insight in these aspects. The tool that we developed provides insight in these aspects and gives the consultants guidance in a standardised process of a network review. In this chapter, we provide information about the building of the tool in Section 5.1, followed by the input that is needed in Section 5.2, an explanation of the calculations for the raw scores in Section 5.3. Finally, we give a conclusion of this chapter in Section 5.4 and answer the fourth research question:

How can a decision support tool complement the network review?

5.1 The Tool

As we explained in Chapter 3, we choose the algorithm SMART to develop the MCDA tool. The environment that we use for implementation is Excel VBA, because this is an accessible program to use for the consultants. The Excel file has eight worksheets, from which the middle sheets provide calculations for the criteria that we used. We provide a reason for choosing these criteria in Section 5.2.

[1. *General instructions*] In this sheet, the purpose of the tool is presented, together as an explanation of each criterion and instructions on how to use the tool.

[2. *Optimisation tool output*] The output of the optimisation tool is the input of the MCDA tool and this data can be uploaded to this worksheet.

[3. *Input*] This sheet shows the scenarios, used warehouse suppliers and used routes from the Optimisation tool output sheet. Then, the decision maker fills in the corresponding parameters that are needed for further calculations.

[4. *Results*] Weights are assigned to the criteria, and raw scores are translated into normalised scores by giving a scale for each criterion. These scores give a ranking of scenarios.

[5. *Sensitivity Analysis*] This sheet gives an overview of all the sensitivity analysis graphs that show the impact of the criteria weights on the overall scores.

[6. *Criteria*] Calculations for criteria '*transportation costs*', '*handling costs*', '*CO2 emissions*', '*inventory time on site*', '*mode mix deviation*', '*transportation risk*' are given.

[7. *Criteria*] Calculations for criteria '*warehouse dependency*', '*IT connectedness*', '*quality used warehouses*', '*expected supplier performance score*' are given.

[8. *Criteria*] Calculations for criteria '*existing lanes'* are given.

[9. *Criteria*] Calculations for criteria '*working capital'* are given.

5.2 Input

The first step of the network review process is the identification of the business question. The scope of the review is dependent on the chosen business question and this scope influences the output of the optimisation in the optimisation tool. The output of this optimisation consists of the optimised lanes in scope which includes the scenario name, the source and destination of the lane, the mode of transport, the corresponding flow in tonnes, transportation and handling costs, and CO2 emissions per lane. An example of this output:

TABLE 5-1
EXAMPLES OF LANES: COMBINATION OF SOURCE, CUSTOMER, DESTINATION AND MODALITY

Scenario Name	Source Name	Destination Name	Mode	Flow Units (mts)	Transport-ation Cost (€)	Sourcing Cost (€)	CO2 (kg)
Scenario 1			Vessel T-T	2753	33036	15059	39548
Scenario 1			Vessel T-T	11888	142656	65027	170776
Scenario 1			Vessel T-T	17095	205140	93510	245577
Scenario 1			Rail T-C	11888	233313	46958	30843
Scenario 1		*Confidential*	Truck T-C	4000	71070	15800	293141
Scenario 1			Barge T-C	2753	17069	10874	73304
Scenario 1			Customer Pickup	570	0	2423	0

We give the formulas for the calculations of the raw scores in Section 5.3. In the tool, these calculations are presented in four sheets and a summary of the eventual raw scores are given in a table in the worksheet "Results". The consultant provides the weights and scales he deemed appropriate for the criteria. The tool shows for each criterion a graph with the scale, a graph with the weights, a table with the normalised weights and scores, and an eventual ranking of the scenarios. In the following sheet, he can shift the aggregated weights (on higher criterion level), to analyse the sensitivity of the chosen weights.

5.3 Criteria

The overall objective for the optimisation is to find "the best network". Together with consultants of the NMD department, we found multiple criteria that contributed to this overall goal, shown in Table 4-4 in the previous chapter. Thus, we divided this goal into eight objectives: minimise costs, maximise service, maximise quality, maximise service, maximise the readiness of implementation, maximise sustainability, maximise robustness and minimise inventory time. These objectives should include all the aspirations of the consultant. Since it is not always the case that one single attribute includes all the facets of each objective, the objectives are subdivided further into subobjectives. These objectives and subobjectives are translated into criteria and subcriteria.

After comparing these criteria with criteria found in literature (see Appendix C), we assessed these criteria with the requirements that are described in Section 3.3.1: *completeness*, *non-redundancy*, *minimum size*, *operational* and *decomposability*. We found that the criteria give a complete view of the areas of concern in the overall objective. Some criteria are redundant with each other: *planned lead times* and *working capital* both count lead times, *delivery frequency* and *flow* are both dependent on the expected shipment frequency. We also found that the criteria *nuisance* and *mode mix* can be combined to reduce dimensionality. The criteria cannot be simplified furthermore by breaking them down into more parts without increasing the dimensionality. All criteria are operational, they are useful for reviewing different scenarios. We removed the criteria *planned lead times*, *delivery frequency* and *nuisance*. We operationalised the remaining criteria, shown in Figure 5-1 and we present a description of each criterion in Sections 5.3.1 to 5.3.8.

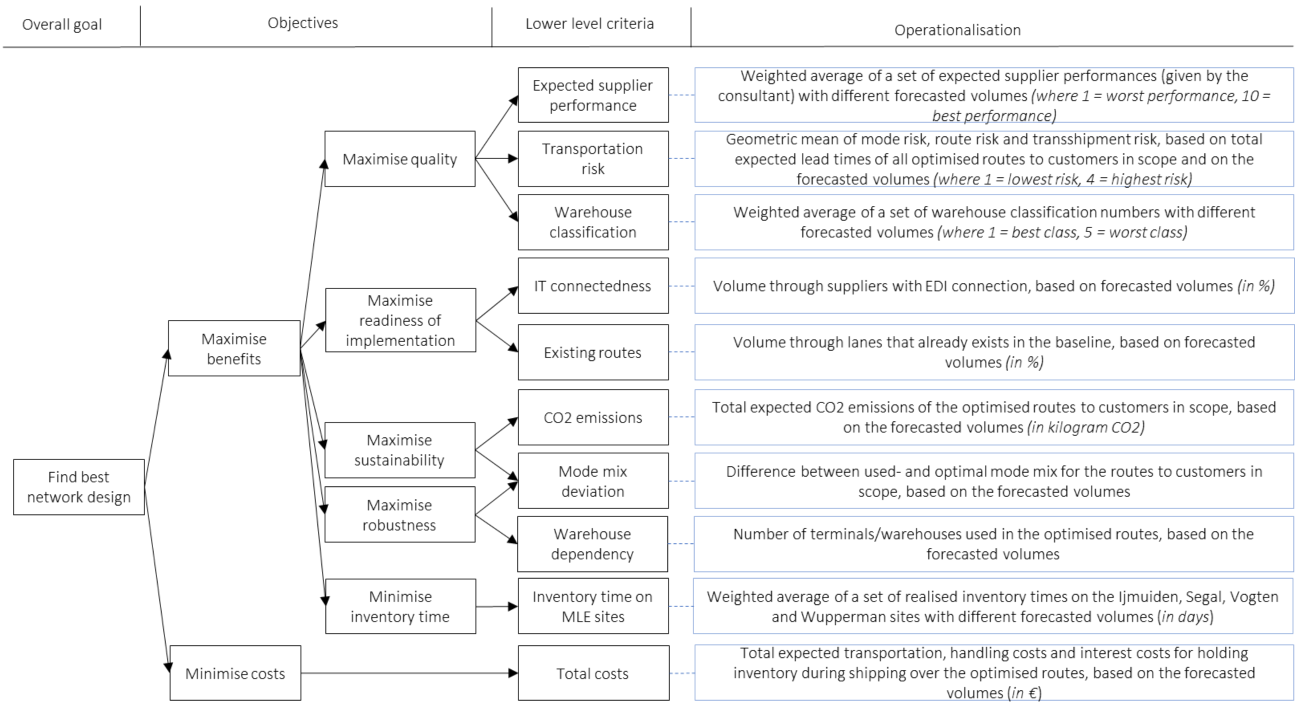


FIGURE 5-1. EVENTUAL CRITERIA AND THEIR OPERATIONALISATION

We give an example to show the preferential independence the criteria: we prefer lower CO2 emissions to higher emissions, assuming that the cost is €500,000 in each case, and we also prefer lower emissions when the cost is €1,000,000 in each case, then *CO2 emissions* is preferentially independent of *total costs*. It does not matter what the costs is, we prefer the lower CO2 emissions. It is mutual preferential independent since the *total costs* is also preferentially independent of the *CO2 emissions*. We give the formulas for calculations in Sections 5.3.1-5.3.6.

5.3.1 Quality

A qualitatively good network consists of reliable suppliers where coils do not get damaged and are transported in a safe way. An example of material damage on rail transport is shown in Figure 5-2.

FIGURE 5-2. EXAMPLE OF MATERIAL DAMAGE

Since quality factors consist of many soft indicators like experiences and relationships, and data is only historical, we use direct rating to score the overall QTS value of the network. An example of insufficient historical data: data on damages only name the supplier who reported the damage. Damage can be caused by that LSP or the previous LSP.

To measure the soft indicators, we ask the consultants to give a score to the overall performance of each supplier s. We multiply this score with the expected throughput of that supplier (percentage throughput over the total forecasted volume for the coming year in scope).

$$Value\ (supplier\ performance)\ = \sum_s \frac{volume_s * expected\ performance_s}{\sum volume_s}$$

The value that results from this calculation is the weighted average supplier performance grade given by the consultant, dependent on the expected throughput of the demand forecast.

An aspect of quality that can be measured is the risk for damages of the network. As discussed in Chapter 3, we can measure the vulnerability of a transportation link. We delete the logistic performance index (LPI_{origin} and $LPI_{destination}$) from the formula because the source and destination of routes is the same for all scenarios. A ranking of LPIs is given in Table 5-2, both LPIs from the Netherlands and Germany are ranked first and second of the world (The World Bank, 2018). Removing the LPIs, leaves the following formula for vulnerability of a transportation link:

$$Transportation's\ vulnerability\ score = (Mode * Route * Transshipments)^{1/3}$$

TABLE 5-2.
LOGISTICS PERFORMANCE INDICES (AGGREGATED 2012, 2014, 2016, 2018) (THE WORLD BANK, 2018)

Country	LPI Rank	LPI Score
Somalia	167	2.00
Haiti	166	2.09
...	...	...
Belgium	4	4.05
Sweden	3	4.07
Netherlands	2	4.07
Germany	1	4.19

Ravindran (2016) determined the risk score for modalities depending on the use of trucks, airplanes and ships in the network, which is dependent on the demand forecast. We added customer pickup and rail and removed the mode airplane since this is only a one-off solution and not strategically planned. Furthermore, we changed ship to barge and vessel, where vessel gives the highest risks. Customer pickup has no risk since this is the responsibility of the customer. Ravindran (2016) also determined the risk for a route. To determine this risk for a scenario, we calculate the percentages of the used modalities depending on the lead time and multiply this with the risk score. We calculate a risk score for transhipments based on the percentage volume in the network that flows via a transhipment.

Another aspect of quality that can be measured is the quality of used warehouses. We calculate a value by analysing the warehouse classification numbers. These numbers are categorized from 1 (best) to 5 (worst). When a warehouse is classified as 5, it fulfils four minimum requirements: the warehouse has a minimum of one-meter free space around trucks, the floor is flat and sound, the floor is suitable for storage of heavy steel products, and that it has an adequate water drainage system. When a warehouse also fulfils the requirements of a sound and water tight roof, and floors in good condition and made of concrete or similar material, this warehouse is classified as a 4. All the requirements and corresponding classification numbers are further explained in Figure 5-3.

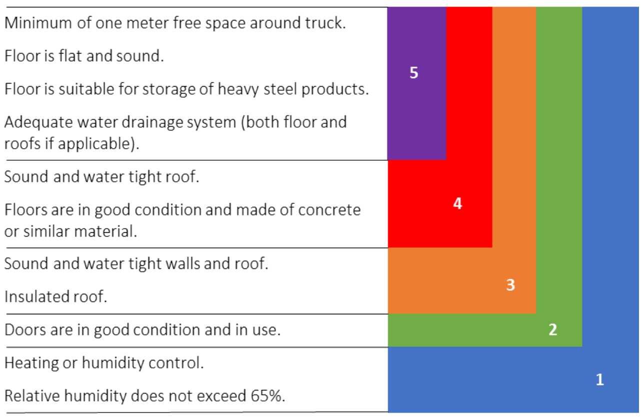


FIGURE 5-3. REQUIREMENTS FOR WAREHOUSE CLASSIFICATIONS

We calculate the value for this criterion as the sum of the percentage throughput for the warehouses (expected throughput from demand forecast), multiplied with the corresponding classification numbers.

$$Value\ (warehouse\ classification) = \sum_{s \in S} \left(\frac{Throughput_s}{\sum_s Expected\ volume_s} * classification\ number_s \right)$$

A source s (= 1,…S) can be a terminal or harbour and has a certain classification number (= 1,…5) and an expected throughput volume. A supplier can have multiple classification numbers when, for example, heating devices are present in the warehouse, but they are not plugged in.

5.3.2 Readiness for implementation

We calculate the criteria readiness for implementation by two lower-level criteria: IT connectedness of all the LSPs to electronic data interchange (EDI) and the percentage of existing lanes in the network. If the supplier is connected to EDI, it is more efficient for Tata Steel to exchange information. The value for this subcriterion is calculated by summing the volumes over each lane in which the supplier is connected to EDI:

$Value\ (IT\ connectedness) = \frac{\sum_{wcdm}(x_s * volume_{wcdm})}{\sum_{wcdm} volume_{wcdm}}$, where x_s = 1 when the supplier s is connected to EDI and x = 0 otherwise. Also here yields that the volumes are obtained from the demand forecast. In a route the combination is used between works (a plant location) (w = IJmuiden, Ivoz-Ramez, Maastricht, Moerdijk), the customer name (c = 1,…C), the destination (d = 1,…D), and the mode of transportation (m = truck, rail, barge, vessel).

The value for the second subcriterion, which measures the percentage of existing lanes for the forecasted period, is calculated as the volume through existing lanes as percentage of the total expected volume for all the lanes.

$Value\ (percentage\ new\ lanes) = \frac{\sum_{wcdm}(x_{wcdm} * volume_{wcdm})}{\sum_{wcdm} volume_{wcdm}}$, where x = 1 when the lane is present in the baseline and x = 0 otherwise.

We assume that the value for the baseline scenario is always the best score, since this never requires implementation of new lanes. However, also the baseline is based on expected volumes for 2019. This means that it is possible that new customers or new route combinations exists in the baseline as well, but that Tata Steel needs to implement these new lanes anyway.

5.3.3 Sustainability

The sustainability of each scenario is measured by the total CO2 emissions, which is a multiplication of the distance (between works and customer at a destination) with the CO2 rate that depends per mode (they are given by the Environmental department of Tata Steel Europe) and the total expected volume from the demand forecast:

$Value\ (CO2\ emission) = \sum_{wcdm} distance_{wcd} * r_m *\ volume_{wcdm}$, where *w*, *c*, *d*, and *m* are again the works, customers, destinations and modalities. Rate *r* depends on mode *m*. The rates used by Tata Steel are presented in Table 5-3.

TABLE 5-3.
KILOGRAM CO2 PER TON SHIPPED OVER A KILOMETRE PER TRANSPORT MODE

Modality	Kg CO2 / tonkilometre
Truck: > 20 ton	
Rail – combination (average NL)	
Barge: 300-3000 ton	*Confidential*
Vessel: 0-10000 ton (sea transport)	
Vessel: 635-4080 TEU (container transport)	

5.3.4 Robustness

A robust network can cope with changes in the network. This means that when a transportation mode or an LSP cannot be used, for example due to weather conditions as explained in Section 1.3.1., this has minimal effect on the network. The network should not only consist of one LSP, or ship everything by one modality. A higher number of modalities and suppliers must give a better score to a network.

We calculate the score for mode mix deviation by calculating the difference between the ideal mode mix and the mode mix per scenario in the output of the optimisation tool. The ideal ratio is determined by the consultant. This depends on the policy of Tata Steel (for example, less trucks) and the geographical dependence in that region (for example, high risk for low water levels in the Rhine river, lowers the ideal percentage for barges in East-Germany).

$Value\ (mode\ mix\ deviation) = \sum_m \left|\frac{volume_m}{\sum_m volume_m} - ideal\ ratio_m\right|$, where transportation mode *m* = truck, rail, barge or vessel and the volume is obtained from the yearly demand forecast.

We only took the main legs in consideration for the calculations of the ratios, because this gives a better view on the differences between the scenarios. We also did not take customer pickup into consideration, since this is not the responsibility of Tata Steel.

A robust network also consists of a large number of warehouse suppliers to reduce dependability. We calculated the value for supplier dependency by the number of suppliers where volume flows through, according to the demand forecast for the next year.

$Value\ (supplier\ dependability) = \sum_{wcdm} x_s,\ \forall s \in S$, where x_s = 1 when supplier *s* is used in the route and *x* = 0 otherwise, *S* is a set of Tata Steel's warehouse suppliers, and w, c, d, m represent again the works, customers, destinations and modalities.

5.3.5 Inventory Time

Inventory time on the production site (flow) is an important criterion for Tata Steel. Low flow means high inventory times of the coils on site and this causes congestion at the internal warehouses, which can cause delays in production and a financial impact.

Coils can be produced too early and therefore lie a long time in inventory before shipping. Furthermore, customers tend to use the warehouses on the site of Tata Steel instead of their own warehouses. This causes in practice higher inventory times than calculated. To analyse this customers behaviour, we calculated the inventory times for each customer that is in our scope for all works and for all modalities from 2018. We used this data to calculate an expected inventory time for each lane (combination of works, customer, destination and mode). We multiplied this with the volume for each lane and divided it by the total volume to get a weighted average inventory time for each scenario.

Let *i* be the produced coil (i_{wcdm} = 1,…I) for a specific route where *w* represent works,, *c* the customer, *d* the destination, and *m* the mode of transportation. Then the total inventory time is equal to the sum of all the volumes multiplied with the average inventory times for that specific route (with the same works, customer, destination and mode of transportation). This value can be interpreted as the expected average days that a coil stays in inventory on MLE works in a scenario.

$$Value\ (Inventory\ time\ on\ MLE\ sites)\ = \sum_{wcdm} \frac{volume_{wcdm} * average\ inventory\ time_{wcdm}}{\sum volume_{wcdm}}$$

The average inventory time for a certain lane is calculated from realisation data as:

$$Average\ inventory\ time_{wcdm}\ = (\sum_{i}^{I} dd_{wcdm} - id_{wcdm}) * \frac{1}{I_{wcdm}}, \qquad \forall c; w; d; m,$$

The parameters used are: dd_{wcdm} (departure date associated with the route from works *w* to customer *c* in destination *d* with mode *d*) and id_{wcdm} (intake date associated with the route from works *w* to customer *c* in destination *d* with mode *d*). The inventory time for a coil for a certain lane is calculated by taking the sum of inventory times for every coil that has this route combination (subtracting the departure date by the intake date) and divide this by the number of coils (I_{wcdm}) that have the same route combination.

When the lane is a new combination of source, destination and mode, realisation data is not always available. In this case, we use an average of realisation data of that destination and mode, but with another source. If this is also unavailable, we use an average of the same source and mode, but different destinations.

5.3.6 Costs

The total costs depends on three things: transportation costs, handling costs and the costs of working capital.

$Value\ (Total\ costs) = \sum_{wcdm} Flow\ of\ tonnes * \left(Flow\ sourcing\ costs\ per\ ton_{wcdm} + Flow\ transportation\ costs\ per\ ton_{wcdm} + Flow\ working\ capital\ costs\ per\ ton_{wcdm}\right)$, where the combination of *w, c, d* and *m* reflects a route

Transportation and handling costs are both calculated in the optimisation tool. Transportation costs depend on several things such as distances, backloads for trucks and region bounded factors such as the market prices. These costs typically depend on the used modality for the route, one can expect a barge to be typically cheaper than a truck. However, a cheaper modality does not always mean less total costs. The finance department takes out a loan for production, which ends when the end customer pays. This means that a loan for a longer time is needed when a modality with a longer lead time is chosen, which results in higher costs. We call this the impact of lead time on working capital costs. We present the formula for this working capital costs below:

$$Impact\ lead\ time\ on\ working\ capital\ costs_{wcdm} = average\ production\ cost\ per\ ton * (debit\ interest + Euribor\ interest) * \frac{average\ lead\ time_{wcdm}}{365}$$

We explain this formula with an example:

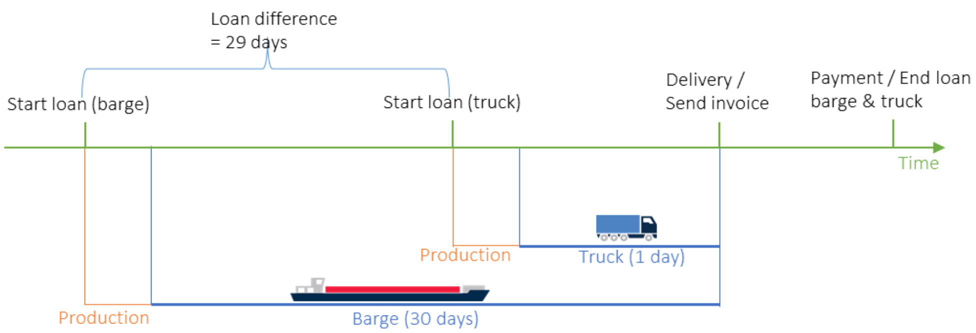


FIGURE 5-4. EXAMPLE OF THE IMPACT OF LEAD TIME ON WORKING CAPITAL COSTS

For customer A, we have the choice of sending the order with barge or with truck (see Figure 5-4). The barge has lower transportation costs per ton, the truck higher. However, the barge has a planned lead time of 30 days, the truck 1 day. This means for the barge, that we need to take a loan for the time the coils lie on site + 30 days + time between payment and delivery. For the truck, we need to take a loan for the time that the coil lies on site + 1 day lead time + time between payment and delivery. Since we assume that time for production and the time between delivery and payment is the same for both modalities, we can leave that out of the comparison. This leaves us with a loan for 1 day (truck) and 30 days (barge). Following assumptions as described below, we calculate that per ton, it is (€1.08 - €0.04 =) €1.04 more expensive to get a loan for the barge then for the truck.

Assumed:

- *Average production costs per ton = €700*
- *Debit interest at the bank = 2.25%*
- *Euribor interest = -0.368%*
- *Average lead time (truck) = 1 day*
- *Average lead time (barge) = 30 days*

Then:

$$Impact\ on\ working\ capital\ (truck) = €700 * (2.25\% + -0.368\%) * \frac{1}{365} = €0.04\ per\ ton$$

$$Impact\ on\ working\ capital\ (barge) = €700 * (2.25\% + -0.368\%) * \frac{30}{365} = €1.08\ per\ ton$$

One could argue that the barge can handle 30 coils, while the truck can handle 1 coil. This means production of the 30 coils takes longer and therefore spend more time in warehouses on site. This leads to higher working capital cost. Yet, production speed is high enough so this barely makes a difference.

5.4 Conclusions

Consultants must make trade-offs in network design, which are based on several aspects of the supply chain. An MCDA tool gives support for this trade-offs and gives a ranking of the alternative scenarios for network design in a certain region. The tool that we build is based on the SMART algorithm and gives a general instruction, an input sheet where input must be uploaded from the optimisation tool, resulting raw- and normalized scores on criteria, and a sensitivity analysis. The raw scores are based on the calculations of the following criteria: quality (supplier performances, transportation risk, warehouse classification numbers), readiness of implementation (IT connectedness, new routes), sustainability (CO_2 emissions), robustness (mode mix deviation, warehouse dependency), inventory time, and costs.

The inner harbour of Tata Steel IJmuiden

6 Results for the Case of West-Germany

In this chapter, we test the tool that we built on data from the network review in the regions Siegerland, Ruhr and Hagen-Dortmund. We follow the analysis phases of the recommended new process and start with explaining the baseline of this case and why alternative scenarios were chosen in Section 6.1. After this, we present the results per criteria in Section 6.2, followed by a calculation of the normalised scores in Section 6.3. We provide a trade-off and a sensitivity analysis in Section 6.4 and we discuss the validation of this tool in Section 6.5. Finally, we give a brief summary of this chapter in Section 6.6 and give answer to the research questions:

What are the results from testing the decision support tool on the West-Germany review?

6.1 The Case

During the development of this research, Tata Steel was already trying to optimise their network in West-Germany. Customers in that region are expected to order around 13% of the total export volume and 65% of the export volume into Germany (see Table 6-1). A clear concentration of the export volumes in Germany is visible in Figure 6-1.

TABLE 6-1
EXPORT FROM TATA STEEL INTO GERMANY

	Production volumes in metric ton (mts) (for March 2019 – February 2020)	In percentage
Total exports Total exports into Germany Total export into regions Ruhr, Hagen-Dortmund, Siegerland (minus backflows)	*Confidential*	

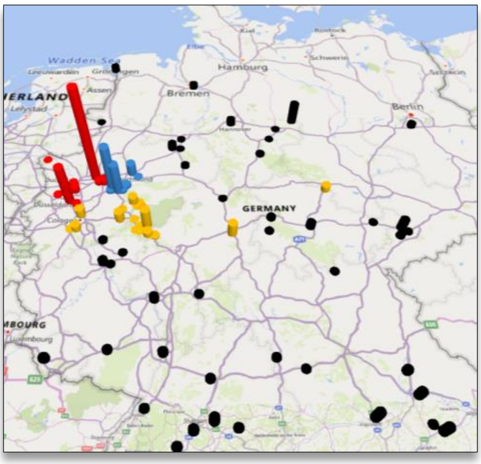


FIGURE 6-1. CONCENTRATION OF ORDERS FOR THE 2019 FORECAST (RED (RUHR), BLUE (HAGEN-DORTMUND) AND YELLOW (SIEGERLAND): CUSTOMERS IN SCOPE, BLACK: OTHER CUSTOMERS IN GERMANY)

The current transportation routes are usually not integrally evaluated as a network, but as a route. The expectation is that the logistics network can be structured cheaper and more sustainable after we evaluate the network. The business question for this review is as follows: *Can the transport to customers in Hagen/Dortmund, Siegerland and Ruhr be structured more efficiently?*

The expected volume flows in 2019 from the works to the customers are shown in Table 6-2 and Figure 6-3. Most of the volume leaving the works goes indirectly to the customer. Other flow possibilities are direct shipment, via service centers where customers can pick up the shipment, or via a backflow (volumes going back to IJmuiden before shipping to the customer). Backflow is a possibility of gathering more volume in IJmuiden so a barge- or rail hub can be realised.

TABLE 6-2
FORECASTED VOLUME FLOWS FROM WORKS FOR 2019

From works	Production volume in metric ton (mts)	In %	To customer	In %	Mode leaving works	In %
IJmuiden (NL)						
Wupperman (NL)						
Vogten (NL)			*Confidential*			
Segal (BE)						
Duffel (BE)						
Llanwern (UK)						
Port Talbot (UK)						

In the current network, 14% of the total transported volume that begins at the works, is shipped directly with the truck to customers. NMD started a network review to test the opportunities to lower the number of trucks, by establishing a hub in the region. Making a hub from a terminal in the region, close to the end customers, it is possible to lower the number of direct trucks deliveries and to gather enough volume for shipments per barge or rail. An example of the hub concept is given in Figure 6-2.

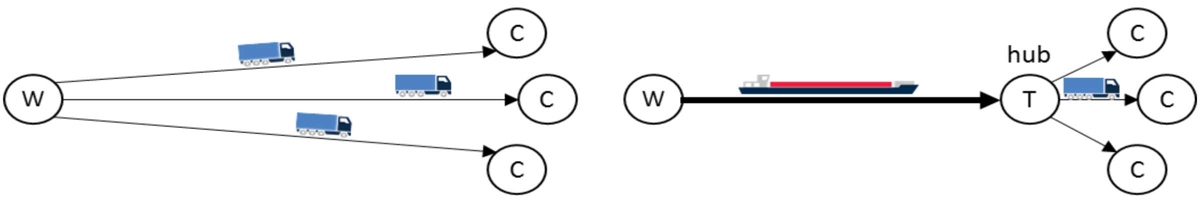


FIGURE 6-2. LEFT: DIRECT FROM WORKS TO CUSTOMERS. RIGHT: THE HUB CONCEPT, INDIRECT VIA A TERMINAL

Confidential

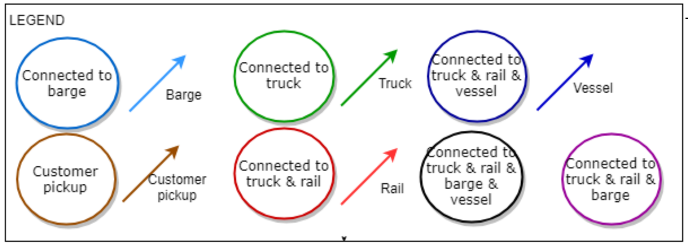


FIGURE 6-3. FORECASTED VOLUME FLOWS FOR 2019 SHOWN WITH THE CURRENT ROUTES (BASELINE SCENARIO)

Terminals X and Y are the only terminals in the region that had place for more stock. As one can see in Figure 6-3, terminal X has a water, rail and road connection and Y has a rail and road connection. NMD chose to make two alternative scenarios: one with a barge hub at X and one with a rail hub at Y. Next to these scenarios we also included the baseline, the free-run and a scenario with no direct truck deliveries to analyse opportunities that the consultant and analyst did not think of yet. Then, the scenarios created by the distribution chain consultant in the third step of the review process are:

1. Baseline scenario. This scenario represents the current situation.
2. Free-run scenario. This is a scenario in which the optimisation tool runs a network optimisation without any constraints about volume assignments. This scenario can bring new ideas for other scenarios.
3. Barge hub scenario. In this scenario, the optimisation tool is restricted to ship a fixed number of tonnes via a barge hub (via terminal X) to its customers.
4. Rail hub scenario. In this scenario, the optimisation tool is restricted to ship a fixed number of tonnes via a rail hub (via terminal Y) to its customers.
5. No truck scenario. the optimisation tool is restricted in its optimisation to ship only with rail or barge to customers in the main legs.

6.2 Results per Criterion

6.2.1 Costs

The network is optimised for each scenario in the optimisation tool and this resulted in an overview of transportation and handling costs per lane for the demand forecast of 2019. To give an idea of how this output looks, Table 6-3 shows the first five lanes from the baseline scenario. The source gives us information about the type of node, name and city where the lane starts, the same holds for the destination. The next columns show the modality, the expected volume from the demand forecast, the transportation costs, holding costs, and total costs.

TABLE 6-3
EXAMPLE OF TRANSPORTATION AND HANDLING COSTS CALCULATIONS PER LANE

Scenario	SourceName	DestinationName	Mode	Sum of FlowUnits (mts)	Sum Transport (€)	Sum Sourcing (€)	Total (€)
Scenario 1			Barge	36,000	233,640	131,400	370,609
Scenario 1			Rail	13,200	208,083.88	48,180	257,625
Scenario 1		*Confidential*	Truck	7,079	48,278.78	30,085.75	78,730
Scenario 1			Truck	3,389	23,112.98	14,403.25	37,691
Scenario 1			Truck	60	1,301.51	0	1,306

The impact of the lead time of a modality on the working capital costs is calculated out of the total expected volumes over each modality, the expected lead time of a modality, the debit interest and the Euribor interest over a year. The values that we used for the calculations can be found in Appendix F. Furthermore, we assumed that the average production cost per ton is €x[3], the debit interest of the bank is y% and the EURIBOR interest is -0.368%.

Table 6-4 shows the total transportation, handling and working capital costs per scenario. The cheapest scenario is the free-run and the most expensive scenario is the baseline.

TABLE 6-4
TOTAL COSTS FOR 2019 FOR REGION IN SCOPE PER SCENARIO

Scenario	Transport costs in 2019 (€)	Handling costs in 2019 (€)	Impact lead time on working capital in 2019 (€)	Total Cost in 2019 (€)
Scenario 1: baseline				
Scenario 2: free-run				
Scenario 3: barge hub			*Confidential*	
Scenario 4: rail hub				
Scenario 5: no trucks				

6.2.2 Inventory Time

We calculate the average inventory times out of data from 2018. This average is given per works, customer, destination and mode in Appendix E. The weighted average inventory time on site for shipments from MLE works to customers in our scope, are shown in Table 6-5. The barge hub scenario has the lowest expected average inventory time, followed by the baseline scenario. Inventory times at UK works are not included because this data is not available in the dataset, and the flows from UK works are similar for every scenario.

TABLE 6-5
THE WEIGHTED AVERAGE INVENTORY TIME ON SITE FOR MLE WORKS, BASED ON REALISATION DATA FROM 2018

Scenarios	Weighted average inventory time on site MLE works (2018)
Scenario 1: baseline	14.5073
Scenario 2: free-run	18.7415
Scenario 3: barge hub	14.0380
Scenario 4: rail hub	16.8189
Scenario 5: no trucks	18.1551

6.2.3 Quality

The consultant gives expected performance numbers for all suppliers and these are multiplied with the forecasted throughput of 2019. The weighted average performance numbers of the scenarios are

[3] For confidentiality

shown in Table 6-6. The averages are close to each other and lie between 7.4 and 7.9. The best scoring scenario is the barge hub scenario, and the baseline scenario scores lowest. Calculation of this performance number is given in Appendix F.

TABLE 6-6
WEIGHTED AVERAGES OF THE EXPECTED SUPPLIER PERFORMANCES

Scenario	Weighted average supplier performance in 2019
Scenario 1	7.4408
Scenario 2	7.7531
Scenario 3	7.8229
Scenario 4	7.7927
Scenario 5	7.8195

After evaluating the total durations and transhipments per scenario, the consultants determined the category limits, which can be found in Table 6-7. The consultant found the mode risk for Tata Steel of a vessel the highest and of customer pick-up the lowest. The route risk depends on the total days of lead times for all the routes in the reviewed network for the forecasted year and the transshipment risk on all the expected volume that flows via transhipments in the reviewed network in 2019. Table 6-8 shows the total transportation vulnerability scores.

TABLE 6-7
CATEGORIES FOR CALCULATING THE OVERALL RISK SCORE FOR TRANSPORTATION NETWORK

Vulnerability of a transportation network		
Transportation mode	**Risk level**	**Risk score**
Customer pickup	No risk	0
Truck	Low	1
Rail	Moderate	2
Barge	Moderate / high	3
Vessel	High	4
Transportation route risk level risk score		
Shipping duration of the network is short duration (terminal-customer)	Low	1
Shipping duration of the network is of moderate duration (works-terminal, works-works, terminal-terminal)	Moderate	2
Shipping duration of the network is of long duration (works-customer)	High	3
Percentage of transshipments (expected for 2019)		
The percentage volume via transshipments is low	Low	1
The percentage volume via transshipments is moderate	Moderate	2
The percentage volume via transshipments is high	High	3

TABLE 6-8
RISK RESULTS FOR EACH SCENARIO

Scenario	Mode risk	Route risk	Volume through transshipments in 2019 (%)	Transshipment risk	Total risk score
Scenario 1	1.6660	1.58	46.9568	3	1.9913
Scenario 2	1.7186	1.70	40.7332	2	1.8012
Scenario 3	1.7710	1.57	45.3048	3	2.0281
Scenario 4	1.7298	1.64	43.4430	2	1.7836

Scenario 5	1.7477	1.58	45.6798	3	2.0504

Table 6-9 gives the weighted average classification numbers for all the scenarios. The rail hub scenario has the best score, and the barge hub scenario the lowest. This means that the rail hub has the most volume flowing through the better rated warehouses. The warehouse classification number for each supplier is given in Appendix F.

TABLE 6-9
RESULTS FOR WEIGHTED AVERAGE CLASSIFICATION NUMBER FOR EACH SCENARIO

	Weighted average classification number in 2019
Scenario 1: baseline	1.6711
Scenario 2: free-run	1.6686
Scenario 3: barge hub	1.7623
Scenario 4: rail hub	1.5615
Scenario 5: no trucks	1.7074

6.2.4 Readiness for Implementation

We calculate readiness for implementation with two lower-level criteria: IT connectedness and with the percentage of existing routes, see Table 6-10 and Table 6-11. We found what warehouse suppliers are connected to EDI, in the Warehouse Management Database. The baseline scenario scores best on both criteria (24% volume goes via EDI connected terminals and 0% new routes). The no truck scenario scores worst on IT connectedness (10%), and the rail hub scenario scores worst on new routes (21%).

TABLE 6-10
RESULTS FOR IT CONNECTEDNESS FOR EACH SCENARIO

	Total volume through terminals in 2019 (ton)	Volume through EDI connected terminals in 2019 (ton)	Volume through EDI terminals in 2019 (%)
Scenario 1: baseline	511,058	124,226	24.3076
Scenario 2: free-run	312,611	75,026	23.9998
Scenario 3: barge hub	435,831	75,026	17.2145
Scenario 4: rail hub	372,229	75,026	20.1559
Scenario 5: no trucks	427,650	75,026	17.5438

TABLE 6-11
RESULTS FOR THE CRITERION OF EXISTING LANES FOR EACH SCENARIO

	Total volume in 2019 (ton)	Volume through existing lanes in 2019 (ton)	Volume through existing lanes in 2019 (%)
Scenario 1: baseline	1,647,190	1647190	100.0000%
Scenario 2: free-run	1,474,219	1,244,179	84.3958%
Scenario 3: barge hub	1,597,439	1,371,997	85.8873%
Scenario 4: rail hub	1,544,854	1,226,191	79.3726%
Scenario 5: no trucks	1,608,469	1,291,260	80.2788%

6.2.5 Sustainability

The total expected CO2 emissions for each scenario are shown in Table 6-12. As explained Chapter 5, this number is dependent on the volumes, distances and the CO2 rate per modality. The free-run scenario has the most CO2 emissions and the no-truck scenario the least.

TABLE 6-12
TOTAL EXPECTED KG CO2 EMISSIONS PER SCENARIO

Scenario	Kg CO2 in 2019
Scenario 1: baseline	12,036,766
Scenario 2: free-run	11,455,783
Scenario 3: barge hub	10,914,522
Scenario 4: rail hub	10,606,460
Scenario 5: no trucks	9,747,521

6.2.6 Robustness

Figure 6-4 to Figure 6-8 show the mode mix over the main legs per scenario. We considered routes from works to customer and from works to terminal or service center as main legs. Table 6-13 gives the ideal mode mix according to the distribution chain consultant, the deviations and the total deviation per scenario. The baseline scenario has the highest deviation and the barge hub scenario has the least deviation.

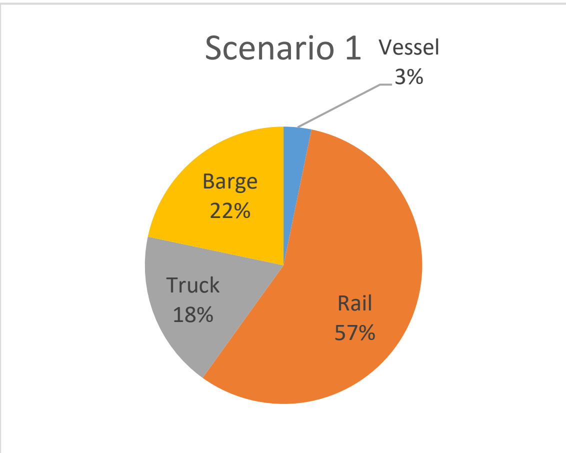


FIGURE 6-4. MODE MIX (2019) FOR SCENARIO 1

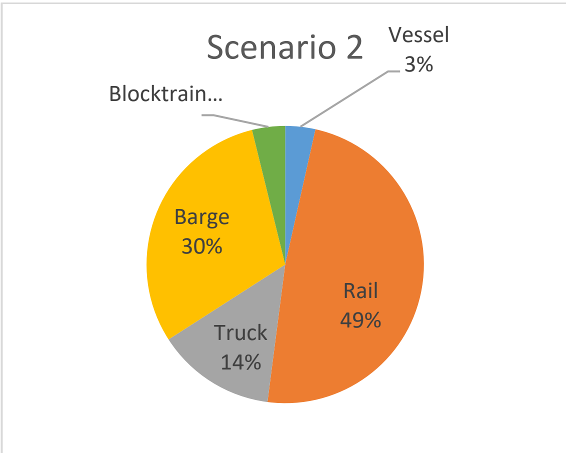


FIGURE 6-5. MODE MIX (2019) FOR SCENARIO 2

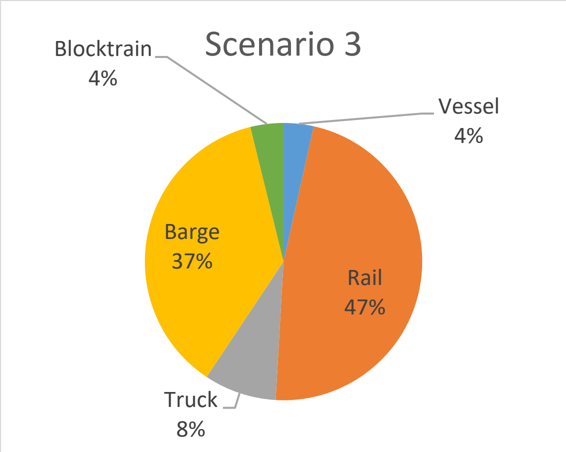


Figure 6-6. Mode mix (2019) for scenario 3

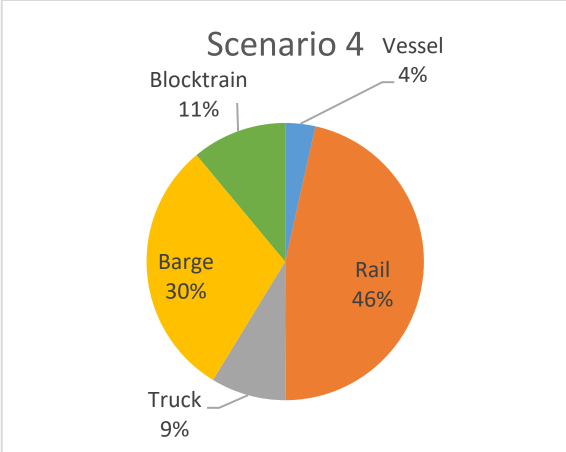


Figure 6-7. Mode mix (2019) for scenario 4

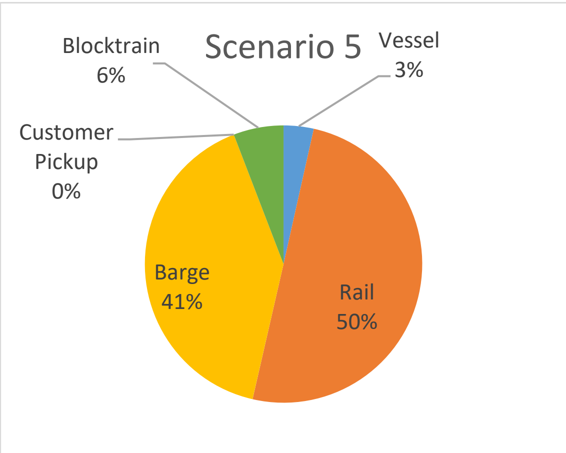


Figure 6-8. Mode mix (2019) for scenario 5

Table 6-13
Ideal mode mix for customers in scope according to the distribution chain consultant

Mode	Ideal mode mix	Scenario 1 deviation	Scenario 2 deviation	Scenario 3 deviation	Scenario 4 deviation	Scenario 5 deviation
Vessel	3%	0.0023	0.0050	0.0050	0.0050	0.0050
Barge	42%	0.2181	0.0976	0.0321	0.0976	0.0057
Rail	40%	0.1469	0.0654	0.0540	0.0442	0.0808
Truck	5%	0.1338	0.0887	0.0346	0.0380	0.0499
Block train	5%	0.0500	0.0115	0.0115	0.0604	0.0084
Total deviation	*100%*	*0.5162*	*0.2682*	*0.1372*	*0.2453*	*0.1499*

A robust network also consists of a great number LSPs to reduce dependability. We calculated the value for supplier dependency by the number of suppliers used in the network, given in Table 6-14. The baseline scenario scores best with 12 suppliers and the free-run, rail hub and no truck scenarios score worst with 8 suppliers.

TABLE 6-14
SUPPLIER DEPENDENCY FOR EACH SCENARIO

Scenario	Number of used LSPs in 2019
Scenario 1: baseline	12
Scenario 2: free-run	8
Scenario 3: barge hub	9
Scenario 4: rail hub	8
Scenario 5: no trucks	8

6.3 Calculation of the Normalised Scores

The fourth step of SMART is about measuring the alternatives on the criteria. In the previous sections, we showed our calculations for each criterion. In Table 6-15, we summarize these raw scores.

TABLE 6-15
RAW SCORES FOR EVERY CRITERION AND SCENARIO

Criteria	Sub criteria	Goal	Scenario 1 Baseline	Scenario 2 Free-run	Scenario 3 Barge hub	Scenario 4 Rail hub	Scenario 5 No direct trucks on main legs
Costs	Transport costs *(€)* Handling costs *(€)* Impact of lead time on working capital costs *(€)*				*Confidential*		
	Total costs *(€)*	Min					
Inventory	Inventory time on MLE sites *(weighted average days between end of production and shipping)*	Min	14.5073	18.7415	14.0380	16.8189	15.9291
Robustness	Warehouse dependency *(number of LSPs)*	Max	12	8	9	8	8
	Mode mix deviation *(% volume flow - ideal % volume flow)*	Min	0.5162	0.2682	0.1372	0.2453	0.1499
Sustainability	CO2 emissions *(kg CO2 emissions)*	Min	12,036,766	11,455,783	10,914,522	10,606,460	9,747,521
Readiness of implementation	Existing routes *(ratio volume flow via existing lanes)*	Max	1.0000	0.8440	0.8589	0.7937	0.8028
	IT connectedness *(ratio suppliers with EDI connection)*	Max	0.2431	0.2400	0.1721	0.2016	0.1754
Quality	Warehouse classifications *(weighted average classification number)*	Min	1.6711	1.6686	1.7623	1.5615	1.7074
	Transport risk *(mode*route*transshipments)^1/3*	Min	1.9913	1.8012	2.0281	1.7836	2.0504
	Expected supplier performance *(weighted average performance)*	Max	7.4408	7.7531	7.8229	7.7927	7.8195

We ask the consultant for weights before he determines the scales to avoid that he is being influenced by knowledge of the performance of alternatives. For weighting, the distribution chain consultant first ranks the lower-level criteria with the use of swing weights. After, as we explained in Chapter 3, the tool calculates the normalised weights, see Table 6-16 and Table 6-17.

TABLE 6-16

SWING WEIGHTS FOR EACH CRITERION BY THE DISTRIBUTION CHAIN CONSULTANTS

Rank	Sub-criterion	Swing weights
1	Total costs	100
2	Expected supplier performance	90
3	Inventory time on MLE sites	80
4	Mode mix deviation	70
5	Warehouse dependency	70
6	Average warehouse classification	70
7	CO2 emissions	50
8	Existing lanes	50
9	IT Connectedness	50
10	Transport risk	40

TABLE 6-17

NORMALISED WEIGHTS FOR CRITERIA

Criteria	Aggregated weights	Subcriteria	Global weights
Costs	0.1493	Total costs	0.1493
Inventory time	0.1194	Inventory time on MLE sites	0.1194
Robustness	0.2090	Warehouse dependency	0.1045
		Modality mix deviation	0.1045
Sustainability	0.0746	CO2 emissions	0.0746
Readiness of implementation	0.1493	Existing lanes	0.0746
		IT connectedness	0.0746
Quality	0.2985	Warehouse classifications	0.1045
		Transportation risk	0.0597
		Expected supplier performance	0.1343
Sum	*1.0000*		*1.0000*

Furthermore, the scale for each criterion is determined by the distribution chain consultant. We ask the consultant for each criterion if a swing at the beginning of the scale was even, less or more important as a swing at the end of the scale. If this was less or more important, than we asked again for the first and last quarter points. The consultant states that the scale from the criteria IT connectedness, CO2 emissions and inventory time must be linear. The graph for each criterion can be found in Appendix G. For each criterion, we give the worst score 0 points, the best score 100 points and the intermediate scores points depending on the graph. Table 6-18 show these normalised scores, together with the weighted average of the benefit values assigned to each alternative.

TABLE 6-18
NORMALISED SCORES FOR EACH CRITERION AND SCENARIO

Criteria	Sub criteria	Normalised weights	Scenario 1 Baseline	Scenario 2 Free-run	Scenario 3 Barge hub	Scenario 4 Rail hub	Scenario 5 No direct trucks on main leg
Costs (0.1493)	Total costs	0.1493	0	100	87	91	76
Inventory time (0.1067)	Inventory time on MLE sites	0.1194	90	0	100	41	12
Robustness (0.1867)	Warehouse dependency	0.1045	100	0	10	0	0
	Modality mix deviation	0.1045	0	39	100	47	93
Sustainability (0.0667)	CO2 emissions	0.0746	0	26	49	63	100
Readiness of implementation (0.1333)	Existing lanes	0.0746	100	47	57	0	10
	IT connectedness	0.0746	100	96	0	41	5
Quality (0.2667)	Warehouse classifications	0.1045	21	22	0	100	11
	Transportation risk	0.0597	9	85	4	100	0
	Expected supplier performance	0.1343	0	93	100	97	100
Aggregate value of benefits		0.8507	39	37	45	47	34
Aggregated value of costs		0.1493	0	15	13	14	11
Overall value		1.0000	39	51	58	61	46
Ranking			5	3	2	1	4

6.4 Decision Making

The scenarios that score highest according to the overall value is Scenario 4, followed by Scenario 3 and 2, see Table 6-18. This overall score follows out of the overall value for costs and the overall value of benefits. We did not separate these two in the calculations since we knew the raw scores and the weights for the costs criteria. However, to show what the relationship is between the costs- and benefit values within the overall value, we present this in Figure 6-9. An example of what we can see from this graph is that the difference of the overall values from Scenarios 2 and 4 are mainly due to the difference in benefit criteria and not to the costs criterion.

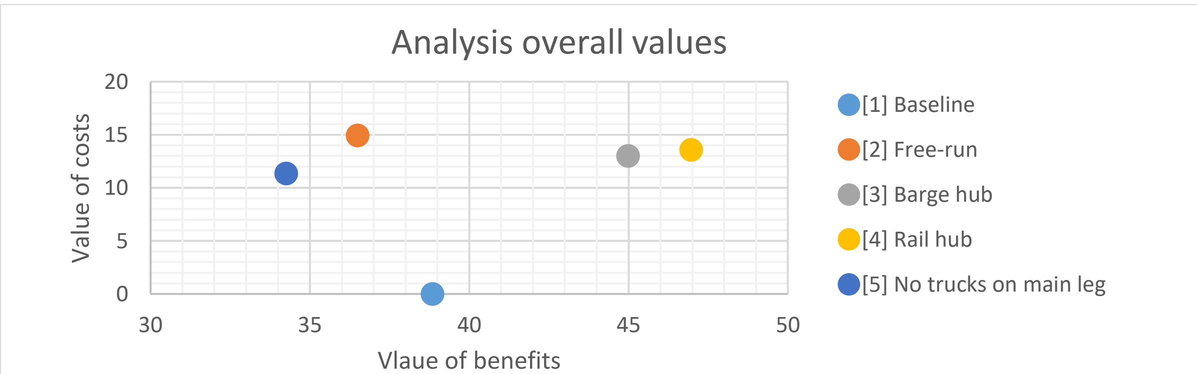


FIGURE 6-9. ANALYSIS TO SHOW INSIGHT INTO THE OVERALL VALUES FOR THE SCENARIOS

Since Scenario 3 and 4 score very similar, we analyse the impact of weights on criteria to see how sensitive the results are, see Figure 6-10. The objective of a sensitivity analysis is to find out when the input data is changed into new values and how the ranking of the alternatives will change. The criterion that is most sensitive to a change in weight is 'inventory time on site', see Figure 6-10. If a weight of 16% is given instead of the current weight of 12% (an increase of 33% of the current weight), another final ranking would be the result and not Scenario 4, but Scenario 3 would score better. A sensitivity analysis for each criterion is given in Appendix H. Other sensitive criteria are 'robustness' which would need an increase of 34% of the current weight, and 'quality' which would need a decrease of 13% of the current weight).

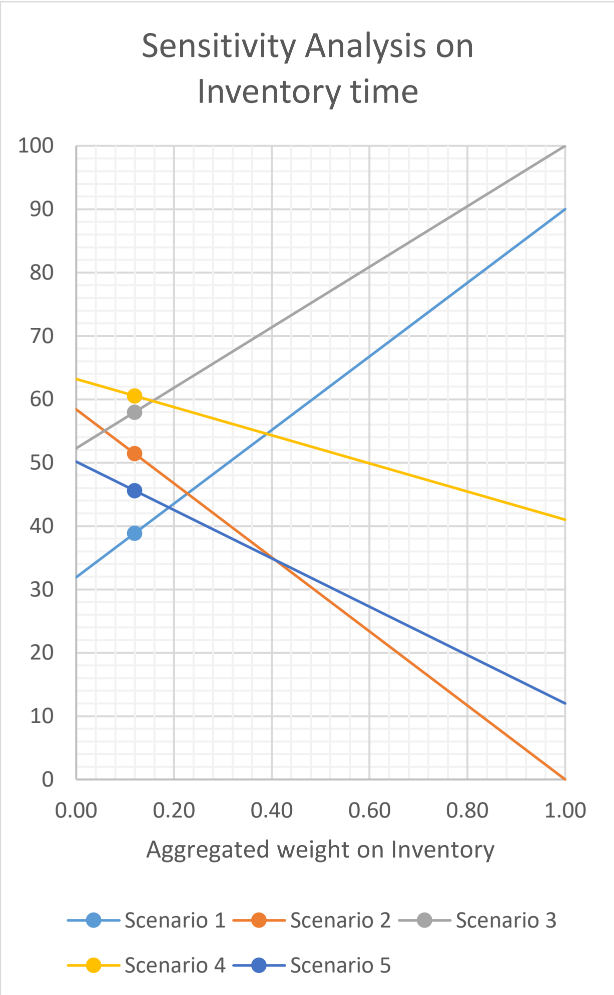


Figure 6-10. Sensitivity analysis on the weight of inventory time

It is important to notice that the distribution chain consultant and the logistic analyst analysed the scenarios as well, parallel to this research with the optimisation tool. After the assignment of weights to the criteria of this research and before determining the scores, the consultant and analyst chose a final scenario that is a combination of Scenarios 3 and 4. Looking at the results from this research, this is indeed an understandable option. Scenario 4 scores highest (61), but Scenario 3 (58) scores very close. This explains why the consultant and analyst chose for a final scenario that is a combination of Scenarios 3 and 4. We add this final scenario to our analysis to validate if that final scenario is indeed in line with the final scores from Scenarios 3 and 4. The results of this validation are given in Section 6.5.

6.5 Validation of the Model

During the development of the tool, we continuously asked information and validated our calculations with several employees of outbound logistics and the financial department, which in the end established credibility for the tool.

We test the tool on the final scenario that was chosen in the review of West-Germany. The distribution chain consultant and the logistic analyst eventually chose for a final scenario that is a combination of Scenarios 3 and 4. This decision was made based on the financial results of the optimisation tool, which represents transportation and handling costs, and on experience.

We add this final scenario to our analysis to validate the tool that we made and to see if the consultant and the analyst chose the right scenario, see Table 6-19. As described in Section 3.5.3., this is possible because we chose for the SMART algorithm, in which one can add options at any time. An overview of this final scenario is given in Appendix I.

TABLE 6-19
ADDITION OF FINAL SCENARIO

Criteria (aggregated weights)	Sub criteria	Normalised weights	Performances Final scenario	Scores Final scenario
Costs (0.1493)	Total costs	0.1493	*Confidential*	93
Inventory time (0.1067)	Inventory time on MLE sites	0.1194	15.9291	60
Robustness (0.1867)	Warehouse dependency	0.1045	8	0
	Modality mix deviation	0.1045	0.1761	77
Sustainability (0.0667)	CO2 emissions	0.0746	10,905,830	50
Readiness of implementation (0.1333)	Existing lanes	0.0746	0.8269	34
	IT connectedness	0.0746	0.2031	44
Sustainability (0.0667)				
Quality (0.2667)	Warehouse classifications	0.1045	1.6504	29
	Transportation risk	0.0597	1.7897	95
	Expected supplier performance	0.1343	7.7911	96
Overall value		1.0000		60

TABLE 6-20
NEW RANKING OF SCENARIOS

	Scenario 1 (baseline)	Scenario 2 (free-run)	Scenario 3 (barge hub)	Scenario 4 (rail hub)	Scenario 5 (no truck)	Scenario 6 (final scenario)
Overall value	38.9	51.4	58.0	60.6	45.6	60.3
Ranking	6	4	3	1	5	2

The overall score for the final scenario (60.3) lies close to the overall scores of Scenarios 3 (58) and 4 (60.6), see Table 6-20. If we only take the transportation and handling costs into consideration, like the consultant did for his decision, the final scenario gives the best overall score in comparison to Scenarios 3 and 4. Since we take more criteria into consideration with the tool, the results are slightly different and the tool recommends to choose Scenario 4, where a fixed amount of steel is transferred via a rail hub to the customers. If NMD would have chosen Scenario 4 instead of the final scenario, then:

- The expected average inventory time on works would be 8% longer (16.8 versus 15.9 days).
- Total CO_2 emissions would be around 3% lower (10,606,460 versus 10,905,830 kg).
- Deviation of the mode mix with the ideal mode mix would be higher (25% versus 18%).
- Volume flows that would go through exiting route combinations would be lower (79% versus 83%).
- More volume would flow through better rated warehouses (weighted average classification number of 1.56 versus 1.65).
- Total costs, warehouse dependency, IT connectedness, transportation risk and expected supplier performances would differ only fairly.

As one can see, the differences between the two scenarios are relatively low. Multi-criteria decision analysis is intended to serve as a tool to help the consultants reach a decision. This is their decision and not the tool's decision. The tool serves as guidance for the consultant, he is allowed to derogate from the results. It is useful for the consultant to explore the results and their sensitivity to different inputs, especially when the MCDA results are surprising. It allows the consultant to explore the reasons for the discrepancy with their expectations.

This case study shows us that the results are found reliable by the NMD team and that the tool is valid. With the tool, the baseline scenario scored lowest and the barge- and rail hub scenarios scored best. With the addition of the final scenario (the scenario that was chosen by the consultant and is a combination of the barge- and rail hub scenario), we expected this scenario to score high as well, near the value score of the barge- and rail hub scenario. This expectation is found to be true, since the overall values are similar.

6.6 Conclusions

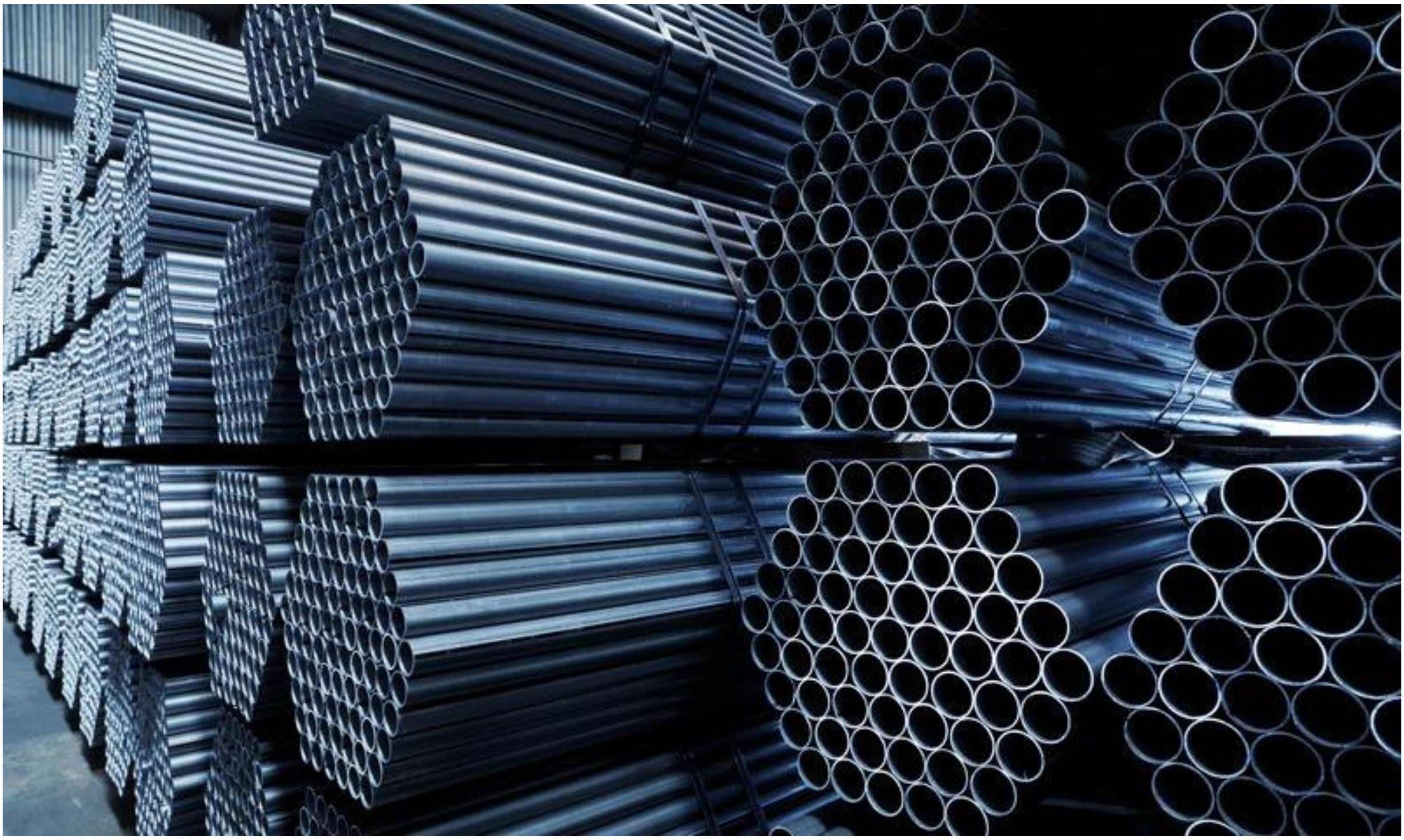
The tool that is built is tested with data from a network review in Germany. This network review was started by NMD because 13% of the total export goes into the regions Ruhr, Hagen-Dortmund and Siegerland and the network was not evaluated for a long time. Also, there are several opportunities for more efficient use of the network like reducing the direct truck deliveries and implementing a barge or rail hub. The business question for the review was as follows: 'How can the transport to customers in scope be structured more efficiently?’. The scenarios that the consultant and analyst took into consideration were: the baseline, a free-run, a barge hub, a rail hub and a no truck scenario. Eventually they chose for a final scenario that is a combination of the barge and rail hub and the no truck scenario.

Using the MCDA tool, we evaluate the performance of these scenarios on the criteria costs, quality, readiness for implementation, sustainability, robustness and inventory time. The decision maker is the distribution chain consultant, and the logistics analyst supported him by showing data and give recommendations. Based on the output from the optimisation tool, the MCDA tool calculates raw scores and the consultant gives weights and scales to the criteria. This results in values of benefits and costs and an overall value for each scenario. The rail hub scenario scores best, followed by the barge hub and no truck scenarios. The baseline scenario scores five out of twelve times, zero points and is the least favorable alternative.

To check if the ranking is robust to changes in the weights, we measure the sensitivity of criteria for the scenarios that scored best (barge hub and rail hub scenarios). The criteria ‘inventory time on site’, ‘robustness’, and ‘quality’ were sensitive. However, they all would need an increase or decrease of more than 10% of its original weights before the other scenario would have a higher overall value.

Adding the final scenario in the model gives a second rank. There is a difference in the scenario that the tool favors and the scenario that is chosen by NMD. The final scenario that was chosen by NMD scores better on total costs, robustness and readiness of implementation. However, the rail hub scenario scores better on inventory time, sustainability and quality. Based on the weights that the consultant gave to these criteria, the rail hub scenario comes out as a better option, but only with a very minimal difference. This result gives the consultant more insight in the decision problem and helps him reach a decision. This is of added value to Tata Steel since the NMD team did not have these insights before.

This case shows us that the results are found reliable by the NMD team and that the tool is valid. Yet, we tested the tool on one case, because there was no data available from other network reviews. It could be that the tool works for this regional review, but not for another. However, we tried to narrow this limitation by generalising the tool for all regions as much as possible.



Tata Steel Tubes, Maastricht

7 Conclusion and Discussion

In this chapter, we look back and summarize the most important things that have been discussed in this research so far. We repeat the answers given to the research questions and give recommendations and suggestions for further research. Furthermore, we reflect on the contribution of this research.

7.1 Conclusion

The network of Tata Steel is complex due to the size and structure of the logistics network. This complexity brings challenges with it like the choice of modalities and routes. NMD needs to make trade-offs in order to redesign the optimal network by evaluating the impact of scenarios on multiple criteria. Furthermore, distribution chain consultants make decisions about (re-)designing the network individually from each other which creates a need for uniform support.

This research provides this support in two ways: a standardized process with guidelines how to review a network and a tool that supports the consultants by giving insights in several impacts that scenarios have on the logistics network.

The approach of this research was as follows. We conducted interviews and analysed internal documents to understand the current way of performing a network review. Next, we analysed concepts and methods of network reviews and decision support tools. We came to the conclusion that, to our knowledge, no literature is available about regional holistic approaches of (re-)designing logistics networks, and that a multi-criteria decision analysis (MCDA) tool is an appropriate tool to solve Tata Steel’s action problem. Following, we developed a standardized process for a network review and a tool with VBA that evaluates the scenarios on multiple criteria. The algorithm used for this tool is the simple multi-attribute rating technique (SMART). This tool was tested on a case with data from a network review of the network in three regions in Germany, which is performed parallel to this research.

The results of this research are as follows. Based on our findings from interviews, observations and desk research, we recommend the following process to follow for a network review:

1. Organise a kick-off phase where the scope, planning and key stakeholders are determined.
2. Validate the baseline scenario to compare other scenarios later in the process.
3. Design alternative scenarios and search for alternative LSPs behind the desk and in the field.
4. Prepare the optimisation tool with the collected data and possible routes and model all the scenarios. This includes an unconstrained scenario and a sensitivity analysis.
5. Use the output of the optimisation tool as the input for the multi-criteria decision model and select the best scenario based on costs, quality, inventory time, readiness for implementation, sustainability and robustness.

6. Discuss the best scenario with the key stakeholders to validate if this scenario is indeed better than the baseline scenario. If this is not the case, then the process stops, and the current network stays unchanged.
7. Get approval from the account manager, the financial controller and dependent on the scope also from the manager of outbound logistics.
8. Implement the new logistics concept and adjust the systems.
9. Monitor the new network design in this region with KPIs to measure its performance on lead time adherence and transportation spend.

In supply chain design, one must always make compromises in different objectives. That is why the fifth step of the review process is about evaluating the network performance of scenarios on multiple criteria. Selection of a final scenario consists of two phases. First, an optimization model provides the optimal routes for each scenario in terms of costs. Second, an MCDA tool is used to examine this optimal network on other criteria as well for each scenario. To calculate the differences and to rank the scenarios, we made a tool using the SMART method. We tested the tool on optimization data from a network review in Germany where five scenarios were analysed. The two scenarios that came out best in the tool were also chosen by NMD in the form of a final scenario (which was a combination of the two highest ranked scenarios). Adding this final scenario in our tool, gave us a surprising result, it was ranked second. First ranked was the scenario in which we used a rail hub to ship steel to the customers.

We notice that the differences between the costs of the final scenario and the rail hub scenario are minimal. At the same time, differences in benefits between the scenarios are more significant. Especially on sustainability and quality of the network, Scenario 4 scores better. It makes sense that NMD chose for the final scenario instead of the rail hub because they only took information from the optimisation tool into consideration about costs and sustainability. Since they find costs more important than sustainability, they chose for the final scenario which is €32,155 cheaper on transportation and handling costs than the rail hub scenario. This shows that NMD needs this tool to give them more insight into the effects of a network redesign.

The main questions of this research were:

How can a standardised review of the transportation network improve the competitiveness of Tata Steel Europe?

a) *What should a standardised process of the network review look like?*
b) *How can an MCDA model that analyses more criteria than only costs, support the network review?*

We can answer these questions by saying that we now know the requirements for a network review from Tata Steel, and present a flowchart of the steps of a network review, see Figure 4-1. We also know that evaluation of scenarios should be based on the criteria of costs, sustainability, readiness for implementation, robustness, and inventory time. We made a tool that calculates the ranking, based on these criteria, and that can be used by NMD members to evaluate scenarios.

The research contributes to practice in various ways. First, it comes up with a standardized step by step process for a network review. This standardized process gives the consultants guidelines and structure which can result in faster reviews and more quality of the results. Second, building an MCDA tool means that scenarios are analysed and critically reflected, pointing out weaknesses of the data gathering methods, and helping NMD to get more insight in the impact of scenarios on the supply chain and reasons for possible discrepancies with their expectations. The employees of outbound logistics are content with the process and the tool and the results are convincing. The MCDA tool can also give suggestions for new alternatives that are a combination of scenarios that scored high.

The scientific contribution is more complicated as this research is specifically made for Tata Steel Europe. Yet, we did not encounter any other paper that combines the research on the general step by step process of a logistics network review with building a SMART model that evaluates multiple scenarios for route and mode selection in a logistics network.

7.2 Limitations

The tool that we developed for Tata Steel must represent reality in the best way possible. However, this is bounded to assumptions and parameters that we used as input. Assumptions that we made for this research are about production costs and interest rates. However, we made these assumptions together with employees of outbound logistics who have a certain expertise in that field of knowledge. We also assumed that realization data from 2019 gives an appropriate measurement for inventory times in the future unless a new logistics concept is implemented. In the latter case, we make assumptions about departure intervals for barges and blocktrains. It is questionable that this data from the past represents reality at all times. Furthermore, although we tried to make the model as objective as possible, we still needed some subjective information from the consultants as well, for example, the ideal mode mix for the reviewed region.

A limitation of using SMART instead of another algorithm is its simplicity, which has the effect that not all the detail and complexities of the real problem are captured. Also, because we used 10 lower-level criteria, it was time-consuming for the consultant to determine the weights and think about the appropriate scales for all criteria.

Furthermore, a limitation of SMART lies in the scoring method. When the raw scores of scenarios are very similar to each other, one can argue that the scenarios should have the same scores. However, with SMART this does not matter since it looks at the relationships between the raw scores. For example, three scenarios have the following raw scores: 0.55, 0.56 and 0.57 on a scale from 0-1. Following a linear scale, the performance scores are then relatively: 0, 50 and 100. This would influence the overall score in a big way (depending on the weight), while the difference is actually quite small.

Finally, the choice of using the distribution chain consultant as the decision maker and not a group of decision makers makes it easier to determine the weights. We assumed in our research that the consultant understands the opinions of all stakeholders, and that is the reason why he represents the key stakeholders as the decision maker. Since weights are subjective, the consultant needs to communicate well with the key stakeholders to get an impression of everything that plays in the regions. It would be problematic if communication is poor, the consultant has not a good view of everything that goes around in the regions and he needs to weight criteria.

7.3 Recommendations

First of all, we would recommend implementing the proposed flowchart of a network review and the decision support tool for evaluating scenarios. For the implementation of the new step by step process of a review, we recommend Tata Steel to:

- ✓ Use the recommended process, give it a place in the operations of NMD, and place it in Nimbus (a process mapping tool for Tata Steel). Also, there should be formats for the kick-off, the final proposal, an implementation plan, a business case, an RFQ, SLA and ATC that are available to employees of the outbound logistics department.
- ✓ Test the new process, adopt it if necessary and gather best-practices of previous projects since this should be an integrated part of knowledge management since this provides improvements regarding process and tool approaches.
- ✓ Develop a review calendar with planning for the reviewed regions. A clear planning and deadline contribute to a faster process and to avoid the fire-fighting modus (start a review after a reactive trigger). We recommend making this calendar together with the departments sourcing and (tactical) operations.
- ✓ Make clear agreements with the departments operations and tactical operations about the division of responsibilities. When is the implementation of a change a responsibility of NMD (and should a (shorter version) network review be performed, when from operations (for small day-to-day problems) and when from tactical operations (in between short- and long-term problems).

- ✓ Adjust the current KPIs of outbound logistics that are related to measuring the network. Good KPIs are specific, measurable, attainable, realistic and timely and give a good impression of the situation and goal of the department.
- ✓ Continuously update data of the current network in the optimisation tool to maintain a representable model of reality. Although this may seem time-consuming, it saves time in the analysis phase of a network review. For example, the network review of Germany took over a year partly because the analyst often had to change the current network and prices in the model. At the same time, this can be a validation of the data in the databases. Furthermore, the analyst can report the restrictions that were used in modelling, so he does not have to invent the wheel each time, i.e., customers cannot be delivered with multiple modalities via different terminals, except for Becker Bonen in Boenen because it has small rail capacity that needs to be open when spot deals are made and steel needs to be delivered from the UK.

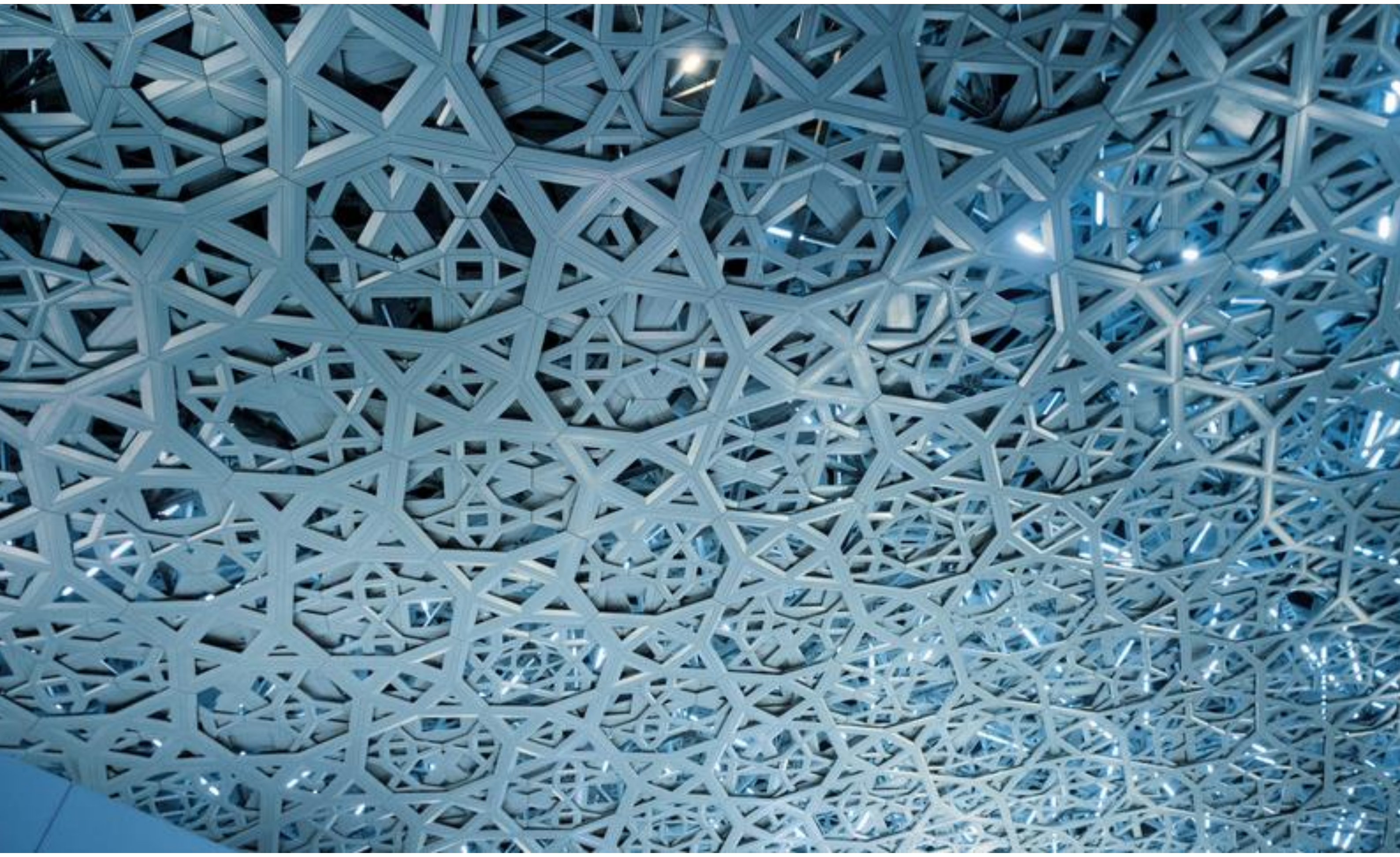
For the implementation of the MCDA tool, we recommend Tata Steel to:

- ✓ Ask for more information about the IT capabilities of an LSP as a checklist, next to a quotation of the price. It becomes more and more important to the business that LSPs have appropriate IT systems that can be easily connected to Tata Steel's IT systems or are willing to change the systems. For example, to set up track-and-trace connections, which adds value to the customer. Examples of questions for LSPs: is your IT in- or outsourced? Do you have your own track & trace system? What is your security standard? Are you willing to build EDI connections?
- ✓ Further examine lead time adherence, working capital, and inventory times on site and in warehouses. In this way, trends can be analysed about customer and supplier behaviour.
- ✓ Connect different datasets around different departments. Differences in the use of a name or typing mistakes make it difficult to use data from several datasets. For example, in one database the name is used of 'X', and in another 'X'. Next to this, departments within outbound use their own datasets and it is sometimes not known by people from other departments that these datasets exist, they do not have access, or the datasets cannot be used due to a different way of reporting data. We recommend connecting these datasets from different departments, and to update them regularly. In one case, it occurred that we could not find a warehouse in the warehouse database because they changed a name years ago.
- ✓ We recommend making more use of the possibilities of the optimisation tool. For example, possibilities to keep track of stock at the used warehouses, or to simulate the network over a certain time period can be useful for network modelling.
- ✓ Research the use of artificial intelligence (AI) in decision making for a possible network redesign. It can be interesting to implement machine learning in logistics network redesign or

supplier selection since these systems learn from human decision and make fast judgements. This can be useful in logistics as complexity grows with more unstructured data, more sophisticated learning algorithms and techniques, and more high-level decision-making tasks.

- ✓ Evaluate the impact that this tool has on decision making by keeping track of the results of the MCDA tool and the scenario that is eventually chosen in a review. Also, if this is the same scenario, evaluate the changed network after some time to see if it was the right decision.

Finally, we identified several areas for further research in general, including 1) the impact of MCDA on decision making. It would be useful if there is a study about the evaluation of the influence of MCDA on decisions made in network design; 2) the level of precision required for an MCDA; 3) ways of verification and validation of an MCDA tool in transportation network design; 4) guidelines for a network review.



Steel integrated in the geometric dome of the Louvre museum at Abu Dahbi

8 Bibliography

Aguezzoul, A. (2014). Third-party logistics selection problem: A literature review on criteria and methods. *Omega 49. The International Journal of Management Science.*, 69-78.

Barfod, M. B., & Leleur, S. (2014). Multi-Criteria Decision Analysis For Use In Transport Decision Making. *DTU Transport Compendium Series part 2*.

Bystrzanowska, M., & Tobiszewski, M. (2018). How can analysts use multicriteria decision analysis? *Trends in Analytical Chemistry*, 98-105.

Capgemini Consulting. (2017). *Strategic Network Design.* Retrieved from Production and Logistics Network Optimization for Sustainable Value Creation: https://www.capgemini.com/consulting-de/wp-content/uploads/sites/32/2017/09/strategic_network_design_0.pdf

De Montis, A., De Toro, P., Droste-Franke, B., Omann, I., & Stagl, S. (2000). Criteria for quality assessment of MCDA methods. *3rd Biennial Conference of the European Society for Ecological Economics.* Vienna.

Edwards, W., & Barron, H. F. (1994). SMARTS and SMARTER: Improved Simple Methods for Multiattribute Utility Measurements. *Organizational Behavior and Human Decision Processes 60*, 306-325.

ElDrandaly, K. A., Ahmed, A. N., & AbdelAziz, N. M. (2009). 9th International Conference on Production Engineering, Design and Control. *An Expert System for Choosing the Suitable MCDM Method for Solving a Spatial Decision Problem*, (p. 10). Alexandria.

Francas, D., & Simon, Z. (2011). *Camelot Management Consultants.* Retrieved from Strategic Network Design: A Focus Topic Paper: https://www.chemanager-online.com/file/track/18651/1

Goodwin, P., & Wright, G. (1991). *Decision Analysis for Management Judgment.* Chichester: John Wiley & Sons, Ltd.

Hwang, C., & Yoon, K. (1981). *Multiple Attribute Decision Making: Methods and Applications.* New York: Springer.

Ishizaka, A., & Nemery, P. (2013). *Multi-Criteria Decision Analysis: Methods and Software.* West Sussex, United Kingdom: John Wiley & Sons, Ltd.

Keeney, R., & Raiffa, H. (1976). *Decision Making with Multiple Objectives Preferences and Value Tradeoffs.* New York: Wiley.

Kopytov, E., & Abramov, D. (2012). Multiple-Criteria Analysis and Choice of Transportation Alternatives in Multimodal Freight Transport System. *Transport and Telecommunication, volume 13*, 148-158.

Macharis, C., & Bernardini, A. (2015). Reviewing the use of Multi-Criteria Decision Analysis for the Evaluation of Transport Projects: Time for a Multi-Actor Approach. *Transport Policy vol.37*, 177-186.

Macharis, C., Springael, J., De Brucker, K., & Verbeke, A. (2004). PROMOTHEE and AHP: The design of operational synergies in multicriteria analysis.: Strengthening PROMOTHEE with ideas of AHP. *European Journal of Operational Research vol.153*, 307-317.

Mota, P., Campos, A., & Neves-Silva, R. (2013). First Look at MCDM: Choosing a Decision Method. *Advances in Smart Systems vol. 3 no. 2*, pp. 25-30.

Pooler, M., & Feng, E. (2017, 10 29). *Steel industry grapples with curse of oversupply.* Retrieved from Financial Times: https://www.ft.com/content/992ad270-b4d3-11e7-aa26-bb002965bce8

Ramanathan, R. (2001). A note on the use of the analytic hierarchy process for environmental impact assessment. *Journal of Environmental Management 63*, 27-35.

Ravindran, A. (2016). *Multiple Criteria Decision Making in Supply Chain Management.* Boca Raton: CRC Press, Taylor & Francis Group.

Roberts, R., & Goodwin, P. (2002). Weight Approximations in Multi-attribute Decision Models. *Journal of Multi-Criteria Decision Analysis*, 291-303.

Roy, B. (1996). *Multicriteria Methodology for Decision Aiding.* Dordrecht: Springen Science + Business Media.

Saaty, T. L. (1977). A Scaling Method for Priorities in Hierarchical Structures. *Journal of Mathematical Psychology 15*, 234-291.

Schmidt, G., & Wilhelm, W. E. (1999). Strategic, Tactical and Operational Decisions: in Multi-national Logistics Networks: A Review and Discussion of Modeling Issues. *International Journal of Production Research*, 35.

Smith, M. (2017, 11 30). *What makes a good KPI?* Retrieved from Bellingham Wallace Accountancy: https://www.bellinghamwallace.co.nz/blog/what-makes-a-good-kpi

Tata Steel. (2018, 10 02). *Markets*. Retrieved from Tata Steel: https://www.tatasteeleurope.com/en/markets

Tata Steel Europe. (2018, 10 03). *Duurzaam in alle opzichten*. Retrieved from Tata Steel: https://www.tatasteel.nl/nl/innovatie/HIsarna/Duurzaam-in-alle-opzichten

Tata Steel Europe. (2018, 10 03). *Tata Steel in IJmuiden*. Retrieved from Tata Steel: https://www.tatasteel.nl/nl/over/organisatie/in–ijmuiden

Tata Steel IJmuiden. (2018, 10 03). *Discover the world of outbound logistics within Tata Steel*. Retrieved from Tata Steel: https://www.tatasteeljobs.nl/professionals/vakgebieden/do-you-want-to-transform-the-steel-business/discover-the-world-of-outbound-logistics-within-tata-steel/

Tata Steel Strip MLE. (2016). Measuring the customer experience through our customers' eyes. *Customer satisfaction survey 2015*.

The World Bank. (2018). *The World Bank*. Retrieved from Aggregated LPI 2012-2018: https://lpi.worldbank.org/international/aggregated-ranking?sort=asc&order=LPI%20Score#datatable

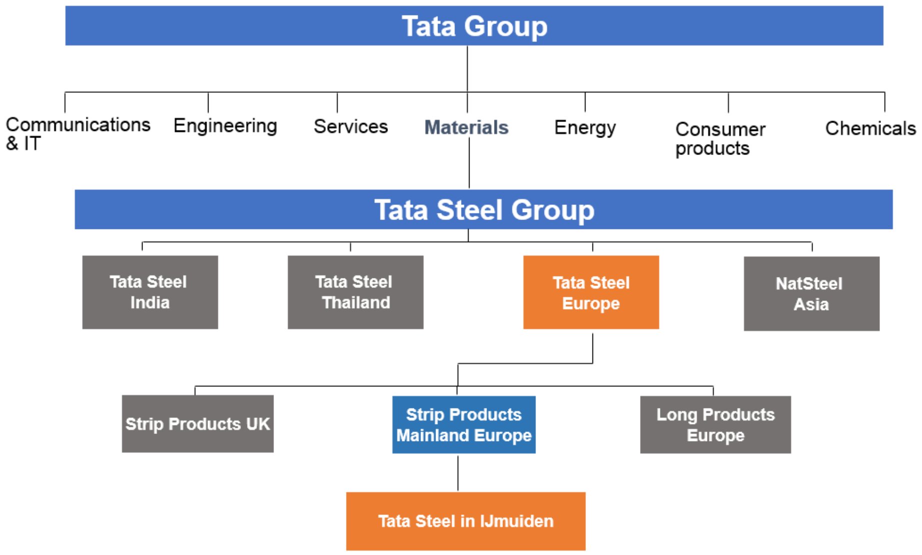
Trujullo Díaz, J., Tarcisio Velásquez Contreras, A., Martinez Rojas, M., Bolivar, H., Franco Franco, C., & Fernando Perez González, J. (2015). Criteria for decision-making in Transportation Logistics Function. *International Conference on Industrial Engineering and Operations Management* (p. 7). Dubai: ResearchGate.

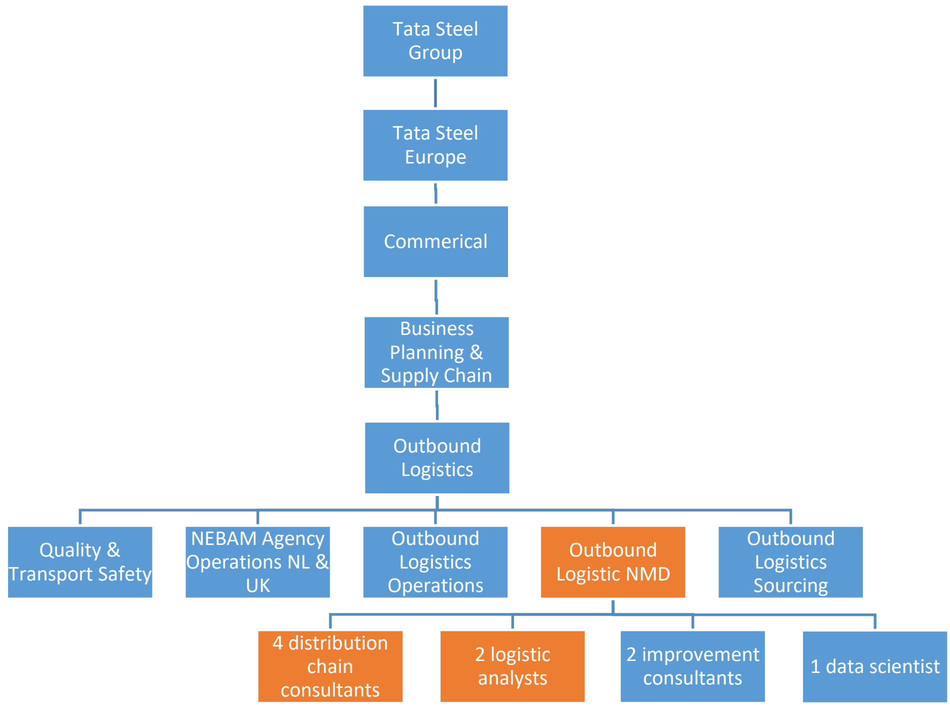
Tzeng, G.-H., & Huang, J.-J. (2011). *Multiple Attribute Decision Making: Methods and Applications.* Boca Raton: CRC Press.

Velasquez, M., & Hester, P. T. (2013). An Analysis of Multi-Criteria Decision Making Methods. *International Journal of Operations Research*, 56-66.

Winston, W. L. (2003). *Operations Research. Applications and Algorithms.* Boston: Cengage Learning.

Appendix A – Organizational Charts





Appendix B – Current Routes to Hagen, Ruhr and Siegerland

<table>
<tr><th>Terminals</th><th>Customer Names</th></tr>
<tr><td>Confidential</td><td rowspan="4">Confidential</td></tr>
<tr><td>Works</td></tr>
<tr><td>Ijmuiden_NL
Vogten_NL
Wuppermann_NL
Llanwern_UK
Port Talbot_UK
Duffel_BL
Segal_BL</td></tr>
<tr><td>Destinations</td></tr>
<tr><td>Confidential</td><td></td></tr>
</table>

Appendix C – Criteria found in literature

Selection criteria for third party logistics			
Costs	Price Cost reduction Low cost distribution Expected leasing cost Operation cost Warehouse cost Cost savings	Flexibility	Ability to meet future requirement Capacity to accommodate and grow the client's business System flexibility index Responsiveness to target market or service request Capability to handle specific business requirements Time response capability
Relationship	Reliability Truth Dependence Alliance Compatibility Reciprocity	Delivery	Time On-time performance On-time shipment and deliveries Delivery speed Accuracy of transit/delivery time Shipment delivery On-time delivery rate
Services	Breadth of services Characterization of services Variety of available services Pre-sale / Post-sale customer services Value-added services	Professionalism	Expertise Competence Experience
Information & equipment system	EDI Tracking / tracing Technology capabilities Information accessibility Availability of computer network Informatization level Technical/engineering capability Materials handling equipment Information security	Location	Distribution coverage Geographical specialization and coverage International scope Market coverage Shipment destinations Distance
		Quality	Commitment to continuous improvement SQAS/ISO standards environment issues Risk management

Criteria for cargo transportation evaluation	
Cost of cargo delivery	Costs for transportation Costs for handling Seasonal fluctuation of tariffs Costs for documentation processing Penalties Possible additional costs during transportation Additional insurance
Time of delivery	Time for transportation Time for border crossing Time for customs clearance Exchange rate fluctuation during delivery time
Reliability of cargo transportation	Exceed of delivery time Cargo safety (loss, damage of cargo) Availability of transport units Safety (theft, unauthorizes access to cargo) Reliability of transport means
Ecological impact	Emission of CO2 Emission of harmful substances Noise & vibration Accidents and disasters from the ecological point of view Death and traumatism of people

(Aguezzoul, 2014) (Kopytov & Abramov, 2012)

Appendix D – Business drivers and triggers

Triggers / business drivers for network redesign	
Group meeting NMD	
Triggers that currently cause a network review	
1	Performance of the network
2	Monitoring the network
3	A change in volume to a certain region
4	Customer complaints about lead time, quality, cost or pollution
5	Cost reductions instructed by management
6	A sustainability whish by the customer or management
7	A change in transport strategy to mitigate risk
8	Movement of Tata Steel regarding a joint-venture
9	Investment projects
10	Network breakdown
11	LSP performance deteriorates
12	Price developments
13	Commercial opportunity
14	Line loading policy, which encompasses the production location
15	On-site issues by congestions
Capgemini (2017)	
Business drivers for strategic network (re-)design	
1	Mergers and acquisitions
2	Customer shift
3	Restructuring and downsizing
4	Major change of key parameters (margins, raw material prices, duties, etc)
5	Readiness for eCommerce
6	New market entry
7	Launch of new product lines
Camelot (2011)	
Business drivers for strategic network (re-)design	
1	Mergers & acquisitions
2	Expansion
3	Restructuring & simplification
4	Downsizing
5	New geographic market entry
6	New business field entry
Business drivers for tactical network (re-)design	
7	Transportation spend
8	Changes in distribution structure

Since this list exists of 15 categories and some are overlapping, we had individual meetings with the consultants to structure them into less categories. The following changes were made:

- We combined the triggers 'volume change', 'line loading policy' and 'on-site issues' in the category: 'changes in customer volumes and production'.
- We combined the triggers 'cost reductions', 'sustainability', 'transport strategy', 'movement of Tata Steel' and 'investment projects' in the category 'changes in the strategy of Tata Steel'.

- We removed the triggers ‘network performance’ and ‘monitoring’, because this is more a way to continuously evaluating the network instead of an ad hoc driver.

After the change we got seven trigger categories: ‘changes in customer volumes and production’, ‘changes at LSPs’, ‘commercial opportunity’, ‘price developments’, ‘disruption in the physical route’, ‘customer complaints’, and ‘changes in the strategy of Tata Steel’.

As described in Chapter 3, we found business drivers that consultancy firms defined for strategic and tactical network design. When we compared these business drivers to our triggers we noticed the following:

- The business driver ‘customer shift determined by new markets or change in the customer expectations in terms of price, service quality and response time’ looks similar as the triggers ‘changes in customer volumes and production’ and ‘customer complaints’. However, we keep the name of the triggers, because production change is not included in ‘customer shift’ or in another business driver.
- Since the business driver ‘change in key parameters’ includes the trigger ‘price developments’ and more, we change the name of this trigger.
- The trigger ‘changes in the strategy of Tata Steel’ includes the business drivers ‘M&A’, ‘restructuring’, ‘downsizing’, ‘expansion’ and ‘simplification’.
- Since we do not have the business driver ‘transportation spend’, we add this to our list
- The trigger ‘commercial opportunity’ includes the business drivers ‘new market entry’ and ‘new business field entry’.
- We combine the triggers ‘changes at LSPs’ and ‘disruption in the physical route’ to ‘change in distribution structure’.

Editing the list, we eventually had the following triggers for a network review:

- Changes in customer volumes and production
- Commercial opportunity
- Change of key parameters
- Customer complaints
- Changes in the strategy of Tata Steel
- Change in distribution structure
- Transportation spend

Appendix E – Average Inventory Times

Average inventory time on site (from realisation data 2018)	IJMUIDEN			SEGAL_Ivoz Ramet			VOGTEN_Maastricht			WUPPERMAN_Moerdijk		
DIRECT	Truck	Rail	Barge	Truck	Rail	Barge	Truck	Rail	Barge	Truck	Rail	Barge
Confidential	*Confidential*			*Confidential*			*Confidential*			*Confidential*		

AVERAGE				
INDIRECT				
Confidential	*Confidential*	*Confidential*	*Confidential*	*Confidential*
AVERAGE				

Appendix F – Expected volumes, lead times and interest rates

Expected volumes (ton)	Mode of transport	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
NL-DE	Barge	214898	275538	334849	275538	369060
NL-DE	Rail	450559	420509	410194	466416	448997
NL-DE	Truck	149386	125621	76625	85214	9000
DE-DE	Rail	226784	99784	163693	99784	99784
DE-DE	Truck	102935	108688	167999	168306	223727
NL-NL	Barge	15555	34206	34206	39723	48028
NL-NL	Rail	49200				
NL-NL	Truck	28000				
UK-NL	Vessel	31736	31736	31736	31736	31736
UK-UK	Rail	44049	44049	44049	44049	44049
UK-DE	Truck	12313	12313	12313	12313	12313
BE-DE	Barge	1000	1000	1000	1000	1000
BE-DE	Rail	33293	29793	29793	29793	33293
BE-DE	Truck	12274	8949	8949	3449	60
BE-NL	Barge	3389	10214	10214	15714	15603
	sum	*1375371*	*1202400*	*1325620*	*1273035*	*1336650*

From – to (countries)	Mode of transport	Expected lead time (days)	Interest per ton over the according lead times
NL-DE	Barge	6	
NL-DE	Rail	4	
NL-DE	Blocktrain	4	
NL-DE	Truck	3	
DE-DE	Rail	4	
DE-DE	Truck	2	
NL-NL	Barge	5	
NL-NL	Rail	4	
NL-NL	Truck	2	*Confidential*
UK-NL	Vessel	4	
UK-UK	Rail	4	
UK-DE	Truck	4	
BE-DE	Barge	6	
BE-DE	Rail	4	
BE-DE	Truck	3	
BE-NL	Barge	5	

Average production cost per ton:	*Confidential*
Debit Interest Bank:	
EURIBOR Interest:	-0.368%

Calculations of mode risk scores:

Scenario	Mode of transport	Volumes	Volumes (%)	Risk score	% * Risk
Scenario 1	Vessel	31736	2%	4	0.08
Scenario 1	Rail	803885	49%	2	0.98
Scenario 1	Truck	304908	19%	1	0.19
Scenario 1	Barge	234842	14%	3	0.43
Scenario 1	Customer Pickup	271819	17%	0	0.00
Scenario 1	Blocktrain	0	0%	2	0.00
Scenario 2	Vessel	31736	2%	4	0.09
Scenario 2	Rail	559270	38%	2	0.76
Scenario 2	Truck	255571	17%	1	0.17
Scenario 2	Barge	320958	22%	3	0.65
Scenario 2	Customer Pickup	271819	18%	0	0.00
Scenario 2	Blocktrain	34865	2%	2	0.05
Scenario 3	Vessel	31736	2%	4	0.08
Scenario 3	Rail	612864	38%	2	0.77
Scenario 3	Truck	265886	17%	1	0.17
Scenario 3	Barge	380269	24%	3	0.71
Scenario 3	Customer Pickup	271819	17%	0	0.00
Scenario 3	Blocktrain	34865	2%	2	0.04
Scenario 4	Vessel	31736	2%	4	0.08
Scenario 4	Rail	540042	35%	2	0.70
Scenario 4	Truck	269282	17%	1	0.17
Scenario 4	Barge	331975	21%	3	0.64
Scenario 4	Customer Pickup	271819	18%	0	0.00
Scenario 4	Blocktrain	100000	6%	2	0.13
Scenario 5	Vessel	31736	2%	4	0.08
Scenario 5	Rail	573241	36%	2	0.71
Scenario 5	Truck	245100	15%	1	0.15
Scenario 5	Barge	433691	27%	3	0.81
Scenario 5	Customer Pickup	271819	17%	0	0.00
Scenario 5	Blocktrain	52882	3%	2	0.07
Scenario 6	Vessel	31736	2%	4	0.08
Scenario 6	Rail	552455	36%	2	0.72
Scenario 6	Truck	265886	17%	1	0.17
Scenario 6	Barge	358251	23%	3	0.70
Scenario 6	Customer Pickup	271819	18%	0	0.00
Scenario 6	Blocktrain	56930	4%	2	0.07

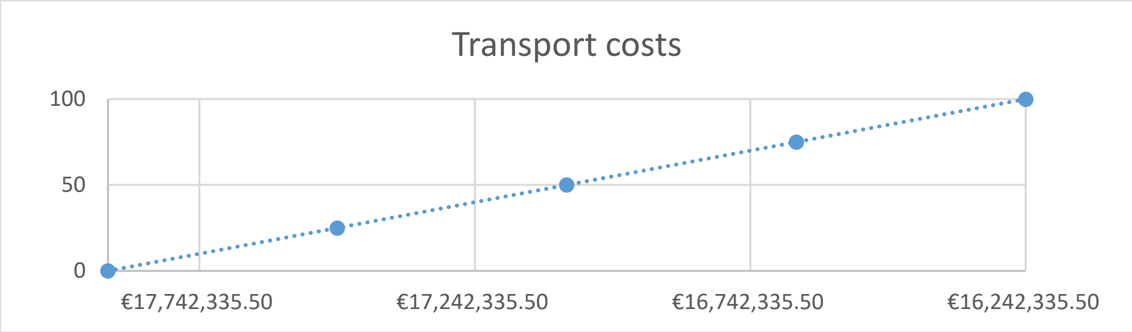
Properties of LSPs and the throughput:

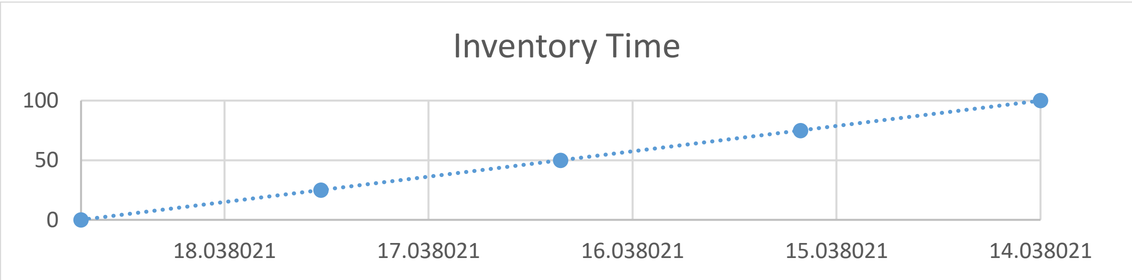
Logistics service provider	EDI connection	Warehouse classification number (1=best, 5=worst)	Expected supplier performance (10 = best, 1=worst)	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Confidential	Yes	3.5 (3-4)	8	31,736	31,736	31,736	31,736	31,736
	No	2	8	27,268	62,500	121,811	62,500	156,022
	No	1	9	22,606	22,606	22,606	22,606	22,606
	Yes	2	5	49,200	0	0	0	0
	No	1	7	120,784	99,784	99,784	99,784	99,784
	No	2	7	12,000	0	0	0	0
	No		8	12,313	12,313	12,313	12,313	12,313
	No	1	8	69,861	40,382	40,382	100,000	61,899
	Yes	3	8	11,554	11,554	11,554	11,554	11,554
	No	1.5 (1-2)	7	28,000	0	0	0	0
	No	2	8	94,000	0	63,909	0	0
	Yes	2	8	31,736	31,736	31,736	31,736	31,736
Sum expected volume through terminals				*511,058*	*312,611*	*435,831*	*372,229*	*427,650*
Sum expected volume through works				*18,944*	*44,420*	*44,420*	*55,437*	*63,631*
Sum expected volume through service centers				*243,465*	*243,465*	*243,465*	*243,465*	*243,465*
Sum expected volume through transshipments				*773,467*	*600,496*	*723,716*	*671,131*	*734,746*

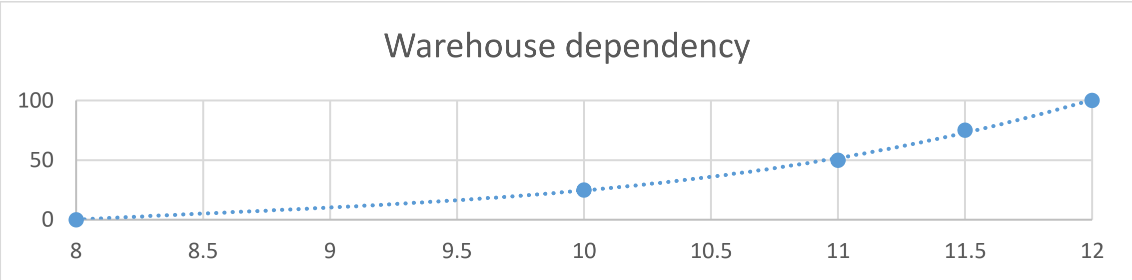
Calculation of the weighted average supplier performance:

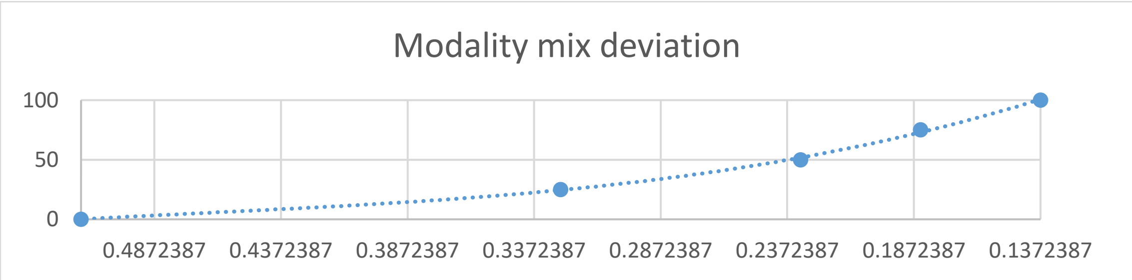
	Supplier performance *(10 = best, 1=worst)*	Scenario 1 *(volumes (%), and volumes multiplied with performance)*		Scenario 2 *(volumes (%), and volumes multiplied with performance)*		Scenario 3 *(volumes (%), and volumes multiplied with performance)*		Scenario 4 *(volumes (%), and volumes multiplied with performance)*		Scenario 5 *(volumes (%), and volumes multiplied with performance)*	
Confidential	8	6%	0.4968	10%	0.8122	7%	0.5825	9%	0.6821	7%	0.5937
	8	5%	0.4268	20%	1.5994	28%	2.2359	17%	1.3433	36%	2.9187
	9	4%	0.3981	7%	0.6508	5%	0.4668	6%	0.5466	5%	0.4757
	5	10%	0.4814	0%	0.0000	0%	0.0000	0%	0.0000	0%	0.0000
	7	24%	1.6544	32%	2.2344	23%	1.6027	27%	1.8765	23%	1.6333
	7	2%	0.1644	0%	0.0000	0%	0.0000	0%	0.0000	0%	0.0000
	8	2%	0.1927	4%	0.3151	3%	0.2260	3%	0.2646	3%	0.2303
	8	14%	1.0936	13%	1.0334	9%	0.7412	27%	2.1492	14%	1.1579
	8	2%	0.1809	4%	0.2957	2%	0.1809	3%	0.2483	3%	0.2161
	7	5%	0.3835	0%	0.0000	0%	0.0000	0%	0.0000	0%	0.0000
	8	18%	1.4715	0%	0.0000	15%	1.1731	0%	0.0000	0%	0.0000
	8	6%	0.4968	10%	0.8122	7%	0.5825	9%	0.6821	7%	0.5937
Sum			*7.4408*		*7.7531*		*7.8229*		*7.7927*		*7.8195*

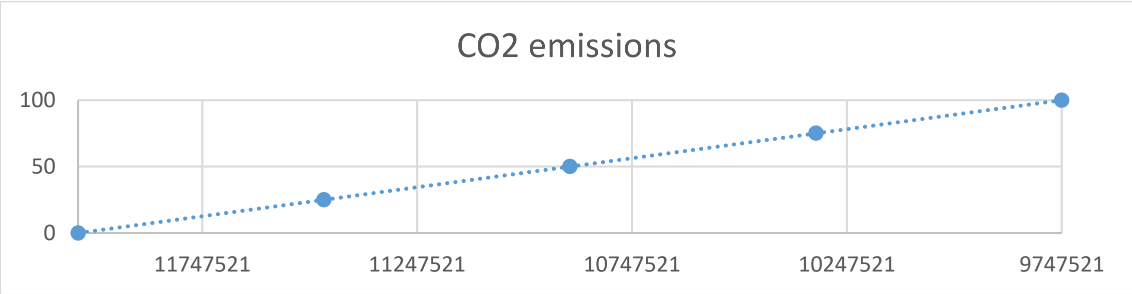
Appendix G – Determining the Scale for Each Criterion

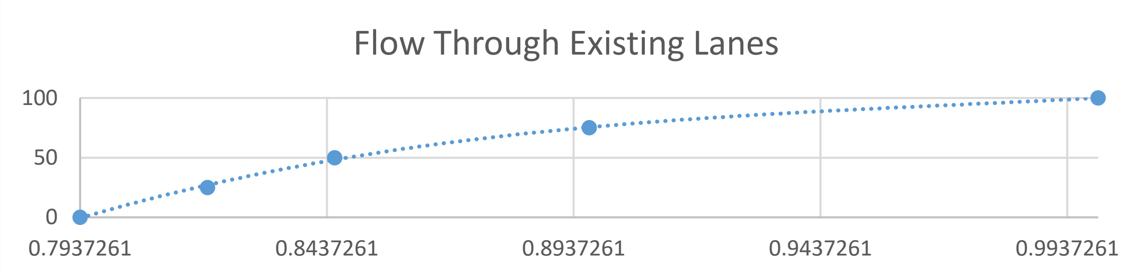


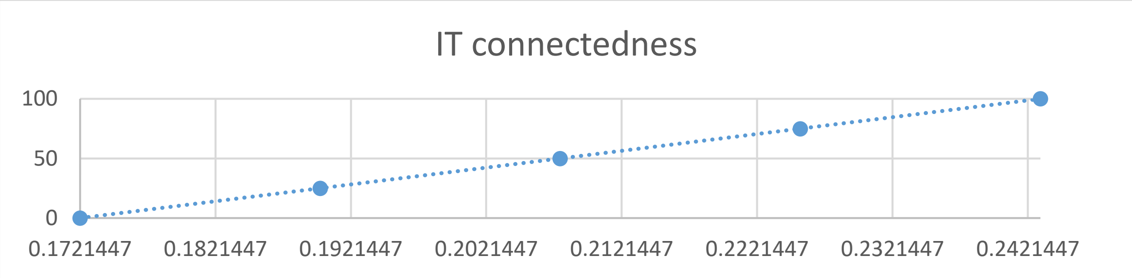


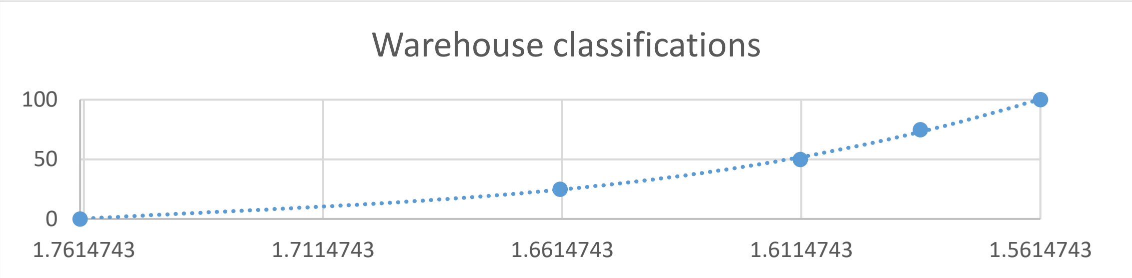


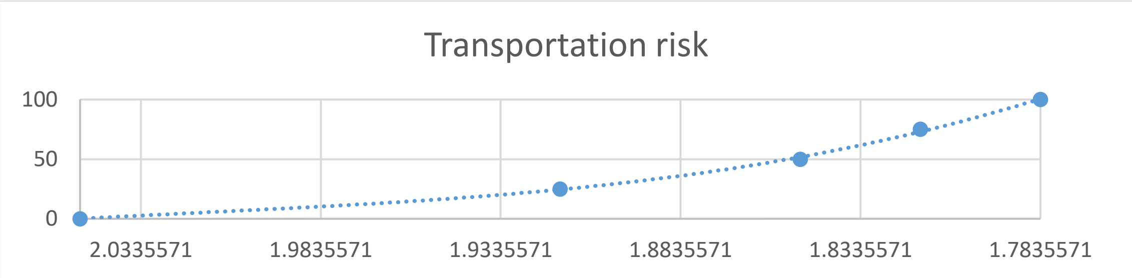


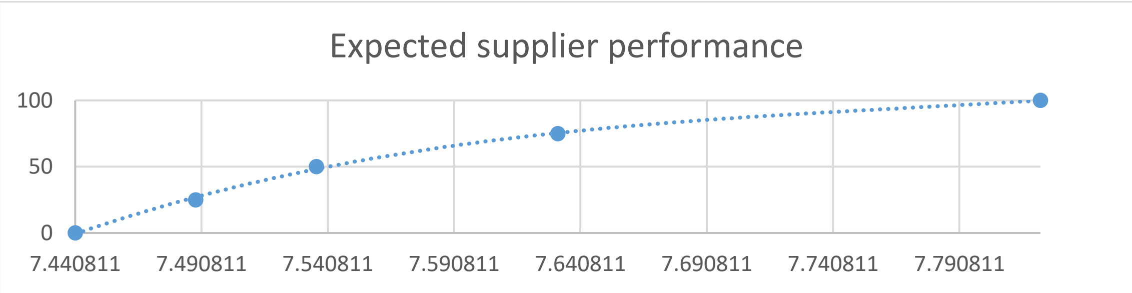



Flow Through Existing Lanes
100
50
0
0.7937261
0.8437261
0.8937261
0.9437261
0.9937261

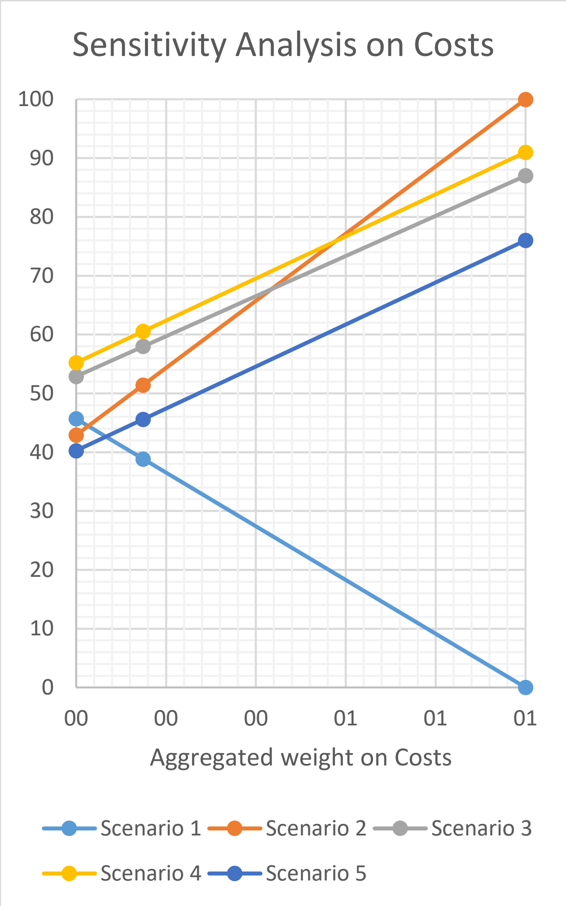

IT connectedness
100
50
0
0.1721447
0.1821447
0.1921447
0.2021447
0.2121447
0.2221447
0.2321447
0.2421447

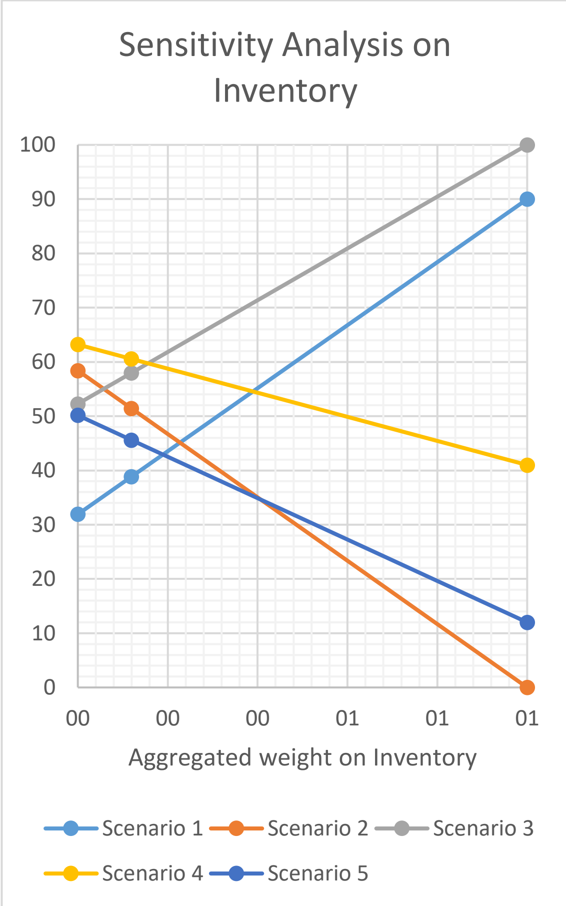

Warehouse classifications
100
50
0
1.7614743
1.7114743
1.6614743
1.6114743
1.5614743

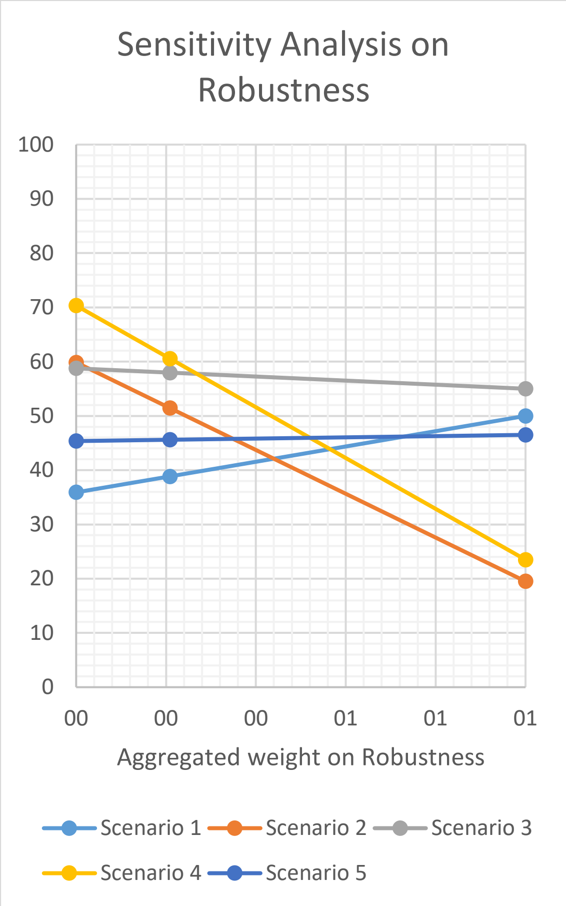

Transportation risk
100
50
0
2.0335571
1.9835571
1.9335571
1.8835571
1.8335571
1.7835571

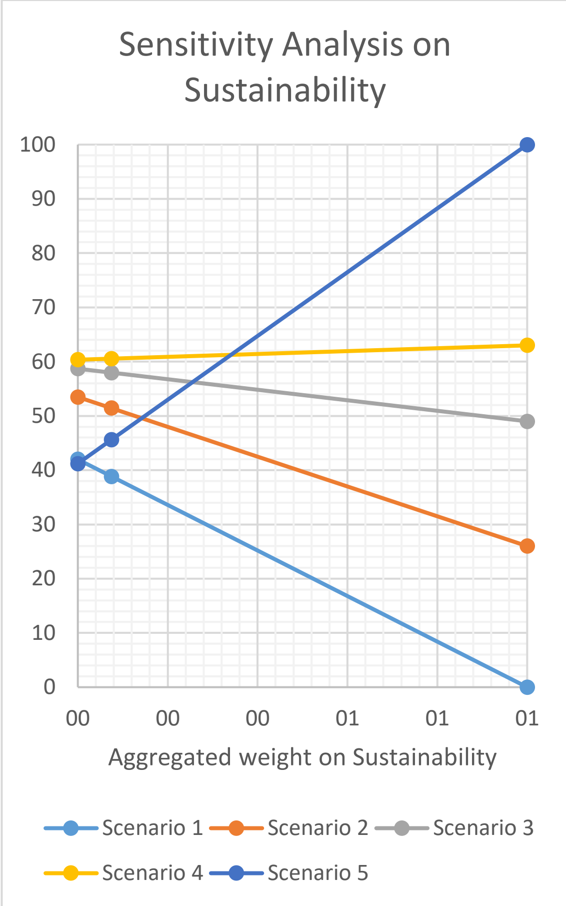

Expected supplier performance
100
50
0
7.440811
7.490811
7.540811
7.590811
7.640811
7.690811
7.740811
7.790811

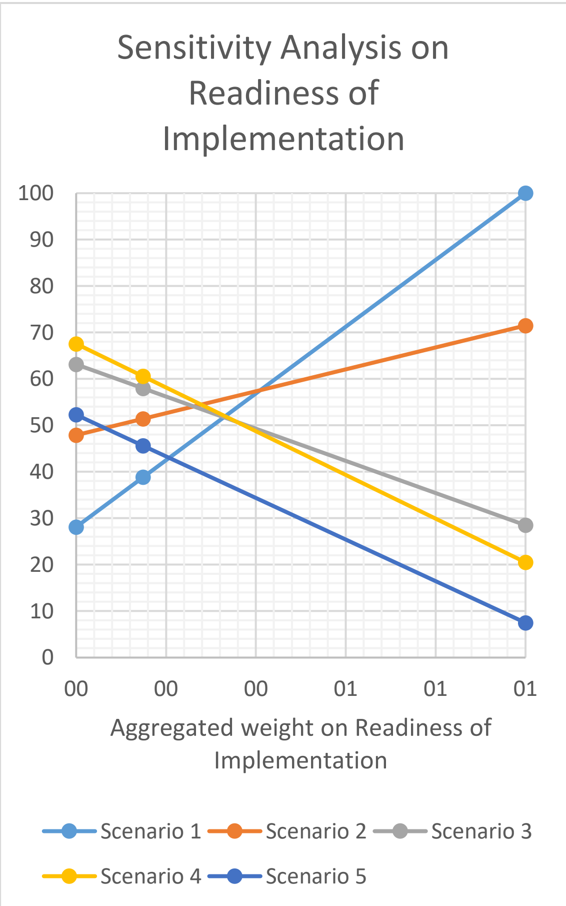
Appendix H – Sensitivity Analysis for Each Criterion

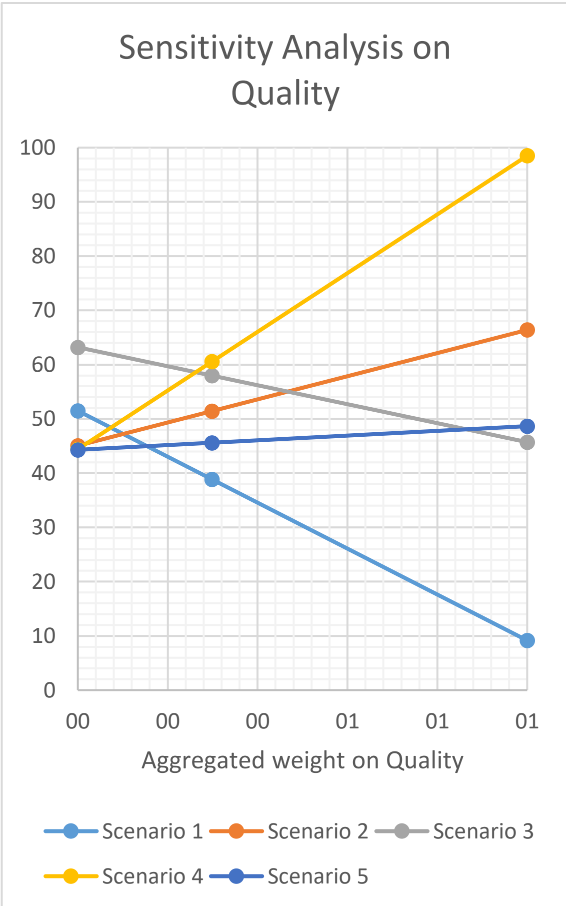





Sensitivity Analysis on Robustness
100
90
80
70
60
50
40
30
20
10
0
00
00
00
01
01
01
Aggregated weight on Robustness
Scenario 1
Scenario 2
Scenario 3
Scenario 4
Scenario 5


Sensitivity Analysis on Sustainability
100
90
80
70
60
50
40
30
20
10
0
00
00
00
01
01
01
Aggregated weight on Sustainability
Scenario 1
Scenario 2
Scenario 3
Scenario 4
Scenario 5


Sensitivity Analysis on Readiness of Implementation
100
90
80
70
60
50
40
30
20
10
0
00
00
00
01
01
01
Aggregated weight on Readiness of Implementation
Scenario 1
Scenario 2
Scenario 3
Scenario 4
Scenario 5


Sensitivity Analysis on Quality
100
90
80
70
60
50
40
30
20
10
0
00
00
00
01
01
01
Aggregated weight on Quality
Scenario 1
Scenario 2
Scenario 3
Scenario 4
Scenario 5

Appendix I – Overview Final Scenario

Confidential