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A structured approach towards the selection of a new hard- and software system supplier

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Preface

All the data provided in this thesis is fictional and therefore does not reflect reality. Textual data and data in figures or tables are multiplied by a random number.

This thesis is written in order to complete the bachelor Industrial Engineering Management at the University of Twente. The assignment is performed under the supervision of Company X and the University of Twente.

The execution of this bachelor assignment and the valuable learning experience that comes with it would never be there in the first place without Company X. I would sincerely like to thank Company X for the opportunity to perform this bachelor assignment at their company and the knowledge and expertise their employees shared which contributed to the learning experience. During the period at Company X I experienced a very pleasant collaboration with my direct supervisor Jeroen, who was always very responsive and always available whenever I had questions or when meetings were planned. Next to the first supervisor, I would also like to thank Ronnie and Marcel. Ronnie was always good company while we were working together, especially skilled in zooming out, getting an overview of the situation and creating an approach together. Marcel played a key role during the thesis assignment at Company X, where I learned a lot about the ICT perspective of the assignment. All in all, I felt very welcome at the office in Oss and the whole crew of employees always reinforced each other to make the best of it.

Secondly, I would like to thank my first supervisor Leo van der Wegen and Hans Heerkens for their good guidance and effort throughout the whole bachelor assignment. Leo was always available on short terms, where we had good discussions about the content and direction of the bachelor thesis. In these discussions the critical ability from Leo was very helpful.

Lastly, I want to thank the Dutch company NS for making their railways available such that I could safely make the world trip from Enschede to Oss station. During this return trip consisting of four hours, my knowledge of the Dutch meadows increased significantly as well as my patience needed for the skill of sightseeing.

Research Information

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Summary

Problem context

Company X has been dedicated for 65 years to transporting liquid foodstuff, only in bulk. Company X is responsible for multiple companies, namely Company X, Company X-I, Company X-II, Company X-III and Company X-IV. Company X (after this abbreviated to Company X) is one of the market leaders in transporting liquid foodstuff and does this by means of intermodal solutions. The on-board computers and fleet management software system linked to the on-board computers that Company X uses to support their operations in transporting liquid foodstuff in bulk, are outdated. This leads to several problems:

- Drivers are not scheduled to their full working capacity
- Customers are not always informed on time about changes in delivery time
- Drivers do not always get fuel at contracted gas stations with discount
- The scheduling of orders is not always based on accurate information

To solve these problems, a new on-board computer and fleet management software system needs to be purchased. The action problem is formulated as follows:

Company X must decide on a new on-board computer and software system

Problem solving approach

To advice Company X on a new on-board computer and software system and on who should supply it, the following framework is used for evaluation of the software and guidance during the process:

1. *Requirements definition*
2. *Preliminary investigation of availability of software packages*
3. *Short listing packages*
4. *Establishing criteria for evaluation,* with essential input coming from:
    a. Relevant articles from literature
    b. Managers from Company X involved in this project
5. *Evaluating software packages,* where the evaluation is done using:
    a. The Analytical Hierarchy Process (AHP)
6. *Selecting software package*

Boundary conditions and evaluation criteria

The shortlisting of packages is carried out using two boundary conditions:

1. Possibility to detach the navigation screen (coupled to the on-board computer)
2. Availability of charter application (the on-board computer software can be used by third parties as well)

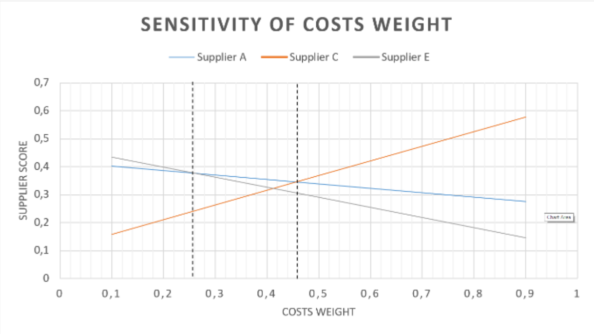
In addition, five main criteria and eight sub-criteria are selected to evaluate the possibilities:

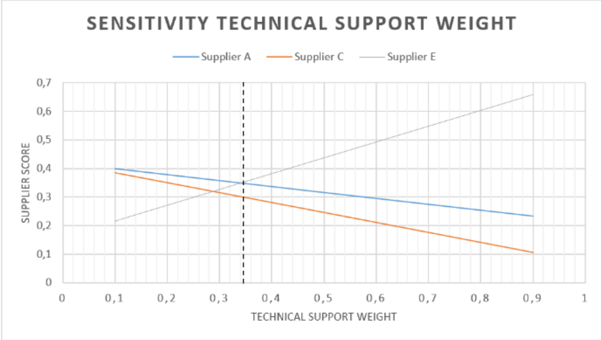
1. Costs
    a. Monthly subscription all vehicles
    b. Total hardware and installation costs
2. Implementation time of software
3. Fidelity of vendor
    a. Number of customers where the supplier installed their software
    b. Owners position of the company
4. Flexibility of software solution

    a. Ability to reprogram specific software parts to own needs
    b. Activation/deactivation of modules
5. Technical reliability
    a. Service centers throughout Europe
    b. Experience with software-as-a-service solution

Results using the Analytical Hierarchy Process
Using the evaluation criteria as central input for the application of the AHP, this yields the following results for the potential suppliers:

1. **Supplier A 0.356**
2. Supplier E 0.333
3. Supplier C 0.311





Based on solely the AHP result, the advice for Company X would be to take Supplier A as a supplier. To make sure this outcome is a robust solution, a sensitivity analysis is performed on all main criteria.

Only the criteria ‘costs’ and ‘technical reliability’ proved to be sensitive for the solution. The solution would change to Supplier C if the weight awarded to costs would exceed 0.460 (currently 0.392) and change to Supplier E if the weight awarded to technical reliability would exceed 0.345 (currently 0.312) or when the weight of the attribute costs decreases below the value of 0.260.

Final advice to Company X
The evaluation and granting of weights is done two times by the problem owner, therefore we assume that the current weighting is an accurate reflection of the problem owner his concerns about the decision problem. Therefore, as Supplier A scores equal or better on six out of nine lowest level attributes than Supplier E and Supplier C, the advice to Company X is to select Supplier A as their new supplier for the on-board computers and software system.

Recommendation for implementation
The introduction of the software system to the company should have some goals, where the following goals are recommended:

1. Raising awareness to all involved employees that Company X is changing from software supplier
2. Every employee knows what is going to change and what is expected from them within that change
3. How new functionalities can contribute to general goals and targets from the Business Unit Manager Transport

Kotter (2007) mentions in his article “leading change” eight steps that give transformation effort the best chance of succeeding. Three steps of them are as follows:

1. Forming a powerful guiding coalition
2. Creating a vision
3. Communication the vision

These three steps are useful to reinforce with the three goals of the introduction. The most obvious team is the ICT manager and Business Unit Manager Transport. This is because the Business Unit Manager Transport is responsible for the departments involved in this project. Furthermore, the ICT manager has the most technical knowledge and understanding about every functionality of the software system.

The vision needs to be created by the Business Unit Manager Transport and this vision can entail the goals and targets for this year and how the software functionalities can contribute to this. To create impact, this vision should be substantiated by how employees can actually achieve this vision and within which period.

Lastly, the vision created by the Business Unit Manager Transport should be communicated well to the employees. The goals of introduction can perfectly be used as content of the message.

Table of contents

1. Introduction

This research concerns the advice on the decision making for the investment on a hardware system and software system used in the trucks of Company X. The company from Company X which is addressed is Company X, which focusses especially on the transportation of goods itself. Next to the advice of what the hardware and software should comply with, it also concerns the advice on decision making for which supplier should supply it. To advice Company X on this, first I identify problems and I am taking a look at their operations that are related to the on-board computer and software system, searching for points of improvement. These improvement points together with desires from the manager of Company X are main input for the functional requirements of the hard- and software systems. Evaluation criteria will be established to assess different software suppliers. Literature research is then performed to determine which decision analysis method can be used to make a decision between different suppliers.

This chapter functions as introduction to the bachelor thesis. First, the company Company X is introduced in Section 1.1 and then I explain which companies are part of the Company X. Second, the reason for writing this thesis becomes clear in Section 1.2 and the core problem is identified in Section 1.3. The last sections of this chapter tell about how the problem is approached (Section 1.4), which deliverables the approach includes (Section 1.5) and what the limitations of this research are (Section 1.7).

1.1 Introduction to Company X

Company X has been dedicated for 65 years to transporting liquid foodstuff, only in bulk. Company X is responsible for multiple companies, namely Company X, Company X-I, Company X-II, Company X-III and Company X-IV. Company X (after this abbreviated to Company X) is one of the market leaders in transporting liquid foodstuff and does this by means of intermodal solutions. Intermodal transport means that during delivery of cargo from origin to destination, at least two transport modalities are used. During the transition between two modalities, the foodstuff remains in the loading unit and only the loading unit is transferred. The loading unit that Company X uses is a tank container.

Company X is divided into a few operational departments which are management Accounts & Telesales, management operations West Europe & UK, management operations East Europe and management of Multiple day Material Planning (MMP). Accounts & Telesales is responsible for maintaining relations with all clients. The West Europe & UK and East Europe departments are responsible for the Truck Container Planning (TCP). TCP is the planning of allocating trucks (and corresponding drivers) on the right moment to the right destination. Trucks are allocated in such a way that the lowest costs are obtained and the minimum number of kilometers is driven. The MMP allocates the right type of tank to an order, since not every type of tank is suitable for every trip (it is dependent on capacity, isolation, destination). MMP also determines the route for the tank container. Since the TCP is the most related to the physical process of the transportation of goods, during this bachelor assignment I am mostly active in the operational departments West Europe & UK and East Europe.

As this research is concerned with the purchasing of new hardware and software systems, here follows an overview of the currently used systems at Company X. Drivers of Company X need guidance from the operational department to know what their tasks are. Simultaneously, the department needs information about the driver or truck – information dependent and independent on the driver. Therefore, every truck is equipped with a few hardware products. First, every truck contains an *on-board computer.* This computer can track all kinds of data, such as vehicle speed, tire pressure, fuel consumption, idle time and so on. These data are stored independently from the drivers input.

Attached to the on-board computer (or mobile/removable), is a touchscreen/navigation screen. This is a small hardware unit, containing software as well, to be called a *navigation screen.* The function of this navigation screen is to enable communication between the driver and Company X their operational department, and to navigate the right route based on the incoming order as well. For example, a loading order can be sent from the department to the driver. He will receive it in his navigation screen and can reject of accept it. The department can also cancel an order.

In addition, Company X is working with a Transport Management System, called *Transfusion* (see appendix A for all entities that Transfusion includes). This is a kind of Enterprise Resource Planning system, but specially made and customized for transport. Transfusion takes care of registering transport orders, managing transport equipment and creating invoices. Also, it performs the route planning (by calculating optimal routes based on transport orders) and communicates (sending chats, or files) with drivers through the navigation screen. Transfusion is integrated with and linked to the navigation screen and the on-board computer.

The company that fabricates and designs the on-board computer and navigation screen, also delivers *fleet management software.* This is a software application which combines all collected data from the on-board computer and links the navigation screen. The functionalities of this fleet management software are quite diverse. Functionalities are overviews of subcontractors, interpreting statistics and real-time data of the fleets, overview of all vehicles, strong analytics and reporting tools, etc. During this bachelor assignment, this fleet management software will be referred to as *software system.*

Other hardware the truck contains is a *tachograph.* This is an instrument which records the driving times and resting times of the driver. The driver can only start the truck when he inserts his identification card in the tachograph. Companies need to deliver tachograph information to inspection agencies to deliver proof their drivers are complying with regulations.

Where communication from train and ferry terminals is outsourced for the biggest part, the whole process of allocation, distribution, communication and monitoring of road transport falls almost fully under the responsibility of Company X. Dispatching over more than 180 trucks around all active regions, transparency into all operations as well as monitoring them is key to maintain quality and open ways to improvement.

1.2 Research motivation

As mentioned above, on-board hardware and software systems are crucial to Company X operations given their high volumes and complex logistics. However, over the last ten years the functionalities of such on-board computers have improved a lot. The on-board computers and software system are currently supplied by Supplier C ICT solutions, but are not renewed or updated since many years. Company X is currently not making use of this progress, presenting an untapped opportunity for cost savings on fuel consumption, more control on the execution of transport and response time on updates about orders to their customers. In addition, the old systems have been an increasingly prominent source of problems for certain elements of the transport. Thus, the motivation for this research is finding the consequences in transport operations of Company X that follow from the outdated on-board computers and software system.

1.3 Problem Identification

As briefly mentioned in Section 1.2, the legacy on-board systems form a source of high costs and other problems. In this section, we explicate these problems and position them within the broader business context of Company X. In the first meeting with the Business Unit Manager Transport of Company X, a couple of problems were addressed that are currently present. To begin with, there is not enough control over truck drivers. This means drivers are not always driving the fastest route to a destination which results in extra kilometers, thus higher transport costs (because these costs are not calculated as higher prices for the customer, but taken as a loss). Another result from insufficient control of drivers is that they are not always getting gasoline at contracted gas stations. This results in higher transport costs too. Furthermore, the planning department does not have a full overview of driver behavior and whereabouts. Because planners at Company X do not have information such as how many hours drivers are still allowed to work (important to obey, with strict regulations) or if they are on schedule, they cannot allocate trucks optimally. In addition, when clients request information about the cargo they cannot be informed due to lack of information about the estimated arrival time. Besides, turnover of truck drivers is high and the instruction is not optimal.

1.3.1 Problem Cluster

Based on conversations with the Business Unit Transport Manager and employees from the departments West Europe & UK and East Europe, a list of problems is made. All these problems are mapped in a problem cluster. A problem cluster gives the cause and effect relations between problems (Heerkens, 2012). Potential core problems are problems that cause other problems, but do not have a cause themselves (Heerkens, 2012). These can be identified in a problem cluster. See the problem cluster in Image 1.1 below.

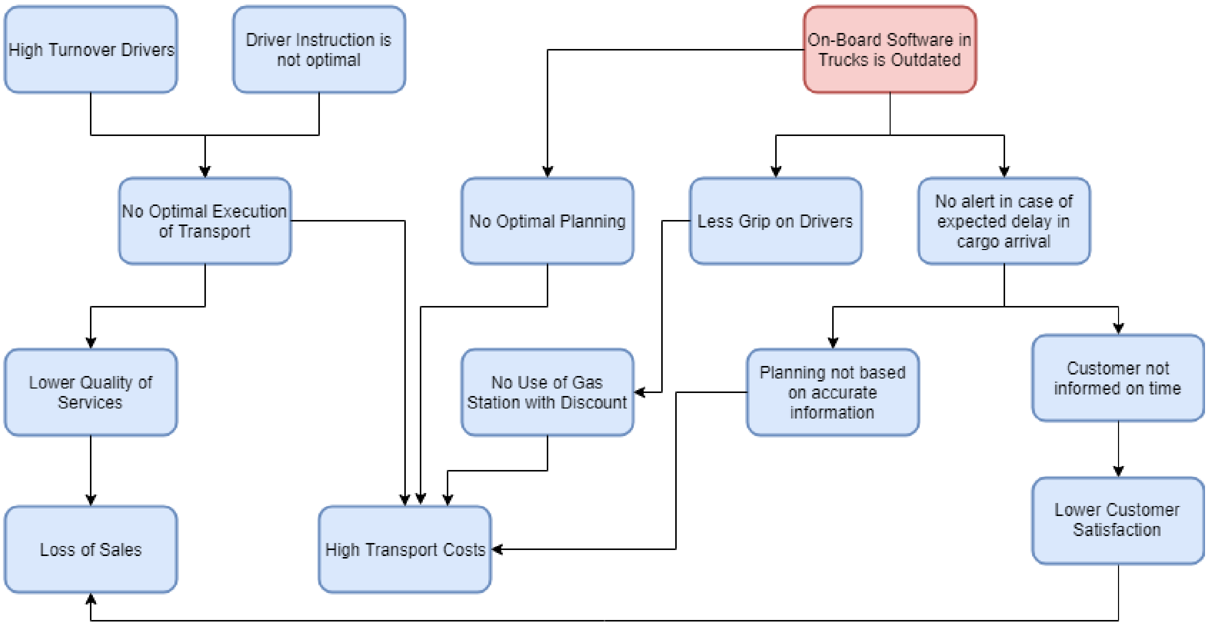


IMAGE 1.1 PROBLEM CLUSTER SITUATION COMPANY X

As can be deducted from the cluster graph (which is made under supervision from the Business Unit Manager Transport), there are three potential core problems. These three problems are briefly discussed.

High turnover of drivers

This is a problem which is causing no optimal execution of transport. There can be many reasons for high turnover. For example, it could be caused by Company X (bad working conditions) as well by the drivers (violating rules, bad driving behavior or personal circumstances).

Driver instruction is not optimal

Certainly, with high turnover of drivers, a good driver instruction is crucial. How are new drivers trained? How are they instructed? What are the differences in different countries? If there is miscommunication between drivers and other departments in a transport company this will only contribute to an even lower quality of execution of transport.

On-board computers and software of trucks are outdated

With trucks being away from the company, communication and overview is key. The whereabouts and status updates from cargo vehicles must be transparent for all operations to be integrated and executed in the desired way. Currently, this is not the case since Company X is working with an outdated on-board software system.

1.3.2 Core problem and motivation

Now that three potential core problems have been identified, the next step is to decide on which problem is the most effective one to solve. This is done by using an Impact/Effort matrix. The Impact/Effort matrix gives quick insight in how much effort one of each potential core problems will take to solve and how much impact it will have once it is solved. The cell with "high" in the impact column is marked green, because solving the problem has a big impact which is positive. The cell with "high" in the effort column is marked red, because it takes a lot of effort to even solve the problem.

From the three potential problems categorized in Table 1.1, the outdated software system is the most influenceable problem. In addition, this is the problem being the source for most of the other problems. The software system is integrated with multiple departments, which result in a big part of the company affected when the software system is outdated. Because the outdated software has high impact but requires medium problem-solving effort, the outdated software system is the core problem and will be addressed.

Potential Core Problems	Impact of problem solving	Effort of problem solving
High turnover of drivers	Medium	High
Driver instruction is not optimal	Medium	High
On-board software in trucks is outdated	High	Medium

TABLE 1.1 IMPACT/EFFORT MATRIX OF POTENTIAL CORE PROBLEMS

When research is performed, Heerkens (2012) makes a distinction between a *knowledge problem* and an *action problem.* A *knowledge problem* is "a description of the research population, the variables and where necessary, the relationships being investigated." In this case there is need for information. An *action problem* is "A discrepancy between the norm and reality observed by the problem owner." In this case, things are not going how they should, and there is need for action to change the reality towards the norm. This distinction from Heerkens (2012) is useful, and will be used by setting up the research of this thesis.

The core problem, which is an action problem, is formulated as follows:

Company X must decide on a new on-board computer and software system

Therefore, this action problem has a norm and a reality. The reality is that Company X does not know which hard- and software system they want and which supplier should provide that solution. The norm is that Company X should know what hard- and software system they want to invest in, and which supplier best suits this solution.

1.4 Problem Approach

Now that the action problem is clear, we must choose an approach on how to solve it. This approach serves as a structure for our research methodology, and the remaining chapters of this thesis all cover one individual component of the approach. The goal of the research is to advice Company X on decision making for their new hard- and software system. The problem approach is divided in four phases:

1. Problem analysis
2. Alternative decisions
3. Decision
4. Recommendations for implementation

In Image 1.2, you can find how the overall approach is divided into different phases. In the next sections, each phase is explained in more detail.

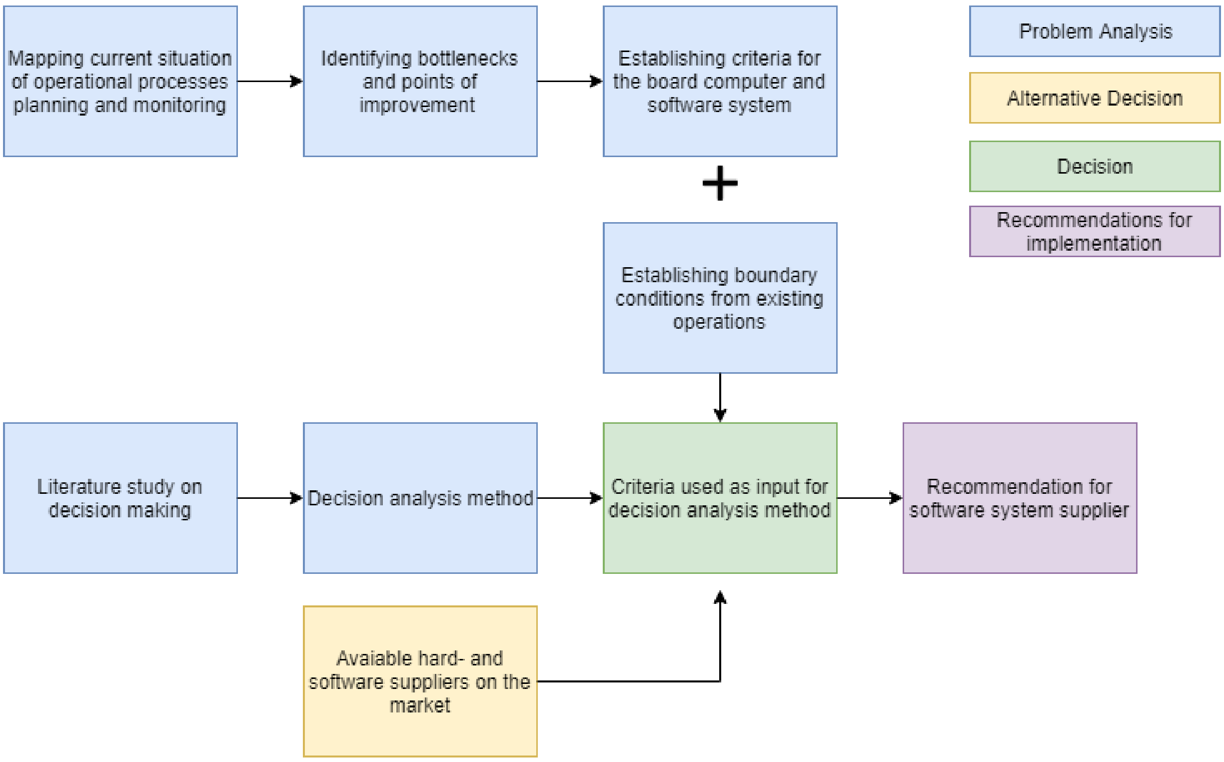


IMAGE 1.2 VISUALIZATION OF THE PROBLEM APPROACH

1.4.1 Problem Analysis

The goal of the problem analysis is to create a better view of what it takes to make a well-founded decision for the problem owner. The final goal is a recommendation for a new hard- and software system. Therefore, it is important to know which business processes rely on the on-board computers and software system. The on-board computer hardware and software system are especially used for the TCP planning. Since the on-board computer collects all kinds of data from the transport process, what Company X is monitoring is related to this as well. So, to give Company X advice on this decision, I first need to map operations of planning and monitoring to understand what level the current functionalities of the on-board computer and software system are performing. Accordingly, Chapter 2 will answer the following knowledge questions:

2. The current situation of transport planning and monitoring of operations at Company X

a. What does the Truck Container Planning of West-Europe & UK and East Europe look like?
b. What do monitored operations at Company X look like?

To see what can be improved, a good description of current operations is needed in the first place. To map both the planning and monitoring operations, the following employees are approached:

- Two employees from planning West Europe & UK
- Two employees from planning East Europe
- One technical employee (knowledge of current on-board computer)
- One ICT employee (knowledge of back-office platforms)
- One employee from monitor department (i.e. gas fuel monitoring)

Because all employees are working daily in their specific department, they can provide the right information. But how much information is needed and to what extent do sub questions a and b need to be explained?

The planning process needs to be understood on the following aspects:

- On what criteria trucks are allocated to a new order
- At what moment new trucks are allocated to new orders
- If and how the daily and weekly schedules are adjusted based on incoming job activity status
- What real-time information planners need from each operating truck

The operations that are monitored need to be understood on the following aspects:

- What data is collected and analyzed
- In which/how many cycles they monitor
- Based on what information they act to improve
- What key performances of transport currently are not monitored

1.4.2 Formulating alternative decisions

Once current operations are mapped and described, we have to identify what can improved and what is currently missing in information provision to perform operations in an optimal way. This is done in Chapter 3:

3. Boundary conditions and evaluation criteria for the on-board computer and software system

a. What are shortcomings of the Truck Container Planning of West Europe & UK and East Europe?
b. What are shortcomings of the monitored operations?
c. How can the on-board computer and software system be evaluated?
d. What are the boundary conditions and evaluation criteria?

Questions a and b are knowledge questions, because there is need for information that is unknown. Questions c and d on the other hand are action problems since they involve choice about what approach for evaluation we must choose. These questions build upon Chapter 2. If the shortcomings are determined of current operations, this is key input for the boundary conditions and functional requirements for the on-board computers and software system.

A boundary condition is a functional requirement or other criterion which the software system *must meet.* Evaluation criteria are criteria where the software system supplier will be judged upon. The list of boundary conditions and evaluation criteria is proposed to stakeholders, and drawn up together with stakeholders of Company X, before finalizing the list.

But what suppliers are available on the market? And what are their specific offers regarding on-board computers and software systems? What are the differences between these companies? These questions will be answered in Chapter 4. The goal of the chapter is to get a picture of what suppliers can help Company X with a solution and how they score upon evaluation criteria. This starts with an introduction of all companies (question a) describing about their reach in Europe or worldwide, how long they are active on the market and what clients they currently have. This is followed by the assessment on boundary conditions and scoring on evaluation criteria for each supplier.

4. Possible on-board computer and software system suppliers for Company X

a. Which software suppliers are available on the market?
b. Do the software systems of the suppliers meet the boundary conditions?
c. How do the suppliers score on the evaluation criteria?

1.4.3 Decision

Now that the problem is fully analyzed and the potential solutions have been identified, there is sufficient information for making the final decision on which system to choose. To make a structured decision, we need a framework or method to structure this. Literature research is done on Multi Criteria Decision Analysis (MCDA) methods in Chapter 5. Chapter 5 answers the following questions:

5. Literature Research

a. What multi criteria decision analysis methods can be found in literature?
b. Which multi criteria decision analysis is selected?
c. How can a sensitivity analysis be performed?

From these three sub questions, a and c are knowledge questions but b is an action problem since there must be decide upon something. First, the MCDA methods from literature are discussed and explained. Once the characteristics are clear a comparison is made based on their advantages and disadvantages. The last question is answered using a systematic literature review. Here the knowledge question is answered using articles. All information is acquired from the database Scopus, Google Scholar or Web of Science and possibly from literature books about decision making. With a systematic literature review, key theoretical concepts are defined to arrive at useful search strings. Inclusion and exclusion criteria are then defined and for all articles that are included in the end, a conceptual matrix is made. In this matrix findings from each article are summarized and you can see in one glance what the common concepts between articles are.

The selected method is applied and evaluated in Chapter 6, where the following sub questions are answered:

6. Using a decision analysis method towards a software system supplier decision

a. Which attributes comprise the complete decision problem?
b. How does the problem owner weight the attributes?
c. How robust is the decision?

Chapter 3 is used here as an input for the attributes and to create a hierarchy needed to analyze the decision problem. Another key input comes from the problem owner at Company X. This problem owner is asked to determine the relative importance of all attributes that are involved in the decision problem. This is done via a face-to-face interview.

All sub questions from Chapter 6 are action problems, because they all involve choice. For the first question, we must decide how to convert functionalities into attributes and for the second how the problem owner assesses the relative importance between attributes. In addition, the way the sensitivity analysis is set up depends on the result of the most preferred supplier and involves choice.

The filled in responses of the problem owner on the attributes are analyzed and used in the decision analysis method selected from literature study. Applying the MCDA method, this will result in a preference for a software supplier.

1.4.4. Recommendations for implementation

The new on-board computers and software system will have impact on the operations and require change. Think about different interfaces or job functions that will slightly change based on the new software system. Chapter 7 gives an overview of what changes will take place and how Company X can introduce this to their employees. The recommendations for introduction will consist of how certain people need to be informed, who needs to give a (plenary) presentation about the new software and what is going to change for the employees.

7. Recommendations for implementation

a. What impact does the new software have on Company X?
b. How can the new software be introduced to Company X?

1.5 Deliverables

The deliverables that need to be included in the final report are closely related to the problem approach. Every step towards the advice of a software system decision has some deliverables. See Table 1.2 below.

	Deliverables
	▪ Description of the relevant TCP planning processes and monitored operations at Company X ▪ Description of points of improvement regarding the current situation at Company X ▪ A list of boundary conditions and evaluation criteria for the new software system ▪ A recommendation and justification on choice for a new software system supplier ▪ Description of attention points of implementation

TABLE 1.2 DELIVERABLES OF FINAL REPORT

1.6 Research Design

This section clarifies how the problem approach is executed and how data is gathered and analyzed.

Qualitative data analysis

By means of interviews qualitative data is gathered to get an indication of the current situation of planning and monitoring of operations at Company X. In addition, the problem owner (Business Unit Manager Transport) is interviewed by means of a short survey to obtain his preferences to and between certain attributes and objectives of the decision problem.

Quantitative data analysis
The preferences towards certain attributes and objectives (qualitative data) are converted to quantitative data to perform calculations in the decision analysis method. The sensitivity analysis included in the decision analysis will be using quantitative data as well, which will be calculated using Excel. In addition, some data on fuel monitoring (fuel consumption and the gasoline bought at different gas stations) might be used to look for points of improvement in terms of cost reduction. This data is gathered from the database of Company X.

1.7 Scope and limitations of research

The whole process from the first initiation to search for a new software system to the full implementation and integration of the system is long and broad. The first part of this process already happened, which means that Company X did some market orientation for software system suppliers. The scope of this thesis will focus on two aspects:

1. Problem identification within departments that are related to or depending on the software system
    a. The departments West Europe & UK and East Europe (responsible for planning and operations monitoring) are core departments since this relates most to Company X as transport business, and is therefore emphasized more in research compared to other departments
2. Finding a well-structured approach to the decision-making process of a new software system

Although advice on implementation of the software system will be given, the real implementation and evaluation is out of the scope of this research. After deciding upon a new software system other phases such as contracting, supplier negotiation and implementation follow. Again, this is not part of the research and Chapter 7 (implementation) of this research takes into consideration that by the time the software is ready for implementation, advice from this thesis could be inaccurate due to changes in the company.

1.8 Stakeholders

There are several stakeholders that are involved in the process of choosing new hard- and software. One of the stakeholders is the Business Unit Manager Transport, which is also the problem owner. He is the problem owner because is responsible for the departments mentioned in Section 1.1. His goal is to make an investment which will solve all current problems, improve the control of operations and find a supplier who is a good client for Company X the upcoming years. Other stakeholders are employees from the department West Europe & UK and East Europe. These employees are working with the software daily. They want the new software system to make their operations more effective and give them full transparency and insight into the whole process of transport, such that allocating drivers to orders can be optimized.

2. The current situation concerning transport planning and monitoring at Company X

In this chapter, we are taking a closer look at the operations that are related to, and work with the on-board computers and corresponding software. The reason for describing the planning and monitoring operations is to understand what performance the on-board computer and software are currently delivering and find possible points for improvement. First, the Truck Container Planning process (TCP) is explained in Section 2.1. Next, we focus on what operations are monitored at Company X in Section 2.2. Last, in Section 2.3 we explain how the employees are approached and which employees to collect the needed data.

2.1 The Truck Container Planning of West Europe & UK and East Europe

The operation that proceeds before TCP is Multi Days Material Planning (MMP). This operation allocates the tank container to the right order. Subsequently, it determines the routing the tank container should follow to arrive at the right time, for the right price. The transportation planners are currently using a Transportation Management System (TMS) called Transfusion. Their responsibility is connecting all incoming orders to truck drivers.

In Transfusion, planners have a list of orders that are agreed on with customers (these orders, with their descriptions, are sent from MMP to TCP). The task of the planners is to meet demand. To schedule orders, they proceed as follows:

1. Checking the order specification, for whether the transported product requires a pump or compressor to unload it from the tank container. In some cases, the customer already has the equipment to unload such that neither is required.
2. Checking if the goods that need to be transported are labeled ADR, indicating they are dangerous goods (e.g. pure alcohol). If this is the case, an ADR tested truck and driver with ADR certificate need to be made available in the planning.
3. Connecting an order to the right driver and the right type of truck. In Transfusion, planners see which drivers are available and on which truck they are currently driving. Based on this, the planners make a choice which truck and driver they allocate to an order.
4. Checking the destination and corresponding distance to make an estimation of the time duration of the trip. To get a better estimation of the whole duration, planners add the required resting time of drivers. In addition, they make an estimation for the other activities that are included in the trip such as loading, unloading and cleaning the container. The Transfusion database contains historical data for indications of those time durations, but as planners have to manually search for this, in practice they usually end up simply making a rough estimate.
5. Determining the finishing time for the whole trip.

In the following diagram, this process is visualized.

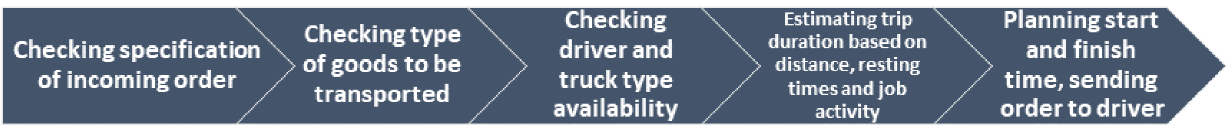


FIGURE 2.1 VISUALIZATION OF TRUCK CONTAINER PLANNING PROCESS

What criteria are used to allocate drivers?

While scheduling all orders, there are a couple of things that employees have to keep in mind. These criteria affect the decision of which driver they connect to a certain order. It is important to highlight these criteria, because this is currently done manually but there might be a possibility to automate this.

1. Maximum driving hours per driver, based on government regulations and restrictions
2. Drivers must return to rest areas after they fulfilled their shifts
3. For all trucks that are not owned by Company X but hired from third parties, there is an agreement on minimum hours they have to be used. Planners have to pay attention to this when scheduling orders

On what dispatch information do planners depend for keeping the planning a continuous process?

To be sure if drivers are running on schedule, some information needs to be known. In addition, updates about job activities (loading, unloading, cleaning) are necessary to act if something is going not according to schedule. Therefore, planners should be provided with the following information.

- Updates on traveled kilometers
- Updates on job activity (loading, unloading, cleaning status)
- Updates on start of loading/unloading
- Overview of available equipment

This information is available for planners and they request this information in the TMS.

2.2 Monitored operations at Company X

In this section we discuss which operations are monitored. Monitored operations are operations of transport where Company X is collecting data from. After the execution of the operations, the collected data is analyzed to see if they are performing at the preferred level. The following things are monitored at Company X:

1. Fuel consumption
2. Refueling at contracted gas stations
3. Key performance indicators

Fuel Consumption

Company X is monitoring the fuel consumption of their drivers (see appendix A, Figure A.1). Trucks are not very sustainable on fuel consumption, therefore Company X tries to optimize the driving behavior of drivers on this respect. To monitor this, they collect the following data of trucks:

1. Distance driven
2. Time driven
3. Average speed
4. Percentage of time driving cruise control
5. Stationary time (number of minutes the engine is working without vehicle driving)
6. Maximum speed (the highest speed over the whole trip)
7. Fuel consumption

In addition, they have an overview of fuel consumption per country (Poland, England and Netherlands). In Figure A.2 in appendix A the vertical axis shows the number of kilometers driven per liter gasoline and the horizontal axis shows the week number.

On what information do they act to improve?

As mentioned, Company X collects the information described above. However, not all these factors related to fuel consumption are influenceable. For example, the distance driven is just the distance the driver has to drive to deliver the order. Company X controls the output specifically of the following collected information:

1. Cruise control
2. Tire pressure
3. Stationary time
4. Engine acceleration

Company X analyzes these outputs because they have direct impact on the fuel consumption. Cruise control reduces the fuel consumption of trucks because drivers do not have to accelerate and decelerate. This is not possible on short or hilly highways, but it is possibly on long and flat highways. The lower the tire pressure, the more resistance the truck will experience with the highway thus the more fuel it will consume. Stationary time means the percentage of time the engine is running while the truck is not driving. For some job activities, such as loading or unloading the engine needs to be running but it is important that the driver is keen on minimizing stationary time. Last, good driving behavior means being aware when to and when not to accelerate. This could be improved by focusing on what other cars in front of you are doing, so you do not have to brake extremely hard at the last moment.
If a driver scores abnormally negative on one of these four indicators, Company X emails the responsible driver with an overview of their scores such that the driver will become more aware of his driving behavior.

Refueling at contracted gas stations
Company X has contracts with Shell, such that they can get gasoline at certain contacted locations with discount. Shell has a service, called Shell alert, which contacts Company X if drivers are getting gasoline at non-contracted gas stations. For Company X this causes a problem, since discount on gasoline is quite important with gasoline being one of the company's largest expenses. Company X monitors the list with an overview of non-contracted gas stations (see appendix A, Figure A.3) where the responsible driver is mentioned and the liters of gasoline he got at the station as well. If the same driver picks non-contracted gas stations repeatedly, Company X contacts him and asks him what the reason was. Furthermore, in the on-board computer the driver always has to justify getting gasoline, including entering the place of the gas stations and the amount of gasoline. This way, also non-contracted, non-Shell gas stations are noted.

Company X made an instruction guide for drivers explaining where contracted gas stations are located. It is their responsibility to monitor their fuel level and think ahead what could be the best place for refueling.

Key performance indicators
The core operation of Company X is transporting liquid foodstuff from one place to another. To do this, first the foodstuff should be loaded somewhere and subsequently, delivered to its destination which is the customer. Company X uses the following indicators to check at what level their core operations are performing:

1. Revenue per truck
2. Loading performance
3. Delivery performance

These Key Performing Indicators (KPI) are divided into different sectors, namely Intermodal (IM), United Kingdom (UK) and Modal (MOD, see appendix A, Figure A.4). For every sector there are three columns, which are Actual (ACT), Last Year Result (LYR) and Target (TGT).

The KPI revenue per truck is assessed based on two things. The first is simply the amount of revenue that Company X makes delivering the order. For each trip, the truck has a pre-determined norm for the revenue it should make. The second one is the percentage of driving with a loaded container (traveled distance with loaded container divided by the total travel distance to deliver the order). Company X gets paid in relation to the occupancy rate of the truck. There is a norm for the percentage driving with a loaded container as well, which is an average of all percentages of trips based on one day. If a specific trip has a percentage of driving with a loaded container above the norm and the revenue of the truck is above the norm, it is marked green. Otherwise, it is marked red.

It is important that drivers load the cargo on time. The TCP department makes time schedules for every job activity of drivers, including loading. When drivers do not meet the agreed loading times, the consecutive orders will be delayed as well, resulting in a lower customer satisfaction. Loading performance is divided into *on time performance*, which simply counts how many times the goods are loaded at the client on time, and *quantity performance,* which counts how many times the right amount of content is loaded (see appendix A, Figure A.5).

The last KPI is delivery performance. This is assessed in the same way as the KPI loading performance; in *on time performance* and *quantity performance.* However, this KPI is more important than loading performance. It is possible that there is a lot of time scheduled between loading and delivering it at the customer. Therefore, being late loading the goods could still mean the customer could be satisfied, delivering the goods within the agreed time frame.

Company X can only monitor the key performance indicators if the right data is collected. Data is collected by the on-board computer in the truck and by data carriers (such as a thermometer in the container).

2.3 Data and information collection

To collect the quantitative and qualitative data to form Chapter 2, multiple employees from several departments were approached. To set a meeting with every employee, I approached the Business Unit Manager Transport first to ask whom to approach for specific information for example about the TCP. The meetings with employees lasted from half an hour to two hours.

During these meetings, most of them were working while I was having a conversation with them. In that way they could demonstrate how things worked directly after I asked something. All employees were very helpful to cooperate with all questions. The communication approach was face to face. The biggest part of the questions were open and broad questions, somewhat exploratory. This was because the goal was to get a picture of the Truck Container Planning process in the best way. With employees of the TCP I had multiple meetings, and after the first meetings the questions were more deep than broad.

The information gained from meetings with employees were partly opinions, and partly facts. For example, some employees were asked what functionalities the new software system should have to make the TCP process even more efficient or what they can really use. This information is an example of opinions. On the other hand, during the meeting with the employee from the department of fuel monitoring rather facts about the monitoring process were given and facts about statistics of performance on fuel consumption. See the appendix B1 for a list of the people that provided information and the questions I asked them.

2.4 Conclusion current situation

In this chapter a picture is provided of the key operations from Company X and the operations that include data collection and analysis. In addition, it is clear how the TCP *process* works and how it depends on the software and hardware system. This information is useful for setting up the functional and non-functional requirements for the hard- and software system. In Chapter 3, we reflect on the way current operations are performed and discuss what parts can improved.

3. Boundary conditions and evaluation criteria for the on-board computer and software system

Now it is clear how planning and monitoring operate at Company X, we should investigate what the new on-board computer and software should comply with. A boundary condition is a functional requirement or other criterion which the software system *must meet.* Besides boundary conditions, the software system and the supplier supplying it need to be evaluated on multiple aspects. Therefore, *evaluation criteria* are established to evaluate the suppliers. So, this chapter starts with looking critically to the current operations and raise the question, what can be improved? What functions could make Company X operate in a better way? This is discussed in Sections 3.1 and 3.2. After, a framework for evaluation is introduced in Section 3.3. The boundary conditions and evaluation criteria are set up to assess different software packages and suppliers. In short, the goal of this chapter is to provide a complete approach for the requirements of the software package and how to evaluate it.

3.1 Shortcomings of the TCP of West Europe & UK and East Europe

In Section 2.1 we discuss how planning is executed at Company X. We will now discuss what parts of the process are not transparent for planners and require improvement or change that could be realized by functionalities of the on-board computer and software system. In Figure 3.1, the planning process is visualized and highlighted in which phases problems occur. All problems identified are included for consideration, because they might give insight in the functional requirements of the software system.

FIGURE 3.1 IMPROVEMENT PHASES TCP PROCESS

The TCP process consists of five phases, where the phases where problems occur are indicated with a red exclamation mark. The third phase of the TCP process, checking driver and truck type availability, is something that could be improved. *Availability* means the number of hours Company X can deploy drivers. The government has determined maximum *driving times* (in hours) for Europe, which are the following:

▪ Maximum consecutive driving period	4.5
▪ Maximum daily driving time	9 (10 hours two times each week)
▪ Maximum weekly driving time	56
▪ Maximum two-weeks driving time	90

In addition, the government determined *resting times* (in hours) for Europe, which are the following:

▪ Minimum daily rest	11
▪ Split rest daily	9 + 3
▪ Minimum shortened rest	9 (allowed three times a week)
▪ Minimum weekly rest	45 (uninterrupted)
o One time every two weeks allowed to shorten to 24	

When employees are checking driver availability, they do not have an overview of driving and resting times per driver. The consequence of this lack of overview is twofold:

1. Drivers are scheduled for certain orders, but this order will exceed their allowed driving time. After the planner sends the new schedule to the driver, the driver informs the planner this planning is not feasible. The schedule needs to be adjusted, which is a waste of time and the additional communication can be confusing.
2. Planners schedule drivers with too much margin, because they do not know the exact amount of remaining driving time. This results in a low occupancy rate of drivers, which means Company X miss out on revenue (because every hour that drivers *are* scheduled, will produce more revenue).

The software packages currently available on the market can give overviews of resting and driving times per driver. This shows the number of hours the driver is still allowed to drive. This solves the problem occurring in phase three.

The fourth phase of the TCP process concerns scheduling the time of the whole order. To determine the time for the whole trip, time estimations must be made for each part of the trip. The main problem is that these are estimations, and can deviate a lot from the actual time it takes. Of course, the more the planning converges to the actual times (when real-time information is used) the better the planning will be, and working with estimations gives the following problems:

1. When estimations are too large, more orders could be executed in the same amount of time
2. When estimations are too tight, the driver will not make it and the planning is delayed or the customer will not have his goods on time

Current software systems can calculate the *expected time of arrival (ETA).* This software uses the location of the truck, the driving speed *and* live traffic information. In addition, they include the required resting time for the driver to calculate the ETA. This change would improve the current operations, resulting in a more accurate planning and optimal usage of time. Singh & Singh (2014) indicate that real time fleet management refines scheduling parameters to tighten up planning for greater consistency and improved fleet management efficiency.

3.2 Shortcomings of monitored operations

In Section 2.2 we discussed what operations are monitored. For each section of that chapter, we are now reviewing what could be improved and how the new software package could play a part in that improvement.

3.2.1 Fuel consumption

The data Company X is collecting about fuel consumption, is about all the data that can be collected. Therefore, there is not a lot of space for improvement on this part. However, when talking about analyzing the data and reviewing it, there could be improvements. Company X exports all data in an Excel sheet, where they calculate averages and mark numbers below or above the threshold value manually. New software has a function called “Driver Scorecards.” This is a dashboard giving an overview of the performance per driver, using the same data points as described in Section 2.2.1. To calculate scores, you can give each data point (such as idle time or number of brakes) a weight. You can also determine when scores of drivers need to be highlighted, for example when they deviate 10% from the average of all drivers. This makes monitoring easier, seeing in one glance if the driver is performing below standards. This driver scorecard has the feature as well to work with alerts, when standards are not met. Therefore, the driver scorecard functionality could be added to the functional requirements since it will certainly improve the effectiveness of operations.

3.2.2 Refueling at contracted gas stations

Monitoring where drivers are refueling is important, because it can reduce the expenses of Company X a lot. Kovács (2017) states that one of the ways the optimal operation of transport routes can be attained, is the reduction of fuel costs of the transport tasks. In particular, refilling the optimal amount of fuel at the optimal gas station. How can this be improved? There are many ways this can be improved, for example by raising awareness of drivers, giving them notifications from time to time indicating where the optimal petrol stations are located. There is a more technical solution, where the on-board computers are involved. The fuel level of the truck is always measured (by sensors). New software is capable of inserting "landmarks" in the navigation of the on-board computers. These landmarks are in this case the preferred gas stations that have agreements with Company X. New on-board computers can make suggestions for routing to gas stations, giving alerts when fuel gets low so the driver is always ahead. In this way, drivers just have to follow instructions from the on-board computer and the number of "mistakes" (getting fuel at non-contracted gas stations) could be decreased significantly, resulting in a big cost reduction. Company X estimated the costs made by not getting discount at fueled gas stations in 2017 around 60.000 euro's. Of course, even having this new functionality this amount probably will not be reduced to zero, but the costs can be reduced for a fair amount.

3.2.3 Key performance indicators

Points of improvement for monitoring the KPI is similar to those of the fuel consumption. The data points that are collected *are* complete and there is no data that is important to have but that cannot be collected currently. However, the visualization of the collected data could be improved and better dashboards are available which can improve the effectiveness of reviewing the KPI.

3.3 Evaluation framework for the on-board computer and software system

Now that planning and monitoring operations are investigated at Company X and their points of improvement are clear, it is time to focus on the hard and software package itself. Jadhav & Sonar (2011) suggest a framework for evaluation and selection of software packages. This methodology is intended as guideline or aid that can be adapted according to requirements of the individual organization. The evaluation framework consists of six stages:

1. *Requirement definition.* Identify functional and non-functional requirements of the software
2. *Preliminary investigation of availability of software packages.* Investigations of suitable candidates.
3. *Short listing packages.* Elimination of candidates that do not provide essential functionalities or do not work with the existing hardware, operating system, data management etc. Criteria related to vendor or price can also be used for elimination.
4. *Establishing criteria for evaluation.* Criteria to be used for evaluation of the software packages are identified and arranged in a hierarchical tree structure format. Each branch in the hierarchy ends into a well-defined and measurable basic attribute.
5. *Evaluating software packages.* Metrics are defined and weights are assigned to each basic attribute in the criteria hierarchy.
6. *Selecting software package.* Rank the available alternatives in descending order of the score and select the best software.

The first stage is carried out in the next section. Stage two is already done by Company X. The candidates which Company X is in negotiation with are introduced in Chapter 4. In Chapter 4 the short listing is done as well, by means of boundary conditions (also known as knock out criteria). The boundary conditions are derived in Section 3.3.2. Stage four, establishing criteria for evaluation, is done in Section 3.4. After the criteria for evaluation are clear, the metrics to score them are derived in Section 3.4.1. Stages five and six are carried out in Chapter 6, where by means of a multi criteria decision analysis *method* founded in literature the evaluation and selection is performed.

3.3.1 Requirements of the hard- and software system

Company X must have a clear picture of the functional and non-functional requirements of the hard- and software. All requirements are listed per category in appendix C. This list is established through a combination of requirements that are derived from shortcomings (explained in Sections 3.1 and 3.2) and for the other part through input by employees of Company X. From employees of Company X, most input is coming from the ICT manager. This ICT manager has the most knowledge of how the software is currently operating and what it should take to implement the new software. The more practical input comes from the Business Unit Manager Transport. The Business Unit Manager Transport discusses logistical problems currently playing with the ICT manager, so he can come up with the functions required to solve those problems. For example, customers of Company X need to be informed on time regarding changes in the delivery time. Singh & Singh (2014) explain fleet management software can automatically pre-advise customers of an updated delivery time when the vehicle is an agreed number of minutes away. This is generated by a function called *geofencing.* As the name suggests (geographically fencing), this function enables Company X to pick a point on the map which is fenced by a circle with a pre-determined radius. When the vehicle enters this "fence", Company X gets an alert. Geofencing is included in the functional requirements.

Kovács (2017) states fuel cost is the highest cost among the cost components of transportation. This is also the case at Company X, where fuel costs and truck driver salary are the two highest variable costs. Therefore, it is significantly important fuel monitoring functionalities are included in the requirements for Company X to reduce their operational cost from this perspective. What is also important to add is the functionality estimated arrival time. Witte & Wiegmans (2013) state that one of the managerial bottlenecks in intermodal freight transport is estimated arrival time.

Derivation of the functional requirements for the software package is useful for Company X. However, besides evaluating the software system on their functional requirements by means of boundary conditions, the suppliers themselves need to be evaluated on certain aspects as well. These aspects are considered establishing evaluation criteria in Section 3.4.

3.3.2 Boundary conditions for the hard- and software system

Some requirements of the software package can be decisive for whether Company X want to continue with a supplier or not. Below the boundary conditions of the hard- and software system are discussed.

Boundary condition 1 Detachability and mobility of the navigation screen

The navigation screen can either be attachable and detachable in the truck, having the shape of a tablet or it can be built into the car. In the latter case, the truck driver can only work with it behind the wheel. Why is this important and what advantages does a detachable navigation screen have? The detachable device, which also has a camera in the back of the device, has the following two advantages:

1. Possibility to detach the device to make pictures of incurred damage on the truck such that it can be send to the administrative department of Company X
2. Possibility to detach the device to make a digital scan of the CMR document

The trucks of Company X run damage occasionally. The insurance company demands Company X to report damage within a certain amount of time. However, the manual process for doing this consists of a lot of steps. The driver has to report the damage, fill in a damage report, send it to Company X and then Company X has to declare the damage to the insurance company. Having this mobile device with camera, the driver can just make pictures of the damage on the truck and send it to Company X which will speed up the administrative process and reduce the chance of not meeting the damage report deadline.

Secondly, truck drivers are holding a CMR document ("Contrat de Transport International de Marchandises par Route", which constitutes a proof of the contract of carriage by road) which they need for shipping goods across borders. These documents have to be returned to Company X after drivers complete their shipping. Drivers need to handle the documents with caution, because they have to pass it through to the next driver driving the vehicle. However, when the device is detachable and has a camera the driver can just make a digital scan of the CMR document and send it to Company X.

Boundary condition 2 Availability of charter application

A charter truck is a truck from a third party where Company X is outsourcing their trucking. Company X works with a substantial number of charters, therefore it is important that their software solution is also available on a charter app. With a charter app, the third party can just install the application of the software Company X is using as well, such that they can be seamlessly included in the operations of Company X. All third parties that Company X works with has hardware which can make use of the software that Company X is using. What if the supplier does not provide the functionality of a charter application? That would mean Company X have to build additional hardware (which works with Company X their software) in those charter trucks. This is very inefficient, since they have to be built in the truck and removed again when Company X is not using the charter trucks anymore, leaving Company X with underutilized on-board computer hardware.

Thus, these are the two criteria the potential supplier *must meet.*

3.4 Criteria and sub-criteria for the evaluation of the software package

Besides boundary conditions that are essential from Company X their perspective, there are also requirements or aspects that each supplier will meet, but to a different extent or a different quality. These are thus criteria where suppliers can *score* upon differently. The aspects that are important when evaluating a supplier, besides the product itself, are now discussed. The main criteria are derived in one of the following two ways:

1. Input from the managers at Company X
2. Based on articles from literature, applicable to Company X' situation

Criterion 1 **Costs**

With a new investment, one of the most important criteria is, of course, costs. The two types of costs, being the monthly subscription costs for all vehicles and installation costs, constitute the sub-criteria. The reason for dividing the costs into two sub-criteria is that one part of the costs is a one-time investment while the other costs are charged monthly for a longer period. Company X is always looking to minimize their costs, as well in this case of the investments and monthly costs.

Sub criterion 1.1 Monthly subscription all vehicles

All suppliers Company X is negotiating with are working with a monthly subscription cost model. This consists of a basic monthly subscription cost and additional costs for more specific services. For most of the suppliers, monthly subscription costs per vehicle are the sum of individual components that can be included or excluded as a service such as driver style feedback, message traffic or truck navigation.

To evaluate the suppliers on this criterion, the same number of components are selected from each supplier.

Sub criterion 1.2 Total hardware and installation costs

The total hardware and installation costs are all costs that are involved with buying all hardware and the installation of this hardware in the trucks. Each supplier charges a certain amount per installation per truck, where about three to six on-board computers can be built into trucks per day.

Criterion 2 **Implementation time of software**

The second criterion for evaluation is the implementation time of the software. Company X is scheduling orders and pushing these schedules towards the on-board computer via their transport management system (TMS). This TMS needs to be linked with the new software in order to function. These links between the new software and the TMS need to be programmed by software developers working at the supplier.

So, what influences the implementation time?

Every transportation company in Europe has its own software system to integrate all business functions that exist in their company. For example, order management, human resources and inventory. A huge number of these software systems are available on the market. As they have indicated themselves, every potential software supplier has experience with different software systems, dependent on the customers they did business with in the past. The software supplier can either have experience with the software system Company X uses or does not have experience with it. This is the factor that influences the implementation time. If the software supplier does have experience with the TMS, they know where links between the two systems have to be made and how to make these links, which saves a lot of time.
Why is this implementation time important? The current software system of Company X is outdated. The longer Company X works with the old software, the longer Company X is missing out on the opportunity of using new functions which will improve transport operations. These improvements are in terms of reduction of fuel consumption, more efficient scheduling of orders and an improved customer response time. In the next chapter we explain how this criterion can be measured.
This criterion is established by input from the Business Unit Manager Transport of Company X. Because the project of acquiring a new software system and on-board computers is already taking a long time, and he finds it urgent Company X is no longer operating with the outdated software, this criterion is included in the evaluation criteria.

Criterion 3 **Fidelity of vendor**

Sub criterion 3.1 Number of customers where the supplier installed his software

Sub criterion 3.2 Owners position of the company

The functional and technical aspects are certainly important in the selection process of a software system. However, these aspects do not cover the customer-supplier relationship aspects and do not guarantee that good service will be provided throughout the years or that commitments are honored. *Fidelity* is defined as "faithfulness to a person, cause or belief, demonstrated by continuing loyalty and support". In this context, fidelity of the vendor means demonstrating loyalty and support to the enterprise Company X throughout the years.

Sun & Zhang et al. (2016) state that reputation is an intangible factor affecting the enterprise-supplier's continuous relationship and that cooperating with suppliers with high reputation will effectively reduce the risk of breaking an agreement. We make the assumption that the more customers a supplier does business with, the better their reputation. Therefore, the first sub criterion is the number of customers where the supplier installed his software.

Looking to the future, it is important that the owners position of the company is stable. For example, if the company is involved in a recent takeover by another company not focused on transport software, or ICT solutions, it can be risky to do business with such a company. The focus can be lost on the ICT solutions, they might not support updates on core functions anymore and they might not develop new functions, because the company does not focus on transport software anymore. The Business Unit Manager Transport mentioned one of the suppliers was involved in a takeover from another industry and emphasized their concerns with that the supplier' focus might change in the future. Because of this input, this criterion is added to the evaluation criteria.

Criterion 4 **Flexibility of software solution**

Sub criterion 4.1 Ability to reprogram specific software parts to own needs

Sub criterion 4.2 Activation/deactivation of modules

The software product that Company X purchases differs slightly per supplier. For example, in the navigation screen the truck driver will see a different interface and a different question path. The question path asks a truck driver if he finished several jobs to continue his journey on the road. If the job description for a driver changes or if the customer demands extra checks in the process, this question path needs to change as well. Therefore, for Company X it is convenient to be able to reprogram this on their own. Some suppliers allow for this freedom to reprogram, whereas for the other suppliers, reprogramming their systems is difficult and needs to be done with assistance of the supplier. To make sure Company X can utilize the possibility to reprogram, this is the first sub criterion. The ICT manager of Company X gave this criterion as input, because the previous software supplier was not very flexible when Company X requested software adjustments.

The advantage of deactivating services that are not used by Company X, is that they will not appear in the navigation screen anymore. With the implementation of new on-board computers, truck drivers need to be trained to work smoothly with the on-board computer system. The more simplified the on-board computer is (which happens if Company X is not using services and deactivating them) the likelier truck drivers will not struggle with the on-board computer system when using them.

In addition, it is important *when* this activation and deactivation is possible (monthly, each half year, each year).

Criterion 5 **Technical reliability**

The criterion technical reliability is established to be certain about the technical performance of the software systems. From meetings with employees from Company X, it became clear that the software system used by employees from the office and the software in the truck used by drivers are fundamental for the transport operations. If one of those systems is offline this results in consequences for multiple parts of the transport process. Therefore, these situations need to be avoided and for the cases that it occurs the problem needs to be solved as soon as possible. The sub criterion "service centers throughout Europe" reflects the situation in which the on-board computer fails and the sub criterion "uptime of the SaaS solution" reflects the situation in which the software systems used in the offices is offline.

Sub criterion 5.1 *Service centers throughout Europe*

Sub criterion 5.2 Uptime of the SaaS solution

When an on-board incurs damage during the delivery or experiences other software failures on the road, quick response time of the supplier' service is important. The sooner the defect is solved, the sooner the freight is delivered and the smaller the problems for the customer. *If* such an incident of on-board failure happens, this has quite some impact for Company X. The on-board computer is central for all the driver his activities, where for example he has to justify his actions for loading and unloading. Therefore, a defect of the on-board computer results in a (temporary) stagnation of the whole delivery process. With service centers, we mean physical service centers somewhere located in Europe. At the service center location itself, multiple mechanics are available. Obviously, the more service centers the supplier has throughout Europe, the shorter the response time will be. However, throughout Europe is not specific enough. Suppose a supplier has 30 service centers throughout Europe but half of them is in Italy and the other half in Greece. If Company X is mostly active in Belgium, a great number of service centers will not give Company X a fast response time. The core regions of Company X are the Netherlands, Belgium, North of France and Great Britain. The next chapter explains how this criterion is measured. Thus, this criterion is important because in case of truck defects delivery time delay is minimized which reduces the negative impact on customer satisfaction.
All suppliers deliver *Software as a Service* (SaaS), which is a software licensing and delivery model in which software is licensed on a subscription basis and is centrally hosted. This software is typically accessed via a web browser. For Company X it is important, since this service is outsourced, no defects or downtime are occurring. In short, the technical reliability of the SaaS solution is highly related to the percentage uptime the supplier can deliver. Uptime is the percentage of time the software system is online. Planners need to get vehicle updates in order to check if the truck is on schedule, and if not, inform customers about changes. In addition, if the system is down, planners cannot schedule new orders or push the orders to the drivers. Therefore, operations will be down as well during downtime. The orders that will pile up can have huge negative impact. Therefore, the reliability of the SaaS solution is an important criterion.

See Table 3.1 for an overview of all criteria.

Criteria	Sub-criteria	Criteria meaning
Costs	Monthly subscription all vehicles	The summed costs of all components of services that a truck uses
	Total hardware and installation costs	All hardware costs involved in the purchase of on-board computers and the software package and the costs of building and rebuilding hardware into trucks
Implementation time of software		The time it takes to fully integrate and link the new software system with the current TMS of Company X
Fidelity of vendor	Number of customers in Europe	Number of customers where they installed their software package
	Owners position of the company	Whether the company was involved with take overs in the

		past indicating the owners position
Flexibility of software solution	Software reprogram possibilities	Ability to reprogram specific software parts to own needs
	Activation/deactivation of modules	The possibility and frequency of options to activate and deactivate modules
Technical reliability	Service centers throughout Europe	Number of service centers available in Europe
	Uptime of the SaaS solution	The percentage of time the supplier can guarantee the software to be online

TABLE 3.1 OVERVIEW OF EVALUATION CRITERIA AND SUB-CRITERIA

3.4.1 Defining metrics for all lowest level criteria

As mentioned earlier, metrics must be defined to score the evaluation criteria (Jadhav & Sonar, 2011). This must be done for all the lowest level criteria, such that the decision maker can measure these criteria. First, the way each criterion is measured (metrics) is showed in the table below. After, I explain why these criteria are measured this way. See Table 3.2.

Criterion or sub criterion	Metric	Metric explained
Monthly subscription all vehicles	Numeric	Measured in Euros
Total hardware and installation costs	Numeric	Measured in Euros
Implementation time of software	Numeric	Measured in number of customers with a TMS where the supplier installed his software
Number of customers	Numeric	Measured in number of installations throughout Europe
Owners position of the company	Yes, No	Yes (involved in a takeover by a company from another industry the last five years), No (not involved in a takeover the last five years)
Software reprogram possibilities	Yes, No	Yes (solution of supplier can be reprogrammed to own needs), No (solution of supplier is unadaptable)
Activation/deactivation of modules	Numeric	Measured in minimum required period to use the service before activation or deactivation is possible, in number of months
Service centers throughout Europe	Numeric	Measured in number of service centers throughout the core regions of Company X in Europe

Uptime of the SaaS solution	Numeric	Measured in the service level agreement of the supplier, guaranteeing the percentage of time the system be online (uptime)

TABLE 3.2 METRICS TO MEASURE SUB-CRITERIA

A lot of metrics can be measured in a numerical way. However, not all sub-criteria can be measured in a numeric way. If the criteria can either apply or not, the metric is just measured as a simple yes or no. This yes or no metric needs to be converted into a score to measure the performance on that sub-criteria between suppliers. For example, if two suppliers both answer the same answer (both yes or both no) their score should be equal. If the answers differ, the relative score should be halfway between an equal score and the maximum difference in score. For example, if the scale ranges from 1 to 9 (1 being equal important and 9 being extremely more important) the score should be 5.

The implementation time of software is measured with a numeric metric. The supplier can either have experience with the TMS of Company X which will improve the implementation time, or they do not have experience with it. We make the assumption that the more installations the supplier did with similar TMS, the faster the implementation time will be because of their advantage in experience and skills.

The service centers throughout Europe are measured as the total number of physical service centers the supplier provides *within* the core regions of Company X.

The uptime of the SaaS solution is measured in the service level agreement of the supplier. This is the percentage uptime the supplier guarantees to deliver and if not, Company X will receive a compensation for this (depending on how long the software system was offline).

3.4.2 Accuracy of representation of decision maker's concerns

Before the decision maker compares the potential suppliers based on the evaluation criteria, we need to check whether the criteria are a useful representation of the decision maker his concerns. Keeney & Raiffa (1976) suggest five criteria[1] that can be used to judge this:

I) Completeness. This is the case if all attributes that are of concern of the decision maker are included.

II) Operationality. This criterion is met when all the lowest-level attributes in the list are specific enough for the decision maker to evaluate and compare them for the different options.

III) Decomposability. This criterion requires that the attractiveness of an option on one attribute can be assessed independently of its attractiveness of an option on other attributes.

IV) Absence of redundancy. If two attributes duplicate each other because they actually represent the same thing, then one of these attributes is clearly redundant.

V) Minimum size. If the list it too long, attributes should not be decomposed beyond the level where they can be evaluated.

Looking to all these criteria, the first criterion is met because the decision maker agreed on all evaluation criteria without having additional remarks. The detailed explanation that all attributes of concern are included (completeness) is done in Section 3.4.3. Jadhav & Sonar (2011) did an extensive literature review on what evaluation criteria software packages are often assessed. The list these

[1] These criteria were originally found in literature research and are used to assess the value tree from SMART

evaluation criteria was a second check to assure no categories were left out for consideration that were applicable to the situation of Company X. Clearly, the criteria are operational too, since all criteria can be measured by the defined metrics as shown above. In addition, the required information for these measurements is available on request by all suppliers.
When talking about the criterion decomposability, one could argue that the attribute “activation/deactivation of modules” is related to the attribute “costs”, since the deactivation of modules would also deactivate the costs originally charged for that service. However, the rationale of the attribute “activation/deactivation of modules” relates rather to the flexibility to add and deselect services to change the functional range of the on-board computer. In addition, the concrete costs involved with the activation or deactivation of the services is not clear, since we do not know what is going to be deactivated, for how many vehicles and what is charged per service. Because the decision maker cannot really tell how attractive the attribute is without seeing a number associated with it, the attractiveness of this attribute does not influence the attractiveness of the attribute costs.

3.4.3 Are all aspects about the decision problem included?

Looking to the whole process of finding a new supplier, some parts are quite critical before arriving at the solution. One of these parts obviously is to set requirements for the software product. These are important to verify if the supplier can match these and it can influence the final candidate selection if some candidates cannot meet the boundary conditions. But more fundamental, are the aspects on which the final candidates are evaluated: the evaluation criteria. This reflects the same criterion as “completeness” from Section 3.4.2. How can we be sure that for the process of evaluation, whether it is the software package itself or the supplier, we did not leave anything left out during the process?

During the establishment of the functional requirements, the boundary conditions and the evaluation criteria, the following sources could be consulted:

1. Involved employees from Company X
2. Literature (such as Scopus (literature database of the University of Twente) or Google Scholar)
3. Involved employees from the suppliers

For each source where information regarding this assignment could be extracted, we briefly explain how these are made use of and to what extent.

Involved employees of Company X
Is every relevant employee of Company X involved in the process, acquiring their expertise and vision on the on-board computer project? The answer is yes. To start with, the Business Unit Manager Transport (who is responsible for all departments related to the on-board computer and software system) who is leading the project is frequently asked for input. Not only on the on-board computer project itself, but also input about which people to approach that could give useful information. Besides the Business Unit Manager Transport the ICT manager was asked for input as well, for example on the functional requirements desired. Furthermore, we investigated which operations were involved with this project and employees from those operations are approached for their expertise (also explained in Section 2.3).

Literature sources
During the process literature is consulted as well. For example, articles giving information about advantages of fleet management software, possible costs reductions using fleet management software, how to evaluate a software package and so on. Literature sources are used to gain information for new insights, for confirmation of conclusions and for example to establish the evaluation criteria.

Involved employees from the suppliers
When setting up the functional requirements, input was asked from the suppliers as well. They were asked for the best features they offered and items Company X should not forget in their selection. The suppliers service many customers and they can see what functionalities are used the most. Therefore, this input is useful for Company X.

All in all, all available and relevant sources were consulted in the process and therefore we conclude, although we can never be certain, important aspects were not excluded or overlooked.

3.4.4 Conclusion on boundary conditions and evaluation criteria

In this chapter the guideline towards assessing the potential suppliers is set. First, a framework is introduced for the evaluation and selection of software. The functional and non-functional requirements are defined to be sure the software package will meet all Company X their needs. However, these requirements are not suitable to evaluate the suppliers themselves. From the functional requirements, boundary conditions are derived. The supplier *must* meet these requirements to stay in the final selection. Besides boundary conditions, evaluation criteria and the way to measure them are defined. In Chapter 4, the suppliers Company X is negotiating with are introduced. Where in this chapter stages one, four and a small part of five of the evaluation framework (defining metrics) are carried out, stages two and three are done in Chapter 4.

4. Possible software package suppliers for Company X

There are many companies on the market that offer on-board computers to support lots of elements of transport such as truck tracking. These companies also offer software that is used for back offices of transport companies to facilitate and reinforce the use of the on-board computers. In this chapter, we give an overview of the suppliers that Company X is currently negotiating with. In Section 4.1 all suppliers are introduced and some important characteristics are mentioned. In Section 4.2, the suppliers are assessed based on the boundary conditions. Are they failing to meet hard criteria, or do all suppliers stay in the selection? After the supplier are assessed on the boundary conditions, we take a look at how they perform on the evaluation criteria in Section 4.3.

4.1 Potential software package suppliers

Company X is negotiating with five suppliers of the on-board computers and software systems. These suppliers were selected because they were recommended to Company X or because the suppliers were known via the network of Company X. Company X also included their current supplier in the negotiations. Company X is negotiating with the following suppliers:

1. Supplier A
2. Supplier B
3. Supplier C
4. Supplier D
5. Supplier E

4.1.4 Supplier A

The Supplier A is a global leader in Enterprise Management Software and Advanced Location-Based IT solutions. Headquarters in Singapore and with major operations and offices in Europe, AME and Asia-Pacific, Supplier A serves MNC, enterprise and government customers spanning numerous regions and industry sectors.

With more than 25 years of experience, Supplier A is recognized as a trusted leader in location based IT services and solutions. A few facts about Supplier A Europe:

- 100+ employees
- 50+ installation partners
- 500+ customers
- More than 25 years of experience

4.1.2 Supplier B

Supplier B is a global provider of vehicle tracking and fleet management systems. Supplier B started their activities in 1997 in Portugal. Since 2008, they started expanding operations to other countries with a very quick and steady growth. Currently, they are distributed over 30 countries around the world where they also have partners located. Especially in South Africa, they have a lot of business going on. Supplier B their vision:

"In an ever-competitive market, companies will need intelligent tools to ensure the efficient use of their fleets, thus maximizing productivity and safety, at the same time minimizing costs and improving customer satisfaction. Supplier B will fulfil that need by providing the most intelligent solutions for professional fleet management."

Subsequently, their mission:

"Supplier B will integrate state-of-the-art telematics with user-friendly software and powerful analytics algorithms, providing a comprehensive SaaS fleet intelligence toolkit which will enable companies to optimize their fleets' performances."

Worldwide locations	Customers in over 30 countries
Traded company	-

4.1.3 Supplier C

Supplier C is established in 1971, employs around 600 employees and has over 20 company-owned subsidiaries. Supplier C is an internationally operating group of companies active in the development, production, marketing and sales of innovative products and services for improving efficiency, safety and uptime multiple sectors, where one of them is transport.

Supplier C includes Supplier C Lubrication Solutions (supplying products for automated maintenance) and Supplier C ICT solutions, specialized in transport management systems and telematics devices for transport and logistics operators. But instead of making custom ICT solutions, Supplier C offers a couple of finished products (of course, tuned to general customer needs) and looks for customer where their product could be a suitable solution.

Supplier C has been Company X their supplier for many years. Currently, Company X is using Supplier C on-board computers in their logistics as well as their software in back-office IT solutions.

In June 2017, the Timken Company, a leader in lubrication systems acquired Supplier C. With this transaction, the owner of Supplier C (sole shareholder and non-executive president) retired from the company.

4.1.5 Supplier D

Supplier D develops and commercializes software, hardware and services for the transport industry fleet operators that lead to more efficient and cost-effective processes, to more productive, safer and ecological driving and to improved customer services. Since 1991, their core business has been developing Fleet Management Systems (FMS) compliant with the needs of the transport industry sector.

- Founded in 1991
- Over 320 employees
- Research and Development in Ieper (BE), Alès (FR), Dublin (IRL) and India
- 1500 customers in 23 countries

Supplier D is a subsidiary of the Wabco company, which is the leading global supplier of commercial vehicle technologies.

4.1.1 Supplier E

Supplier E, founded in 1978 is an international company which is active in different industries. Naming a few, their major industries are construction, agriculture, mobile resource management and more interesting for Company X the transportation and telecommunications industry.

Worldwide locations	Offices in 35 countries
Traded company	NASDAQ stock exchange
Revenues	2.65 billion dollars in 2017

4.2 Assessment suppliers on boundary conditions

Now that all suitable candidates are introduced, it is time to perform stage three of the evaluation framework: short listing packages. This short listing is done by means of checking the candidates upon the boundary conditions. See the table below for the first boundary condition.

Boundary condition 1	**Supplier A**	**Supplier B**	**Supplier C**	**Supplier D**	**Supplier E**
Detachability and mobility of navigation screen					

TABLE 4.1 CANDIDATES ASSESSMENT ON BOUNDARY CONDITION 1

As can be seen in the table above, all candidates meet this boundary conditions except for Supplier D. Supplier D only offers a fixed, built in navigation screen such that the driver can only communicate with Company X and process orders *behind the wheel.* Again, a device that is not detachable is a clear limitation to multiple functionalities, and with companies developing new functionalities continuously, this will be a limitation in the upcoming years as well. Therefore, candidate Supplier D is crossed out from the selection.

Recall the second boundary condition from Section 3.3.2. The remaining suppliers are reviewed on the second boundary condition in the table below.

Boundary condition 2	**Supplier A**	**Supplier B**	**Supplier C**	**Supplier E**
Charter application				

TABLE 4.2 CANDIDATES ASSESSMENT ON BOUNDARY CONDITION 2

As can be seen in the table above, Supplier B is the only candidate not meeting the second boundary condition. From all candidates, Supplier B was the only one without existing installations in the Netherlands. It is possible that the Dutch market works more with outsourced trucking and therefore is more in need of charter applications. Because Supplier B cannot meet this condition, they are crossed out from the selection as well.

Therefore, the candidates Supplier A, Supplier C and Supplier E are included to be evaluated by the evaluation criteria.

4.3 Scoring of candidates on evaluation criteria

In this section the score on each lowest level attribute criterion from each candidate is determined having left the candidates Supplier A, Supplier C and Supplier E. They are now discussed per criterion.

To determine the costs such as monthly subscription per vehicle, all the prices of the requirements from Section 3.3.1 need to be available. Luckily, Company X sent a Request for Quote (RFQ) to all suppliers, asking how much they are charging for all the requirements listed in Section 3.3.1. See the table below for the monthly subscription prices per vehicle, if all functionalities from the list of requirements are included.

Supplier	Monthly subscription per vehicle (Euro)	Total monthly subscription for all vehicles (Euro)
Supplier A	17.35669	3,124.204
Supplier C	8.757962	1,576.433
Supplier E	17.35669	3,124.204

TABLE 4.3 COMPARISON OF MONTHLY TOTAL PRICES

The total hardware costs are displayed in the following table.

Supplier	Hardware costs per truck (Euro)	Total hardware costs (Euro)
Supplier A	340.7643	6,1337.58
Supplier C	512.4204	9,2235.67
Supplier E	493.6306	8,8853.5

TABLE 4.4 COMPARISON OF TOTAL HARDWARE COSTS

To obtain the scores for the criterion costs, only the costs required for installation of the on-board computers in all trucks need to be clear. These costs are displayed in table 4.5 below.

Supplier	Installation cost per vehicle (Euro)	Total installations costs (Euro)
Supplier A	74.84076	13,471.34
Supplier C	73.24841	13,184.71
Supplier E	85.98726	15,477.71

TABLE 4.5 COMPARISON OF TOTAL INSTALLATION COSTS

The investment for the on-board computers involves about 180 vehicles. The calculations for all costs in the tables above are based on this number of vehicles. Furthermore, the remaining information is requested from the three candidates left to acquire all raw scores. Based on the raw scores, a first impression can be done on the differences between the suppliers on the sub-criteria. For each criterion the field(s) having the best (possible) raw scores are highlighted green.

Criterion/Supplier	Supplier A	Supplier C	Supplier E
Monthly subscription all vehicles	3,124.204	1,576.433	3,124.204
Total hardware and installation costs	74,808.92	10,5420.4	10,4331.2
Number of installations with same TMS as Company X	1.273885	0.318471	0
Number of installations	477.707	159.2357	254.7771
Owners position of the company	No (not involved in takeover last five years)	Yes (involved in takeover last five years)	No (not involved in takeover last five years)
Software reprogram possibilities	Yes	No	Yes
Activation/deactivation of modules	1.27 months	3.82 months	3.82 months

Service centers throughout Europe[2]	2.547771	1.592357	6.050955
Uptime of SaaS solution	31.21019%	30.89172%	31.76752%

TABLE 4.5 SCORES PER SUPPLIER ON ALL SUB-CRITERIA

4.4 Conclusion on scores of candidates

This section summarizes the content of this chapter and what conclusions can be drawn. First of all, the possible candidates are introduced which gives insight in their background of their core business and their size as well. After this introduction, the number of candidates is short listed (stage three of the evaluation framework mentioned in Section 3.3) by means of the boundary conditions from Section 3.3.2. For those candidates that did pass the boundary conditions, the scores were measured on all sub-criteria.

If we compare the scores of Supplier A and Supplier E, what is important to notice is that Supplier A is performing better or the same on all criteria except for those on technical reliability (service centers throughout Europe and uptime of the SaaS solution). In addition, if we compare the scores of Supplier A and Supplier C, Supplier A is outperforming Supplier C on all sub-criteria except for the criterion monthly subscription of all vehicles.

With these scores between candidates, you would suppose Supplier A is likely to end up on top. However, since the weights of the criteria are not determined yet, this is no guarantee. Suppose the criterion technical reliability is weighted relatively high compared to the other main criteria, Supplier E will be in favor compared to the other candidates.

The next step is to find a multi criteria analysis method by doing a literature study, such that stages five and six (evaluating the software packages and selecting a software package) of the evaluation framework from Section 3.3 can be performed.

[2] See appendix 4A to see how the total service centers from suppliers are distributed over Company X their core regions

5. Literature research

This chapter describes the literature research to form a basis for the approach of deciding on a software system. A lot is written about decision analysis in literature. The goal of this chapter is to find a suitable way to analyze the current situation in a structured and systematic way.

5.1 Multi criteria decision analysis methods from literature

In the case of this bachelor assignment, a decision should be made where multiple criteria are involved. For example, the software system is assessed upon its cost but on its user-friendly dashboard as well. Therefore, literature about decisions involving multiple criteria is needed. Two well-known decision-making methods involving multiple criteria are (Goodwin & Wright, 2009):

1. SMART
2. AHP

These methods are discussed in terms of how they work, their assumptions and under what conditions they are applicable.

5.1.1 SMART

The central idea is that splitting the problem into small parts, the decision maker is likely to get a better understanding of the problem than gained by taking a holistic view. The methodology is underpinned by a set of axioms (see appendix E, Axioms of the SMART method), and once accepted by the decision maker, the results of the analysis will indicate how the decision maker should behave. Some basic terms that will be used in this method are *objective* and *attribute".* An objective is an indication of the preferred direction or movement. An *attribute* is used to measure performance in relation to an objective. There are also attributes which may not have a direct relation to the objectives, which are called *proxy attributes*" (Keeney and Raiffa, 1976). For each course of action the decision-maker faces, we derive a numerical score to measure its attractiveness to him. If the decision involves no element of risk and uncertainty, we refer to this score as the *value* of the course of action.

Simple Multi-Attribute Rating Technique (SMART) is a technique used for decision analysis widely applied because of its relatively simplicity and transparency. The main stages are:

1. Identify decision-maker (or decision-makers)
2. Identify the alternative courses of action
3. Identify attributes that are relevant to the decision problem (these will be factors that distinguishes alternatives from each other)
4. Assign values to measure the performance of the alternatives on that attribute
5. Determine a weight for each attribute
6. For each alternative, take a weighted average of the values assigned to that alternative
7. Make a provisional decision
8. Perform sensitivity analysis (to see how robust the decision is to changes in the figures supplied by the decision maker)

The execution of each stage from the SMART method is now briefly discussed.

The answers to stage one and two are normally known quite fast. For example, the decision maker is the Business Unit Manager Transport and the alternative courses of action are three software suppliers.
The third stage, can be done by making a value tree. This starts by identifying main attributes, for example ‘costs’ and ‘benefits’. After, these main attributes are broken down into more specific attributes that will make it easier to compare alternatives. To judge whether the value tree is an

accurate representation of the decision-maker's concerns, Keeney and Raiffa (1976) suggest five criteria: completeness, operationality (all lowest-level attributes are specific enough to evaluate), decomposability (attractiveness of an alternative on an attribute can be assessed independently of scores on other attributes), absence of redundancy and minimum size.

To succeed at stage four, there are two approaches to measure the performance of each attribute: direct rating or value functions. Direct rating is used for attributes that cannot be easily quantified, for example the attribute "image of a company". The decision-maker is asked to rank the alternatives from most preferred to least preferred, and assign values to both. After these raw values are assigned they are normalized to a scale from 0 to 100. After that, the decision-maker is asked to rank the other alternatives so that they represent his strength of preference of one alternative over another. This produces interval data.

The second approach, value functions, is used for attributes that are more easily quantifiable. For example, the attribute "size of office" can be quantified in floor area. A value function is made by assigning values to each alternative size of a floor area, where the biggest area can have the highest value of 100 and the smallest to the lowest value of 0. The simplest and most widely used form of a value function method is the additive model, which in the most simply cases can be applied using a linear scale.

There are multiple ways to perform stage five, weighing attributes. A common one is assign numbers to reflect the relative importance of the attributes. However, importance weights may not take into account the *range* between the least and most preferred options on each attribute. If the options perform very similarly on an attribute (so the range between best and worst is small) then this attribute is unlikely to be important in the decision. Therefore, that weight should be very low.

This problem can be avoided by using *swing weights*. These are derived by asking the decision-maker to compare a change (swing) from the least preferred to the most preferred value on one attribute with a similar change in another attribute. First, attributes need to be ranked. This can be done by setting all attributes to their least preferred values and ask the decision maker if one attribute could be moved to its best level, which one would it be? When repeated for all attributes, this will result in a ranking. The first ranked gets a weight of 100. For the second weight, the decision owner is asked to compare a change of the second ranked attribute from its least preferred value to its best preferred value and the first ranked attribute from its least preferred value to its best preferred value. If for example the switch of the second ranked attribute is 80% as important as the switch of the first ranked attribute, the second ranked gets a weight of 80. This is repeated for all attributes.

There are several methods to calculate the overall score of an attribute. A common way is the weighted average, where the weight is multiplied with the score on each attribute, and for an alternative all scores on attributes are aggregated to get an overall score.

Stage seven is quite straightforward after completing the first six stages. Stage eight, the sensitivity analysis is a matter of changing the values of weights (one at a time) if the owner is doubting the values of the weights to see how the final decision is influenced by varying weights.

5.1.2 Analytic Hierarchy Process

The Analytic Hierarchy Process (now abbreviated to AHP) has been very widely applied to decision problems in areas such as economics, planning, material handling and purchasing. The AHP consists of the following five stages:

1. Set up the decision hierarchy

2. Make pairwise comparisons of attributes and alternatives
3. Transform the comparisons into weights and check the consistency of the decision maker's comparisons
4. Use the weights to obtain scores for the different options and make a provisional decision
5. Perform sensitivity analysis

For all stages, we briefly discuss how they work and how they should be executed. The AHP is based on some assumptions, also known as axioms, which can be found in appendix F, Axioms of the AHP method.

Setting up the decision hierarchy in stage one is similar to the value tree from SMART. The main difference is that the alternative course of action also appears on the hierarchy at its lowest level. At the top of the tree, the general objective of the decision problem is stated. The general attributes associated with the decision problem are then set out below this. After, these attributes can be broken down into more detail at the next level. This process continues until all necessary criteria for making the decision have been specified. Finally, the alternative courses of actions (for example, the three possible software suppliers) are added to the hierarchy, below each of the lowest level attributes. The hierarchy tree meets the five recommended criteria (by Keeney & Raiffa (1976)) to check whether the criteria are a useful representation of the decision maker his concerns.
In stage two, pairwise comparisons of attributes and alternatives are made to determine the relative importance of attributes and to compare how well options perform on different attributes. Following each "split" in the hierarchy, the importance of each attribute is compared. This is done for all attributes in the hierarchy (note that since they are compared pairwise, the number of comparisons is (N(N-1)/2), where N is the number of attributes).

For each attribute, the responses for relative importance are limited, and the options are:

Equally important	(1)
Weakly more important	(3)
Strongly more important	(5)
Very strongly more important	(7)
Extremely more important	(9)

Note that intermediate values are allowed (for example, between weakly and strongly more important). The method converts the response to the numbers shown in the brackets. Each set of comparisons can be represented in a table or matrix. This matrix indicates how much more important the *row* attribute is compared with the *column* attribute.

In stage three, the AHP converts each table into a set of weights, which are automatically normalized to a sum to 1. A number of conversion methods are possible, but it is recommended by Saaty (1990) to use a mathematical approach based on eigenvalues. The AHP also yields an inconsistency ratio, which is designed to alert the decision-maker to any inconsistencies in comparisons that have been made.
In stage four, the weights are used to obtain scores for different options and to make a provisional decision. Looking in the hierarchy, all weights from the path from the top of the hierarchy to the bottom are multiplied with each other for a certain alternative to obtain an overall score.
The last stage, number five, is to examine how sensitive the preferred course of action is to changes in the judgements made by the decision maker. Excel can be used for carrying out a sensitivity analysis

5.2 Comparison of analysis methods

Now that is explained how both methods work, it is time to compare them. The similarities are explained, as well as the advantages over each other.

Basically, both methods do have a lot in common if we look to the eight stages of which the SMART method consists. They both select a problem owner, choose alternative courses of action and set up a value tree (defined as hierarchy in the AHP). But, they differ essentially in stage four and five; measuring scores for alternatives on attributes and determining the weights. The SMART uses for measuring scores to attributes one of the following techniques:

1. Direct Rating
2. Value functions

For determining the weights, SMART uses swing weights. The AHP on the other hand, determines weight for attributes by:

1. Pairwise comparisons of attributes and alternatives

Scores of alternatives are subsequently calculated by multiplying the weights of each path of the hierarchy, and results of different paths are summed.

The use of value functions is intuitively an advantage over the AHP. If a criterion is for example square feet of an office, this is an easy quantifiable variable. However, when using pairwise comparisons with verbal responses this quantifiable method is neglected and this might sound like a less accurate way to assign values to attributes.

In addition, SMART does not have the problem that new alternatives can reverse the rank of existing alternatives. When for example, the AHP solution ranks based on weights alternative A as first choice, B as second and C as third, A and B can switch in rank if another solution D is added.

The advantage of the AHP over SMART is the consistency check that the AHP method includes. When the consistency check gives a too high value, it can be useful to reassess the comparisons of attributes.

5.3 Selection of multi criteria decision analysis method

In this bachelor assignment, together with the decision maker from Company X a list of criteria is formulated which is input for the attributes in the decision model. Because the AHP method does well on the following points:

- Requires less explanation about techniques from the method (no need for explanation of swing weights, scales and value functions, which can be exhaustive)
- Includes a consistency check
- Is a structured approach and simultaneously contains a lot of practical simplicity

The AHP method will be applied in the decision problem of this assignment.

5.4 Performing a sensitivity analysis with the AHP method[3]

For each decision problem there are be multiple criteria where the decision is based on. These criteria are established such that the project where a decision is involved can be approached in a structured way to assess different options and arrive at the most suitable solution. But most often, not all these criteria are equally important. Furthermore, when the weights are awarded to different attributes, how can the decision maker be sure the decision will not give a different outcome when the weights

[3] See appendix E for the systematic literature review protocol that is used to answer this knowledge question.

are slightly changed? A sensitivity analysis is useful to see how sensitive the decision for is to changes in certain weights.

There is no guideline to decide for which attributes you should perform a sensitivity analysis. When the decision maker suspects certain attributes are having too much influence, the sensitivity analysis could be performed on these attributes. However, it is also possible to perform it on all criteria.

A sensitivity analysis can be performed by a pre-designed tool, such as Expert Choice+ or Web-HIPRE but since these have to be purchased, it is done manually in Excel.

When it is done manually in Excel, one choice should be made:

1. The attribute for which the weight is going to be changed

With the new weight, calculations can be done again (using AHP) and all data points can be plotted in a chart. When a line is drawn, this will represent the behavior of an attribute over the range from 0 to 1 of another weight.

Often, when the AHP is used to rank a lot of factors, it is interesting to perform a sensitivity analysis on all of them to make sure the decision is a robust one.

Besides the weights, the scores can be changed as well. Using the AHP, this means that for example a change from "weakly more important" to "extremely more important" is evaluated to see what impact it directly has on the weights and indirectly on the decision.

5.5 Conclusion on literature research

This chapter's function is to find a suitable multi criteria decision analysis method so that using the evaluation criteria and the performance of each supplier on the measurement of those evaluation criteria there can be decided upon a software system supplier.

The SMART and AHP are assessed based on their advantages and disadvantages and although they have a lot of similarities, the AHP is chosen over SMART because of the arguments mentioned in Section 5.3.

In addition, literature research is done on performing a sensitivity analysis. The attributes for which their weights are influenced are determined after the calculations are done using the AHP.

6. Using the AHP method towards a software system supplier decision

It is clear from Chapter 5 that the AHP is the best suitable method to use to decide on the best software supplier for Company X. This chapter combines the input of evaluation criteria and the supplier scores on the sub-criteria for the application of the AHP method. By applying the AHP method, the final stages five and six of the evaluation framework from Section 3.3 (evaluating software packages and selecting the software package) are worked out at the same time. The structure of this chapter is similar to the stages described in the AHP method. First, the decision hierarchy is set up in Section 6.1. Based on the decision hierarchy, pairwise comparisons of attributes and alternatives can be derived which is done in Section 6.2. After these attributes are compared pairwise by the problem owner, the pairwise comparisons are transformed into weights in Section 6.3. Using these weights and filling in the decision hierarchy, calculations will provide the selection of the best supplier in Section 6.4. Finally, to confirm the solution is robust, a sensitivity analysis is performed in Section 6.5.

6.1 The decision hierarchy

A decision hierarchy reflects all the important aspects involved in making a certain decision. The hierarchy consists of several levels. The highest level of the hierarchy represents the goal, the second level the criteria that comprise all elements of the goal, the third level the sub-criteria and the fourth level represents all alternative courses.

Recall from Chapter 1, that our action problem is deciding on a new on-board computer and software system. Therefore, the goal is choosing a new on-board computer and software system. For the second and third level the main criteria and sub-criteria from Section 3.4 are used. Of course, the alternative courses for the fourth level are the short-listed candidates from Chapter 4. Combining all these levels, the following decision hierarchy is constructed.

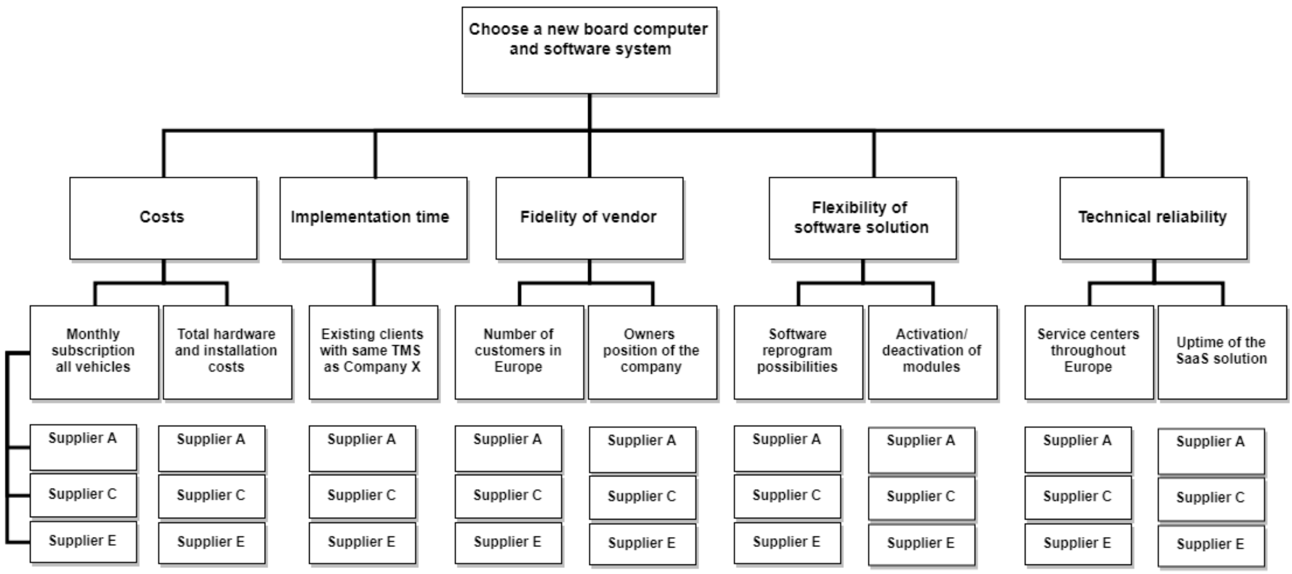


FIGURE 6.1 DECISION HIERARCHY FOR CHOOSING NEW ON-BOARD COMPUTER AND SOFTWARE SYSTEM

6.2 Pairwise comparisons of attributes and alternatives

Having constructed the decision hierarchy, the next step is to find weights of the main criteria and weights of the sub-criteria. To do this, pairwise comparisons of the attributes and alternatives are made. Recall from Chapter 5 that these comparisons are done on a scale from 1 to 9 with 1 meaning attributes are equally important and 9 meaning attribute A is extremely more important than attribute B. Also recall the assumptions (axioms) of the AHP method.

The total number of pairwise comparisons that have to be done to calculate all weights, can be determined with the following equation:

$$Number\ of\ pairwise\ comparisons = M * \frac{M-1}{2} * N$$

where M is the number of alternatives and N is the number of criteria considered for evaluation. For the third level, M = 3 and N = 9. Therefore, the third level consists of 27 comparisons. For the first level with main criteria 10 comparisons are needed and for the second level another 4. Therefore, the total number of pairwise comparisons is 41.

During a meeting with the problem owner at Company X, all comparisons are discussed such that the problem owner could express his preference towards each attribute. To support the problem owner on his judgement of how well each candidate was scoring on the sub-criteria, I provided him with the raw scores on all sub-criteria from Section 4.3. See for all responses of the problem owner on the survey appendix H.

The responses are converted to numerical inputs to reflect the problem owner's preferences. Each set of comparisons is represented in a matrix. Comparing the importance on the main attributes, this results in the following matrix:

	Costs	Implementation time	Vendor Reputation	Flexibility software solution	Technical reliability
Costs	1	3	3	6	3
Implementation time	1/3	1	1/3	5	1/5
Vendor Reputation	1/3	1/3	1	3	1/3
Flexibility software solution	1/6	1/5	1/3	1	1/9
Technical reliability	1/3	5	3	9	1

TABLE 6.1 COMPARING IMPORTANCE OF MAIN ATTRIBUTES

For example, the problem owner judged the criterion costs weakly more important compared to implementation time. These matrices are constructed for the sub-criteria from the second level as well. To obtain scores for each supplier, the same is done. For example, for the sub-criteria monthly subscription of all vehicles the following matrix is constructed:

	Supplier A	Supplier C	Supplier E
Supplier A	1	1/6	2
Supplier C	6	1	6
Supplier E	½	1/6	1

TABLE 6.2 COMPARING SCORES ON SUB-CRITERIA MONTHLY SUBSCRIPTION OF ALL VEHICLES

All other matrices are constructed and put in an Excel document for further calculations of the AHP method, but are not put into the appendix since all pairwise comparisons can already be seen in the survey.

6.3 Transforming the comparisons into weights

Since all pairwise comparisons are performed and the relevance between them can be derived from the matrices, the next step is to calculate the weights. Keeney and Raiffa (1976) recommend the following procedure for these AHP calculations:

1. Sum each of the columns of the matrix and then divide each number in the table by the total of its column
2. Average the numbers of each row
3. Use this average as approximate weight for the attribute

These steps are iterated for each matrix. For example, see the following table as an application on the matrix of Table 6.3:

	Supplier A	Supplier C	Supplier E	Scores (average of row)
Supplier A	0.133	0.125	0.222	**0.160**
Supplier C	0.800	0.750	0.667	**0.739**
Supplier E	0.067	0.125	0.111	**0.101**
Sum column Table 6.2	7.500	1.333	9.000	

TABLE 6.3 EXAMPLE TRANSFORMATION COMPARISONS INTO WEIGHTS

These calculations are performed for all sets of comparisons in the matrices. Before all weights and scores are filled in in the decision hierarchy, a consistency check must be done.

6.3.1 Consistency check of decision maker’s comparisons

Before all the weights and scores are used to calculate which candidate ends on top, first we should check whether the problem owner was consistent in comparing the attributes. The AHP method also yields an inconsistency ratio, which is designed to alert the decision-maker to any inconsistencies in the comparisons that have been made, with a value of zero indicating perfect consistency. For example, the decision maker’s responses imply that attribute A is twice as important as B, while B is judged to be three times as important as C. To be perfectly consistent, the decision maker should judge that A is six times more important than C. Any other response would lead to an index greater than zero. Saaty (1990) recommends that inconsistency should only be a concern if the ratio exceeds 0.1. To see how these inconsistency ratios are calculated with an example from one of the attributes from Table 6.5, see appendix I.

This inconsistency can only be checked for attribute sets containing more than two attributes. This is the case for the main criteria, and the scores on all lowest level criteria (since there are more than two candidates). Calculating all inconsistency ratios, the following values are found:

Attribute table	Inconsistency ratio
Main attributes	0,225
Monthly subscription all vehicles	0,123
Hardware installation costs	0,365
Number of installations with same TMS as Company X	0,189
Number of installations in Europe	0,163
Owners position of the company	0,000
Software reprogram possibilities	0,070
Activation/deactivation of modules	0,000
Service Centers throughout Europe	0,187
Uptime of the SaaS solution	0,070

TABLE 6.4 INCONSISTENCY RATIOS FOR ATTRIBUTE SETS AND CANDIDATE SCORES

Looking to the inconsistency ratios in table 6.4, it is not difficult to notice that more than half of all the inconsistency ratios are too high. Unfortunately, we have to conclude the decision maker was not consistent enough. Therefore, the same survey is discussed again with the problem owner. This time, emphasis is put on the axioms of the AHP to make sure reasonable comparisons are made. See for the new input on the survey appendix H, where the old responses are marked grey and the new responses green. For these new responses, the inconsistency ratios are calculated again. These calculations give the following values:

Attribute table	Inconsistency ratio
Main attributes	0.117
Monthly subscription all vehicles	0,047
Hardware and installation costs	0,000
Number of installations with same TMS as Company X	0,032
Number of installations in Europe	0,057
Owners position of the company	0,000
Software reprogram possibilities	0,000
Activation/deactivation of modules	0,000
Service Centers throughout Europe	0,038
Uptime of the SaaS solution	0,070

TABLE 6.5 RENEWED INCONSISTENCY RATIOS FOR ATTRIBUTE SETS AND CANDIDATE SCORES

With these pairwise comparisons that *are confirmed* to be consistent except for the main attributes, we can proceed with filling in the hierarchy with the founded weights and scores. The inconsistency ratio of the set of main attributes exceeds the threshold of 0.1, but is close to it. Note however that the consistency check is invented such that the decision maker is aware of his inconsistencies and to what extent they are inconsistent. It is not the main goal to be perfectly consistent and to get all ratios below the threshold.

6.4 Using weights and scores to make a provisional decision

So far, the decision hierarchy is constructed and all attributes from which the decision hierarchy consist are pairwise compared such that the corresponding weights and scores could be calculated. In addition, consistency checks were done on all attribute sets to confirm the decision maker expressed his preferences between attributes in a consistent way. These steps correspond with stage five of the evaluation framework from Section 3.3. It is time to carry out stage six, selecting a software package. To make this selection, the hierarchy is filled in with all weights. See the following figure:

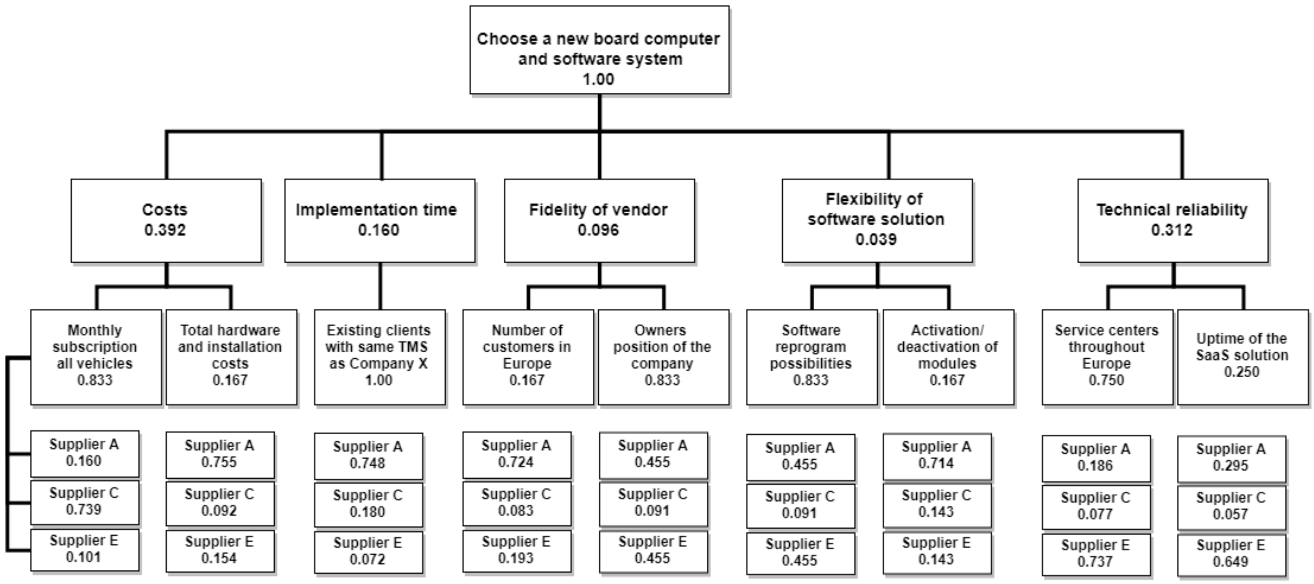


FIGURE 6.2 DECISION HIERARCHY INCLUDING WEIGHTS AND SCORES

To obtain the final scores for each supplier, each weight is multiplied with the weight of the attribute from the next hierarchy level from the top until the bottom. The final scores of the suppliers are calculated below:

Final score Supplier A =	(0.392 x 0.883 x 0.160)	=	0.052 +
	(0.392 x 0.167 x 0.755)	=	0.049 +
	(0.160 x 1.000 x 0.748)	=	0.120 +
	(0.096 x 0.167 x 0.724)	=	0.012 +
	(0.096 x 0.833 x 0.455)	=	0.036 +
	(0.039 x 0.833 x 0.455)	=	0.015 +
	(0.039 x 0.167 x 0.714)	=	0.005 +
	(0.312 x 0.750 x 0.186)	=	0.044 +
	(0.312 x 0.250 x 0.295)	=	0.023
		=	**0.356**
Final score Supplier C =	(0.392 x 0.883 x 0.739)	=	0.241 +
	(0.392 x 0.167 x 0.092)	=	0.006 +
	(0.160 x 1.000 x 0.180)	=	0.029 +
	(0.096 x 0.167 x 0.083)	=	0.001 +
	(0.096 x 0.833 x 0.091)	=	0.007 +
	(0.039 x 0.833 x 0.091)	=	0.003 +
	(0.039 x 0.167 x 0.143)	=	0.001 +
	(0.312 x 0.750 x 0.077)	=	0.018 +
	(0.312 x 0.250 x 0.057)	=	0.004
		=	**0.311**
Final score Supplier E =	(0.392 x 0.883 x 0.101)	=	0.033 +
	(0.392 x 0.167 x 0.154)	=	0.010 +
	(0.160 x 1.000 x 0.071)	=	0.011 +
	(0.096 x 0.167 x 0.193)	=	0.003 +
	(0.096 x 0.833 x 0.455)	=	0.036 +

(0.039 x 0.833 x 0.455)	=	0.015 +
(0.039 x 0.167 x 0.143)	=	0.001 +
(0.312 x 0.750 x 0.737)	=	0.172 +
(0.312 x 0.250 x 0.649)	=	0.051
	=	**0.333**

Therefore, the AHP calculations rank the candidates in the following order:

1. Supplier A 0.356
2. Supplier E 0.333
3. Supplier C 0.311

The first thing that we notice is that the scores of all suppliers are quite close. The margin between Supplier A and Supplier E is 0.023 and the margin between Supplier A and Supplier C is 0.045. However, it is somewhat a surprise that these scores proved to be this close.

Looking to the raw scores, Supplier A was outperforming Supplier E and Supplier C almost on every sub criterion. The results of the raw scores are recognized in the decision hierarchy. Except for the sub-criteria "monthly subscription all vehicles", "service centers throughout Europe" and "Uptime of the SaaS solution" Supplier A is performing equal or better than Supplier C and Supplier E, most often by big margins.

The reason the final score of the suppliers is quite close, is because exactly those criteria mentioned in the previous paragraph are related to the main criteria Costs and Technical reliability. The criteria Costs and Technical reliability represent almost 70 percent of the total weight of the main criteria which is a lot compared to the other 30 percent divided over three other criteria.

Since Supplier A came out on top with the raw scores, it is not strange the AHP selected Supplier A to be the most suitable supplier for Company X. In the next section we take a look on how robust the solution is and how the solution changes if other weights were used.

6.5 Sensitivity analysis

The goal of this section is to perform a sensitivity analysis to gain confidence about the solution of Supplier A being the most suitable supplier. To perform the sensitivity analysis, we must choose which weights are going to be influenced. Looking to the hierarchy tree, two levels of weights can be influenced. The third level could be influenced as well, but since these scores accurately represent the raw scores of suppliers it does not make sense to change these.

Because it appears the criteria Costs and Technical reliability were the biggest reason the final results between candidates were close, the main criteria weights are considered for the sensitivity analysis. All calculations for the sensitivity analysis are performed in Excel. For each of the main criteria, the weight is changed from 0.1 to 0.9 to see how the corresponding scores of all candidates change. The desired result is that no change in preference between candidates occurs when the weights are changed. Below the results of the sensitivity analysis per weight are displayed in charts. The x-axis represents the change in weight and the y-axis represents the new score that corresponds to that weight.

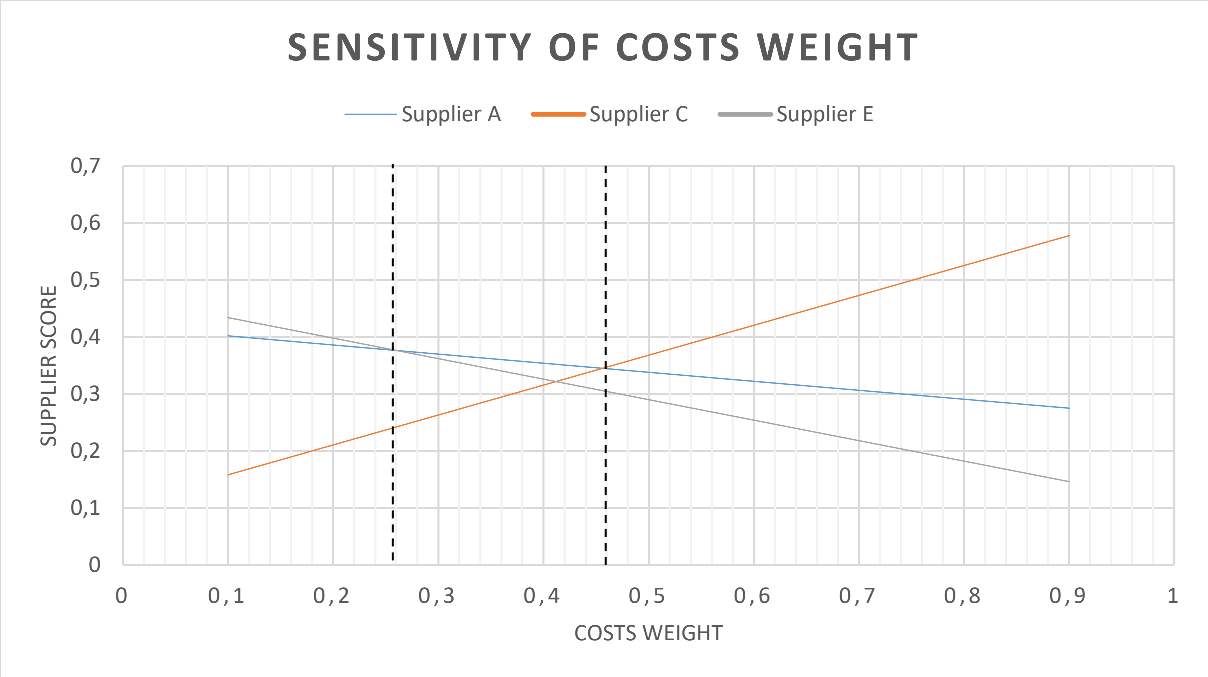


FIGURE 6.3 SENSITIVITY OF THE ATTRIBUTE COSTS

In Figure 6.3 the chart of the sensitivity of the attribute costs is depicted. It is clear to see that when the weight of costs is increased, the solution is changing towards the preference of Supplier C as software package supplier. The switch in preference between Supplier A and Supplier C is happening when the weight of costs is around 0.46. Of course, the closer the actual weight awarded to the costs attribute is to this threshold value, the more the decision maker should be alert to the impact this weight has on the final solution. In addition, the decision maker should reconsider whether the current weight accurately reflects the situation. The weight of the attribute costs resulting from the pairwise comparisons was 0.392. Therefore, an increase of 0,068 is required in weight for the attribute costs for Supplier C to be preferred over Supplier A. In addition, when the weight of the attribute costs is below the value of 0.260, Trimble would come out on top. This change in preference requires a decrease of 0.132, which is quite a lot.

Contrary to the previous chart, in Figure J.1 (see appendix J) we see that the final solution of Supplier A being preferred is not sensitive at all to the attribute implementation time. Whatever the weight of implementation time would be, Supplier A is preferred over Supplier C and Supplier E. It does have an impact on the rankings of the three candidates, where we can see a transition of the 2nd and 3rd place. If the weight of implementation time passes the threshold value of 0.3, Supplier C is ranked second, preferred over Supplier E. The current weight value of implementation time is 0.160. Therefore, it is unlikely that an increase of more than 0.140 would accurately represent the decision owner his concerns.

The attribute vendor reputation is like implementation time neither sensitive to the outcome of software package supplier (see appendix J, Figure J.2). Whatever the value of the weight, Supplier A is preferred over Supplier E and Supplier C and with the weight value increasing, the extent of preference only increases. In addition, the ranking of all candidates does not change with a transition of the weight value.

The results of the sensitivity analysis on the criterion flexibility of the software solution is depicted in Figure J.3 (see appendix J). This figure shows that the attribute is not sensitive for the outcome of most suitable supplier nor the ranking of the suppliers. The higher the weight, the higher Supplier A scores. This increase of Supplier A scores is compensated by a decrease of Supplier C their score, with Supplier E remaining constant throughout the increase of the weight.

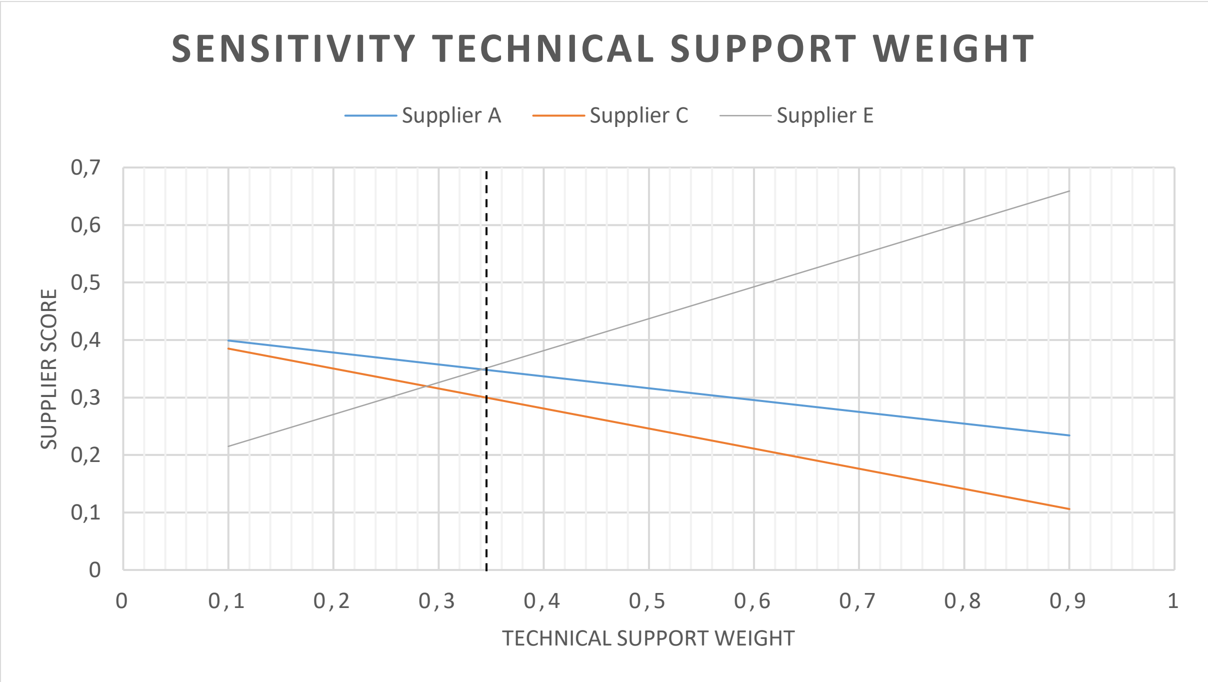


FIGURE 6.4 SENSITIVITY OF THE ATTRIBUTE TECHNICAL RELIABILITY

The sensitivity analysis on the last attribute of the main criteria, the technical reliability attribute, is depicted in Figure 6.4. It is important to note that this attribute is far from insensitive to the outcome of best supplier. The dotted line marks the point where the transition of preference between Supplier A and Supplier E takes place. The threshold value here is about 0.345, which means that if the weight of attribute technical reliability exceeds 0.345, Supplier E would obtain the highest score and results in the best solution of software package supplier. The current weight of this attribute is 0.312. Therefore, an increase of 0.033 on the weight of the attribute technical reliability is required for Supplier E to be the most suitable supplier, preferred over Supplier A and Supplier C.

6.6 Conclusion on sensitivity analysis and AHP

In this chapter the AHP method is applied with the decision problem of picking a supplier of hard- and software for Company X. Based on the results, we can draw a couple of conclusions:

1. The provisional decision from the AHP yields Supplier A to be chosen by Company X as supplier
2. The attributes “costs” and “technical reliability” are the only attributes for which the decision is sensitive
3. Supplier A scores equal or better on six out of nine lowest level attributes than Supplier E and Supplier C

From these three conclusions, only the second one can have an impact in changing the outcome of the AHP. As mentioned in Section 6.5, Supplier C is most preferred if the weight of the attribute costs exceeds a value of 0.470 and Supplier E is most preferred if the weight of the attribute technical reliability exceeds a value of 0.360.

Because of these sensitivities, before giving a final advice to Company X on the supplier decision, I would recommend the decision maker (Business Unit Manager Transport) to have another look on the distribution of weights on the main criteria. However, the main criteria are already assessed on relative importance twice because the first assessments resulted in consistency ratios that were too high. Therefore, we might assume that the current distribution of weights accurately represents the decision maker's concerns on the total decision problem.

In short, because of the AHP result, the good performance on most of the lowest level attributes and the decision maker his judgements, the choice on most suitable software package and hardware supplier is Supplier A.

7. Conclusions and recommendations

The last chapter of this research functions to finalize this thesis by making a conclusion on the action problem, giving recommendations and by a discussion on this research. The conclusion is carried out in Section 7.1 and elaborates more on how the action problem is solved. The recommendations carried out in Section 7.2 can be split into two parts: recommendations for implementation of the hard- and software system for Company X and recommendations for improvement the next time a similar research is done. Last, we take a critical look to the robustness of decisions that have been made throughout this research in the discussion (Section 7.3).

7.1 Conclusions

Central to this research is the core problem which needed to be solved. Recall the core problem from Chapter 1:

Company X must decide on a new on-board computer and software system

To approach this problem, a framework was used which consisted of six stages. These six stages were establishing the functional requirements of the system, investigation of availability of software packages, short listing the packages, establishing criteria for evaluation, evaluating the software packages and selecting a software package. After the functional requirements were established, Company X had already contacted potential software package suppliers that were used for the candidate list. These candidate list consisted of Supplier A, Supplier B, Supplier C, Supplier D and Supplier E. The short listing of suppliers was done by means of creating *boundary conditions.* A supplier that could not meet a boundary condition was crossed out from the candidate list. There were two boundary conditions: the first one indicating the navigation screen (hardware system) needs to be mobile and detachable and the second one indicating the suppliers can provide a charter application, which means a third party (a client of Company X) can use the same software application Company X is using.

After assessing the candidates on the boundary conditions, Supplier B was crossed out (not meeting boundary condition two) and Supplier D as well (not meeting boundary condition one).
The established evaluation criteria used in stage four are supported by literature and experts from Company X. The five main evaluation criteria are: costs, implementation time, fidelity of vendor, flexibility of software solution and technical reliability. Each of these main criteria is linked to a sub criterion necessary to measure the performance on these criteria, which are the following: monthly subscription costs of all vehicles and total hardware and installation costs (costs), number of existing clients with same TMS as Company X (implementation time), number of customers in Europe and owners position of the company (fidelity of vendor), software reprogram possibilities and activation/deactivation of modules (flexibility of software solution) and service centers throughout Europe and uptime of the SaaS solution (technical reliability).

For the evaluation of software packages from Supplier A, Supplier C and Supplier E the Analytic Hierarchy Process (AHP) was used (selected from literature research). The main- and sub criteria were pairwise compared to evaluate their relative importance and to obtain weights. In addition, the software suppliers were pairwise compared on the lowest level criteria to obtain scores. From the AHP, the final scores for each supplier were obtained which provided the following ranking between suppliers in descending order: Supplier A (0.356), Supplier E (0.333) and Supplier C (0.311). These scores seem quite close. However, because Supplier A also scored equal or better on six out of nine lowest level attributes than Supplier E and Supplier C. In addition, the pairwise comparisons were done by the problem owner twice because the first time not all consistency ratios were at the desired values.

Because the problem owner did the pairwise comparisons twice, we may assume the weights obtained for the evaluation criteria are a good representation of the decision maker his concerns. Taking all this in consideration, we recommend Company X to choose Supplier A as their new hard- and software supplier.

7.2 Recommendations

As explained in the introduction of this chapter, Section 7.2 gives recommendation for the implementation process to Company X as well as recommendations for future research.

Recommendations for implementation

Before coming up with ideas how and to whom the software should be introduced, goals for the introduction should be set. What is the goal of the introduction? And when is it successful? The goals of the introduction are the following:

1. Raising awareness to all involved employees that Company X is changing from software supplier
2. Every employee knows what is going to change and what is expected from them within that change
3. How new functionalities can contribute to general goals and targets from the Business Unit Manager Transport

Kotter (2007) mentions in his article “leading change” eight steps that give transformation effort the best chance of succeeding. These eights steps are used for big changes in organizations, but since this change does reflect that much the change of the *organization* of Company X itself, only three steps are selected. These three steps are as follows:

1. Forming a powerful guiding coalition
2. Creating a vision
3. Communicating the vision

These three steps are useful to reinforce with the three goals of the introduction. To start with the first step, who needs to be the guiding coalition? The most obvious team is the ICT manager and Business Unit Manager Transport. This is because the Business Unit Manager Transport is responsible for the departments involved in this project. Furthermore, the ICT manager has the most technical knowledge and understanding about every functionality of the software system. If new functions of the software application need to be explained to employees he is the perfect fit to do this.

The vision needs to be created by the Business Unit Manager Transport and this vision can entail the goals and targets for this year and how the software functionalities can contribute to this. To create impact, this vision should be substantiated by how employees can actually achieve this vision and within which period.

Lastly, the vision created by the Business Unit Manager Transport should be communicated well to the employees. The goals of introduction can perfectly be used as content of the message. Those goals were formulated quite general, but more specific to Company X they could be formulated as follows:

1. Explain the reason for changing to a new software supplier: the software system and board computers are outdated for a while and because of this, drivers are not scheduled to their full working capacity, a lower customer satisfaction and high transport costs
2. Explain what opportunities the new supplier will bring in: position of vehicles, available driving times and estimated time of arrival for TCP employees and driver score cards, idling and cruise control monitoring for fuel monitoring

3. Explain how these new opportunities can be exploited by the employees to achieve goals

Next to this introduction strategy, the truck drivers have to be informed and trained with the new software as well. Truck drivers do not visit the office often, so the best way to announce the introduction would be via email. Furthermore, the suppliers offer training to get used to the on-board computers for truck drivers. This is something Company X should make use of.

We described the strategy for introduction and communication. To make the actions that have to be performed more concrete, see the table below.

Responsible	Action	Message containing at least	Audience	Timing
Business Unit Manager Transport	Plenary presentation (PowerPoint)	1. Explaining reasons for changing new software supplier 2. New opportunities with new supplier 3. How opportunities can be exploited by employees	The whole office	Four weeks before implementation begins
Business Unit Manager Transport	Meeting	Logistic schedule for rebuilding and building in board computers into trucks	Manager fleet & equipment, Technical support	Three weeks before implementation begins
Fleet & Equipment	Project planning	Logistic schedule for rebuilding and building in board computers into trucks	-	Three weeks before implementation
Technical support	Reading user guide board computers and connect with Supplier A service contact	-	-	During implementation
Business Unit Manager Transport	Email	A mail towards all truck drivers of Company X announcing the introduction of new on-board computers	Truck Drivers	Four weeks before implementation begins
Technical support (together with staff Supplier A)	Meeting	Training the truck drivers for the new on-board computers		

TABLE 7.1 ACTIONS SCHEDULE FOR IMPLEMENTATION

Points of improvement for research

The next time a better way to measure the criterion implementation time might be by making an estimation of the total implementation time. However, the measurement is in that case still dependent on the quality of estimation of the supplier. Therefore, it *might* be an improvement but any way it sounds more logical to measure the criterion implementation time by actual time.

Furthermore, to reduce the possible criticism of the way the process is depending for quite a big part on the judgmental ability and input of the problem owner, a team could be appointed instead of one manager to perform the pairwise comparisons of the evaluation criteria. This is more complex, since the more people involved the more opinions can be contradictory.

Can this bachelor assignment have additional value in the future?
Of course, this assignment is quite specific to the situation of Company X. The collaboration between Company X and Supplier A is probably contracted for three to five years. Of course, by the time they need a new or other software system, the approaches from this bachelor assignment can be useful. Although, by that time whole other boundary conditions for the software system and evaluation criteria for the suppliers might be of concern.

7.3 Discussion

In this section, the discussion, there is room to reflect on decision that have been made and we take a look on the robustness of the whole process of supplier selection. To answer whether the selection process is robust, we should identify the elements the decision is dependent on. The following aspects were key in constructing the decision:

- Establishing the boundary conditions for the software package, the evaluation criteria for the suppliers and the metrics to measure the performance of the suppliers on those criteria
- The input and judgmental ability of the problem owner at Company X
- The selected multi criteria decision analysis method

To comment on the first point, are the metrics used to measure the performance of suppliers on the criteria a logical choice and do they reflect the criteria in a correct way?
The implementation time is measured with the number of customers of the supplier where the supplier installed his software. However, a better way to measure this criterion might be to ask suppliers for an estimation of the total implementation time (this was unfortunately noticed too late in the process).

In addition, for each sub-criterion you actually want to know how often such a case occurs. For example, the number of breakdowns of the software system of Company X or how often the reprogramming of software was needed. Unfortunately, this data was not collected at Company X and thus not available. To confirm the importance of the sub-criteria, such data could be useful.

To comment on the second point, seeing the problem owner his position in the company (as Business Unit Transport Manager, responsible for all departments related to the on-board computers and software system) and given his position in the project he should have the best judgmental ability for the decision making.
Furthermore, the SMART and AHP method have a lot of similarities and with the right metrics to measure the attributes used as input for these methods, in fact they should yield the same outcome.

References

Goodwin, P., & Wright, G. (2009). *Decision Analysis for Management Judgment* (Fourth ed.). Wiley.

Heerkens, H., & Winden, A. V. (2012). *Geen probleem: Een aanpak voor alle bedrijfskundige vragen en mysteries: Met stevige stagnatie in de kunststoffabriek*. Nieuwegein: Van Winden Communicatie.

Jadhav, A. S., & Sonar, R. M. (2011). *Framework for Evaluation and Selection of the Software Packages: A Hybrid Knowledge Based System Approach*, 1394-1407

Keeney, R. L., & Raiffa, H. *Decisions with Multiple Objectives: Preferences and Value Tradeoffs*. New York: John Wiley & Sons.

Kotter, J. P. (2007). *Leading Change*, 1-10.

Kovács, G. (2017). *Optimization Method and Software for Fuel Cost Reduction in Case of Road Transport Activity*, 201-208

Saaty, T. L. (1990). *The Analytic Hierarchy Process*. Pittsburgh: RWS Publications.

Singh, S., & Singh, A. (2014). *Design and Evaluation of a Real-time Fleet Management System*, 2(3), 95-99

Sun, Y., Zhang, J., Xuemei, Zhang, X., & Lou, P. (2016). *A Reputation Evaluation Method for Supplier Selection*

Appendix A Transfusion

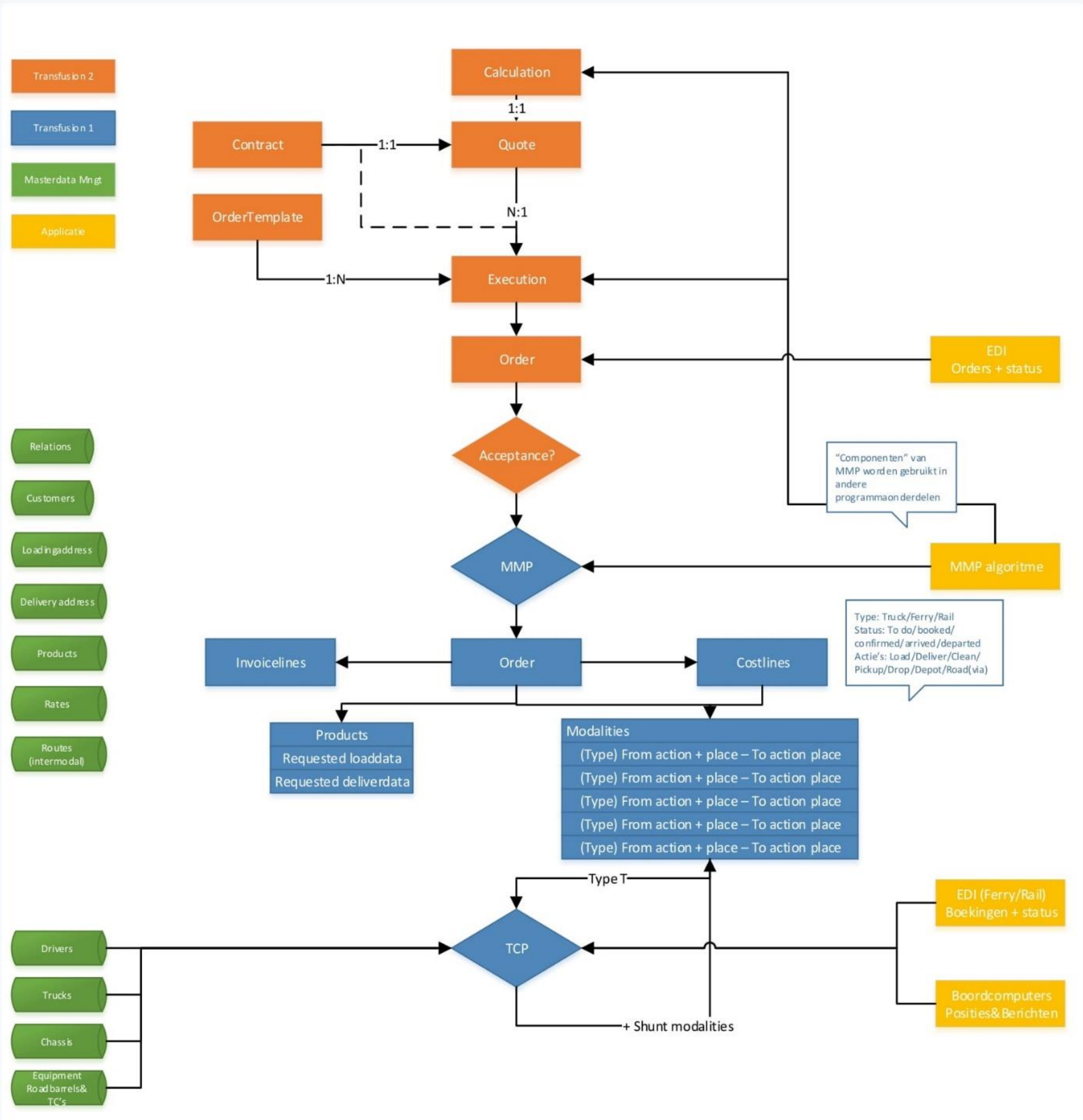


FIGURE A.1 ENTITIES IN TRANSFUSION

Appendix B Fuel consumption and data collection Company X

Verbruik UK per chauffeur 2018 week 18

Code	Driver	Afstand (km)	Rijden	Average speed (km/h)	Driving cruise control	Stationary %	Max speed (km/h)	Driving fuel consumption (Km/1L)	PTO %	Rollout %
5849		2.339	35:19:35	66	52,69	28,62	115	3,47	15,3	12,8
5736		3.026	46:35:39	65	35,26	20,87	105	3,34	0,0	8,7
5755		3.830	51:36:34	74	38,41	15,98	102	3,25	0,0	8,9
5822		2.493	35:05:26	71	58,64	29,57	100	3,24	23,0	12,7
5747		2.954	43:20:00	68	57,06	36,75	125	3,23	0,0	7,9
5751		2.298	32:31:18	71	65,30	26,23	109	3,22	0,0	7,8
5920		2.803	40:05:19	70	27,34	21,07	100	3,22	0,0	10,0
5839		2.010	29:01:30	69	4,36	35,41	105	3,20	20,8	9,6
6310		2.436	36:08:30	67	36,86	19,38	104	3,18	0,0	10,7
8574		1.982	29:34:19	67	58,18	12,25	96	3,08	0,0	9,2
8565		1.645	26:34:44	62	38,61	23,83	95	3,07	0,0	11,9
5705		2.412	36:28:25	66	61,39	21,92	98	3,00	0,0	7,6
8536		2.510	36:10:50	69	61,67	24,82	94	3,00	0,0	11,0
5921		2.061	29:34:15	70	58,97	18,46	99	2,98	0,0	6,1
5824		3.123	39:25:49	79	34,31	12,82	120	2,97	0,0	8,1
5630		2.141	33:58:12	63	39,73	27,67	98	2,96	10,4	12,4
6320		2.507	37:49:38	66	22,41	19,34	107	2,94	0,0	14,7
5676		2.663	39:30:31	67	53,98	17,76	102	2,92	8,1	10,8
5636		2.584	39:16:17	66	58,50	18,69	102	2,88	2,9	12,1
6580		1.903	29:43:40	64	38,26	25,60	100	2,87	14,5	6,9
5774		322	04:42:32	68	67,30	18,07	94	2,84	0,0	12,7
6840		2.415	34:07:46	71	53,77	29,78	100	2,84	13,6	8,9
5722		2.307	33:52:26	68	36,97	16,12	99	2,79	0,0	9,1
5843		2.525	36:05:08	70	49,31	20,05	104	2,77	4,5	9,7
5779		1.818	32:46:20	55	45,57	41,19	96	2,76	18,2	8,9
5941		2.556	36:21:44	70	32,34	21,19	97	2,74	5,0	8,7
5734		2.175	33:13:06	65	0,00	30,53	95	2,71	8,1	13,5
	Gewogen gemiddelde	63.838		68	43,28	23,20	102	3,03	5,04	9,92

FIGURE B.1 FUEL CONSUMPTION PER DRIVER

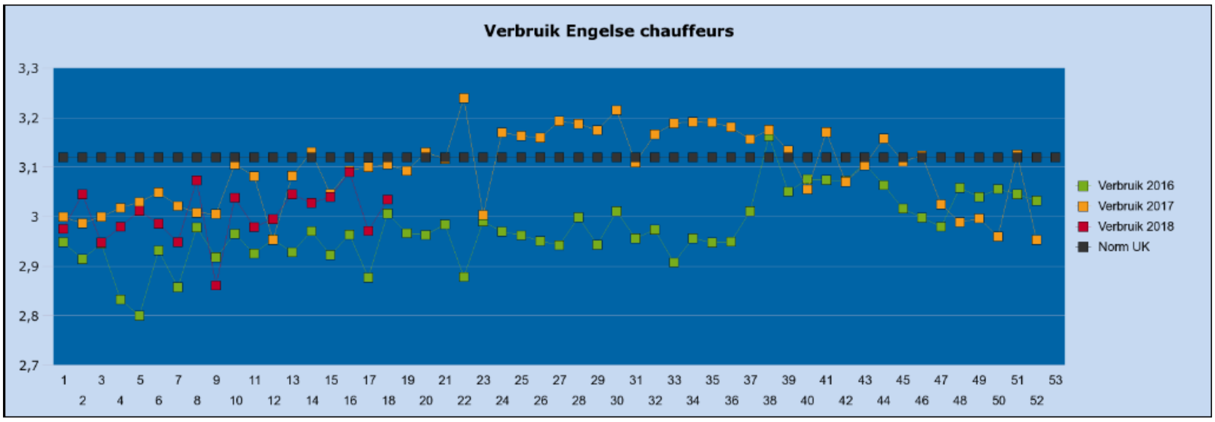


FIGURE B.2 FUEL CONSUMPTION CHART OF ENGLISH DRIVERS OVER THE YEARS

Liters	-BV	Intra	-PL	Trucking Ltd	Totaal
December	12.018	7.802	20.028	5.981	45.830
January	35.897	7.635	71.877	30.488	145.897
February	27.257	6.729	58.749	23.180	115.915
March	26.774	4.963	43.863	20.232	95.910
April	27.951	5.510	31.006	16.056	80.663
May					
June					
July					
August					
September					
October					
November					

FIGURE B.3 NUMBER OF LITERS REFUELED

Trucking	ACT	LYR	TGT
Revenue per own truck	**2.731**	**2.983**	**2.873**
IM	2.513	2.592	2.667
UK	3.455	4.732	3.500
MOD	2.598	2.440	2.756
Loading performance	**68%**	**64%**	**90%**
IM	67%	63%	90%
UK	78%	71%	90%
MOD	79%	92%	90%
Delivery performance	**73%**	**74%**	**90%**
IM	74%	72%	90%
UK	71%	77%	90%
MOD	75%	86%	90%

FIGURE B.4 OVERVIEW KEY PERFORMANCE INDICATORS PER SECTOR

Orders			On time performance				Quantity performance			
Total	AM	PM	N/C	Too late	On Time		N/C	Incorrect	Correct	
27	25 25	2 2	0	4	23	85%	0	3	24	89%

FIGURE B.5 EXAMPLE OF KPI LOADING PERFORMANCE AT NON-CONTRACTED GAS STATIONS PER MONTH

Appendix B1 Employees approached at Company X and questions asked

To acquire the necessary information at Company X, employees from the following departments were approached:

1. Manager Fleet & Equipment
2. Technical Support
3. Fuel Monitoring
4. Planning West Europe & UK
5. Planning East Europe
6. ICT Manager
7. Manager Intermodal Transport

For example, the following questions were asked in a meeting with Fuel Monitoring:

1. What is done at Fleetcontrol?
2. What is being monitored / controlled / checked at Fleetcontrol?
3. Which data is should be collected to monitor this?
4. What are the key performance indicators being checked?
5. How often / in what cycles are they monitoring / checking the data?
6. What elements cannot be monitored now but does Company X want to control?
7. On what information that is collected focusses Company X?
8. What is done if standards are too low?
9. On what information does Company X act to improve?
10. What actions are taken to improve KPI's?
11. How is fuel consumption being monitored?
12. How are contracted gas stations monitored?

In addition, these questions were asked from employees working at planning:

1. What *is* done at TCP?

2. What steps are taken to fulfill the process?
3. What information is needed make the decisions/perform the operation?
4. What criteria for decision making/planning are used?
5. What information need to be dispatch by the on-board computer?
6. When are trucks allocated to a new order?
7. At what *moment* are trucks allocated to new order
8. How is the planning adjusted after job activity status are available
9. What real-time data is the TCP dependent on

Appendix C Functional and non-functional requirements

1. **On-board computer unit**
    a. Truck navigation
    b. Orders, trips, tasks
    c. Message traffic
    d. Document digitalization via camera
    e. Portable device
    f. Driving Style Feedback
2. **Software applications**
    a. Activity registration workflow based on forwarded messages
    b. Option to push & pull messages
    c. Option to add app's f.e.: Transfollow, vehicle checks, Company X academy, Eurotracs
    d. Current position of vehicles
    e. Estimated Time of Arrival
    f. Available driving times (remaining work hours)
    g. Geofencing (ability to define)
    h. Guided Truck navigation
    i. Contracted gas stations integrated in navigation
3. **Fuel monitoring**
    a. Alert sudden fuel drops
    b. Idling monitoring
    c. Cruise control monitoring
    d. Driver Score Card
4. **Additional services or software**
    a. Extending software license per year
    b. Extending on-board computer software per year
5. **Technical requirements**
    a. Service of repair centers throughout Europe
    b. Technical Support - Service Level Agreement
    c. Component Based Solution
    d. Possibility of re-routing messages (to other departments)
    e. Mass memory download without driver interaction
    f. Screen sharing/mirroring
    g. Installation of the on-board computers
    h. Extra software engineering
6. **IT**
    a. SAAS environment (no components to be installed)
    b. Interface towards TMS: Messages, Positions, etc
    c. Standard interface Gatehouse, Eurotracs/Logenius

d. Share portal towards customers based on orders

Appendix D Number of service centers in Europe per core region

CORE REGION / NUMBER OF SERVICE CENTERS	SUPPLIER A	SUPPLIER C	SUPPLIER E
NETHERLANDS	2	2	5
BELGIUM	4	2	5
(NORTH) FRANCE	1	1	6
GREAT BRITAIN	1	0	3
TOTAL	**8**	**5**	**19**

Appendix E Axioms of the SMART method (Goodwin & Wright, 2009)

1) "**Decidability.** We assumed that the owner was able to decide which of two options he preferred. For example, we assumed that he could state whether the improvement in image between Location 1 and Location 2 was greater than the improvement between Location 1 and Location 3. It may have been that the owner was very unsure about making this comparison, or he may have refused to make it all."
2) "**Transitivity.** The owner preferred the image of Location A to that of Location B. He also preferred the image of location B to that of location C. If transitivity applies, then the owner must therefore also prefer the image of location A to that of location C."
3) "**Summation.** This implies that, if the owner prefers A to B and B to C, then the strength of preference of A over C must be greater than the strength of preference of A over B.
4) "**Solvability.** This assumption was necessary for the bisection method of obtaining a value function. Here, the owner was asked to identify a distance from the center of town that had a value halfway between the worst and best distances. It was implicitly assumed that such a distance existed. In some circumstances there may be 'gaps' in the values that an attribute can assume. For example, the existence of a zone of planning restrictions between the center of the town and certain possible locations might mean that siting an office at a distance that has a value halfway between the worst and best distances is not a possibility that the decision-maker can envisage."
5) "**Finite upper and lower bounds for value.** In assessing values, we had to assume that the best option was not so wonderful and the worst option was not so afwul that values of plus and minus infinity would be assigned to these options."

Appendix F Axioms of the AHP method (Goodwin & Wright, 2009)

1) "**Reciprocal axiom.** If A and B are options or attributes in the decision hierarchy and A is *n* times more preferable (or more important or more likely) than B, then B must be 1/*n*th as preferable (or important or likely) as A. For example, if Reliability is four times more important than After-Sales Support, then After-Sales Support must be only ¼ as important as Reliability."
2) "**Homogeneity axiom.** The elements being compared should not differ by extreme amounts on a criterion. For example, this axiom would be violated if A were 24 times more important than B. This axiom is reflected in the range of the AHP verbal scale, which runs from 1/9 to 9. As we discuss below, this axiom can be relaxed if this is judged to be absolutely necessary."
3) "**Synthesis axiom.** Judgements about the importance of elements in a hierarchy do not depend on the elements below them. For example, in our hierarchy, judgement about the relative

importance of Reliability and After-Sales Support does not depend on the packaging machines that are available. Thus, the relative importance would be the same even if a different set of machines were on offer. This axiom may be violated in many practical applications. For example, suppose that we state that Reliability is four times more important than After-Sales Support and then discover that all of the available machines have extremely high and similar levels of Reliability that far exceed the minimum acceptable level. However, they differ to a considerable extent in the quality of After-Sales Support as being more important in our choice between the machines. To guard against this danger, it is recommended that a "bottom-up" approach be applied when evaluating the elements in an AHP hierarchy (i.e. we should start with the alternative courses of action and work upwards). By comparing the machines' performances on Reliability and After-Sales Support first, we would learn about their similarities in reliability, and this would inform our judgment when we came to compare the importance of these two attributes. Alternatively, the analytical network process (ANP) provides a formal approach to this problem but at the cost of greater mathematical complexity."

4) "**Expectation axiom.** Decision makers should make sure that their ideas are adequately represented in the decision model. This is similar to the concept of requisite decision modeling in SMART. If the decision-maker's intuitively preferred option differs from the best option suggested by the model, then this indicates that the model should be investigated to identify the reason for the discrepancy. Perhaps the hierarchy is incomplete or the relative importance of attributes is not independent of the options (see the synthesis axiom above). Alternatively, the investigation might reveal that the decision-maker's intuition is at fault because he or she is unable to comprehend a complex decision problem in its entirely."

Appendix G Systematic literature review protocol

Define key theoretical concepts

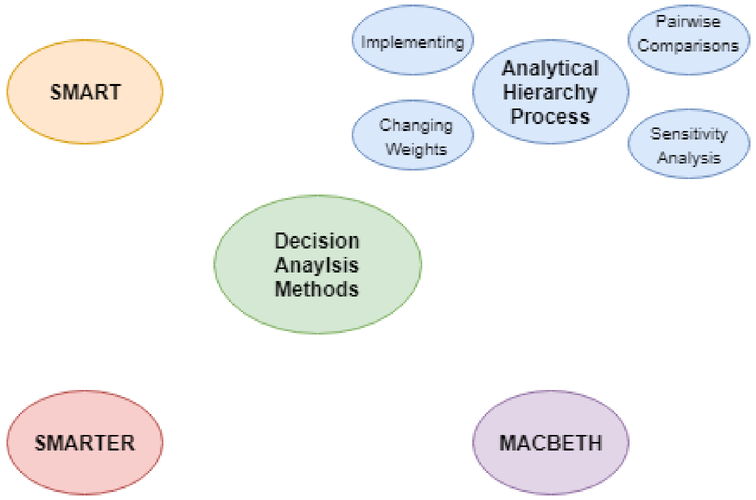


IMAGE G.1 CONCEPT MAP OF DECISION ANALYSIS METHODS

Define search strings

Key words used:

I. AHP
II. Sensitivity Analysis
III. Sensitivity Analysis Methods
IV. Changing Weights
V. Implementing

Search String	Scope	Date of Search	Date Range	Nr. of Entries
"AHP"				
AND "Sensitivity Analysis Methods"	Title, keywords and abstract	5 April 2018	All years allowed	5
AND "Sensitivity Analysis" AND "Implementing"	Title, keywords and abstract	5 April 2018	All years allowed	19
AND "Changing Weights"	Title, keywords and abstract	5 April 2018	All years allowed	8

TABLE G.1 SEARCH STRINGS

Determine inclusion and exclusion criteria

Number	Exclusion Criteria	Reason for exclusion
1	Not downloadable	Scopus could not download the article due reasons such as copy right
2	"fuzzy" mentioned in abstract	Fuzzy AHP applications are related to decision making under uncertainty, which is not the case in this bachelor assignment

3	Sensitivity Analysis done with complex mathematical calculations	These calculations fall under a specialized area of sensitivity analysis which are out of this scope
4	References from unidentifiable sources	The references showed signs of not scientific based article
5	Unclear Sensitivity Analysis	The researcher mentioned a sensitivity analysis was done, but did not explain how it was performed
6	Removing duplicates	Same article found in multiple search strings
Number	Inclusion Criteria	Reason for inclusion
1	Sensitivity Analysis deeply discussed	Theory about Sensitivity Analysis can be summarized
2	Visible how weights of attributes are manipulated	Enables deeper understanding of Sensitivity Analysis

TABLE G.2 INCLUSION AND EXCLUSION CRITERIA

TOTAL IN ENDNOTE	**32**
NOT DOWNLOADABLE	-16
UNCLEAR SENSITIVITY ANALYSIS	-4
"FUZZY" MENTIONED IN ABSTRACT	-3
EXCLUSION CRITERIA 3	-3
EXCLUSION CRITERIA 4	-1
EXCLUSION CRITERIA 6	-1
TOTAL SELECTED FOR REVIEW	**4**

TABLE G.3 ARTICLES SELECTED FOR REVIEW

Use a conceptual matrix

Journal	Author (Year)	Methodology	Key Findings regarding Sensitivity Analysis
School of Management	Sarkis & Sundarraj (2003)	Multi-attribute evaluation of Componentized EIT's	Possible to graphical visualize an attribute (such as cost/benefit-ratio) on multiple criteria of that attribute (the alternatives)
Environmental management	Ananda (2007)	Mapping stakeholder preferences into forest land-use policies with the Analytical Hierarchy Process	Sensitivity analysis can be performed for one weight at a time, and shows how preferences to alternatives changes when weight is varied
Journal of Advanced Manufacturing Technology	Almomani, Abdelhadi, Mumani, Momani & Aledeemy (2014)	A proposed algorithm to find the best route for LEAN implementation using lean assessment and AHP	Increasing each weight with 10%, robustness in ranking of preference of alternatives can be checked
Journal of Business and Systems Research	Luthra, Mangla, Kumar, Garg & Haleem (2017)	AHP methodology to prioritize identified critical factors for successful implementing Reverse Logistics practices	By ranking the weights first of the main attributes, targeted sensitivity analysis can be done on the criteria influencing the problem solution

TABLE G.4 CONCEPTUAL MATRIX

Appendix H Survey application of Analytical Hierarchy Process

This survey is made for a bachelor thesis from the field of Industrial Engineering Management. The survey contains an instrument which is an application of the Hierarchy Analysis Process. The goal is to determine the relative importance of attributes and to compare how well the options perform on different attributes. For all attributes relevant to the decision problem, see the decision hierarchy on the other page. The decision maker can express his preference towards attributes using the following verbal responses:

Equally important	(1)
Weakly more important	(3)
Strongly more important	(5)
Very strongly more important	(7)
Extremely more important	(9)

Intermediate are allowed if the decision maker allows this. For example, between weakly and strongly more important would be converted to a 4.
Please express your preference pairwise between all attributes, per hierarchy, in the following tables.

Costs	**9**	**7**	**6**	**5**	**3**	**1**	**3**	**5**	**6**	**7**	**9**	**Implementation time of software**
Costs	9	7	6	5	3	1	3	5	6	7	9	**Vendor reputation**
Costs	9	7	6	5	3	1	3	5	6	7	9	**Flexibility of software**
Costs	9	7	6	5	3	1	3	5	6	7	9	**Technical reliability**
Implementation time of software	9	7	6	5	3	1	3	5	6	7	9	**Vendor reputation**
Implementation time of software	9	7	6	5	3	1	3	5	6	7	9	**Flexibility of software**
Implementation time of software	9	7	6	5	3	1	3	5	6	7	9	**Technical reliability**
Vendor reputation	9	7	6	5	3	1	3	5	6	7	9	**Flexibility of software**
Vendor reputation	9	7	6	5	3	1	3	5	6	7	9	**Technical reliability**
Flexibility of software	9	7	6	5	3	1	3	5	6	7	9	**Technical reliability**

Monthly subscription all vehicles	**9**	**7**	**5**	**3**	**1**	**3**	**5**	**7**	**9**	**Hardware and installation costs**
Number of installations in Europe	9	7	5	3	1	3	5	7	9	**Owners position of the company**
Software reprogram possibilities	9	7	5	3	1	3	5	7	9	**Activation/ deactivation of modules**
Service Centers throughout Europe	9	7	5	3	1	3	5	7	9	**Uptime of the SaaS solution**

1. **Monthly subscription all vehicles**

Supplier A	9	7	6	5	3	2	1	3	5	6	7	9	**Supplier C**
Supplier A	9	7	6	5	3	2	1	3	5	6	7	9	**Supplier E**
Supplier C	9	7	6	5	3	2	1	3	5	6	7	9	**Supplier E**

2. **Hardware and installation costs**

Supplier A	9	7	6	5	3	1	2	3	5	6	7	9	**Supplier C**
Supplier A	9	7	6	5	3	1	2	3	5	6	7	9	**Supplier E**
Supplier C	9	7	6	5	3	1	2	3	5	6	7	9	**Supplier E**

3. **Number of installations with same TMS as Company X**

Supplier A	9	7	5	3	1	3	5	7	9	Supplier C
Supplier A	9	7	5	3	1	3	5	7	9	Supplier E
Supplier C	9	7	5	3	1	3	5	7	9	Supplier E

4. **Number of installations in Europe**

Supplier A	9	7	5	3	1	3	5	7	9	Supplier C
Supplier A	9	7	5	3	1	3	5	7	9	Supplier E
Supplier C	9	7	5	3	1	3	5	7	9	Supplier E

5. **Owners position of the company**

Supplier A	9	7	5	3	1	3	5	7	9	Supplier C
Supplier A	9	7	5	3	1	3	5	7	9	Supplier E
Supplier C	9	7	5	3	1	3	5	7	9	Supplier E

6. **Software reprogram possibilities**

Supplier A	9	7	5	3	1	3	5	7	9	Supplier C
Supplier A	9	7	5	3	1	3	5	7	9	Supplier E
Supplier C	9	7	5	3	1	3	5	7	9	Supplier E

7. **Activation/ deactivation of modules**

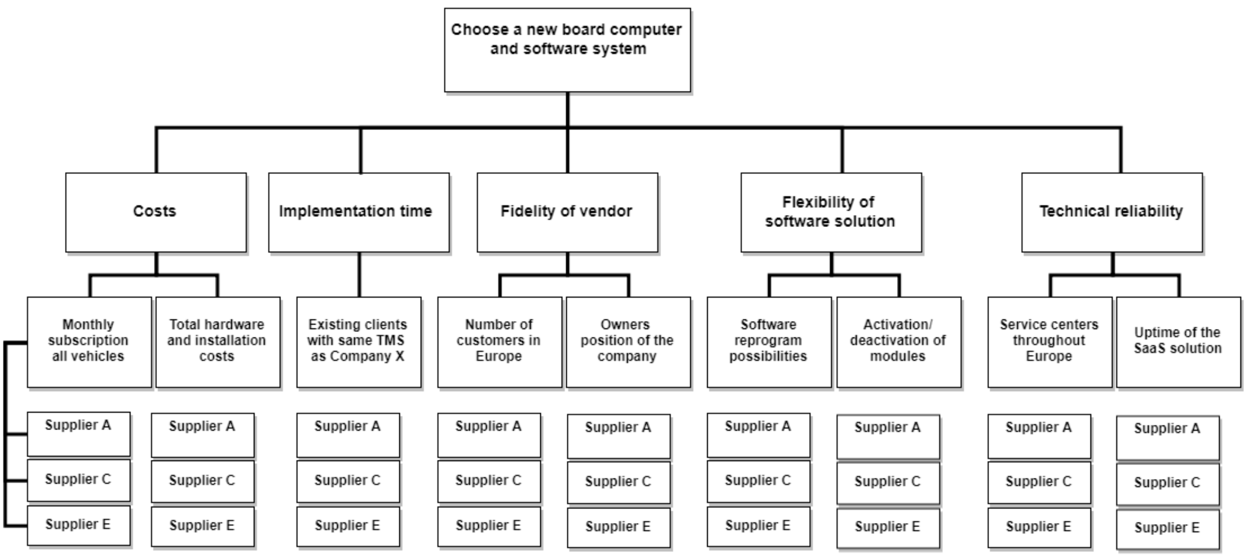
Supplier A	9	7	5	3	1	3	5	7	9	Supplier C
Supplier A	9	7	5	3	1	3	5	7	9	Supplier E
Supplier C	9	7	5	3	1	3	5	7	9	Supplier E

8. **Service Centers throughout Europe**

Supplier A	9	7	5	3	1	3	5	7	8	9	Supplier C
Supplier A	9	7	5	3	1	3	5	7	8	9	Supplier E
Supplier C	9	7	5	3	1	3	5	7	8	9	Supplier E

9. **Uptime of the SaaS solution**

Supplier A	9	7	5	3	1	3	5	7	9	Supplier C
Supplier A	9	7	5	3	1	3	5	7	9	Supplier E
Supplier C	9	7	5	3	1	3	5	7	9	Supplier E



Decision hierarchy including all attributes

Appendix I Procedure calculation of consistency ratios

The calculation of consistency ratios for sets of attributes (where more than 2 attributes are compared) can be done with the following steps:

1) For the matrix where all attributes are compared on importance, write the weights of those attributes on top of each column.

	Supplier A	Supplier C	Supplier E
Weights	0,168	0,751	0,081
Supplier A	1	0,143	3
Supplier C	7	1	7
Supplier E	0,333	0,143	1

TABLE I.1 EXAMPLE CONSISTENCY INDEX FOR ATTRIBUTE MONTHLY SUBSCRIPTION ALL VEHICLES

2) Multiply the weight at the top of each column by each of the numbers in that column. Then sum each row of the resulting table.

	Supplier A	Supplier C	Supplier E	Sum
Supplier A	0,168	0,107	0,243	0,518
Supplier C	1,176	0,751	0,567	2,494
Supplier E	0,056	0,107	0,081	0,244

TABLE I.2 EXAMPLE CONSISTENCY INDEX FOR ATTRIBUTE MONTHLY SUBSCRIPTION ALL VEHICLES

3) Divide each of these sums by the weight for that attribute. Then average the resulting ratios.

	Sums	Weight	Ratio
Supplier A	0,518	0,168	3,085
Supplier C	2,494	0,751	3,321
Supplier E	0,244	0,081	3,023
Average ratio			3,143

TABLE I.3 EXAMPLE CONSISTENCY INDEX FOR ATTRIBUTE MONTHLY SUBSCRIPTION ALL VEHICLES

4) An inconsistency index can be calculated using the following formula:

$$Inconsistency\ index = \frac{average\ ratio\ from\ step\ 3 - n}{n - 1}$$

Where n is the number of rows in the table we are investigating. In our case, n is 3 so we have

$$Inconsistency\ index = \frac{3{,}143 - 3}{3 - 1} = 0{,}071$$

5) Divide the inconsistency index by the appropriate value from Table A.4 to obtain the inconsistency ratio. The values in the table were generated by (Saaty, 1990) to estimate the inconsistency indices for random tables.

n	2	3	4	5	6	7	8	9	10
Random index	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

TABLE I.4 RANDOM INDICES FOR CHECKING THE CONSISTENCY OF A TABLE

Our consistency ratio is therefore 0,071/0,58 = 0,123. This exceeds the recommended value of 0.1 so the decision maker should be alerted his judgements were inconsistent.

Appendix J Chart results from the sensitivity analysis

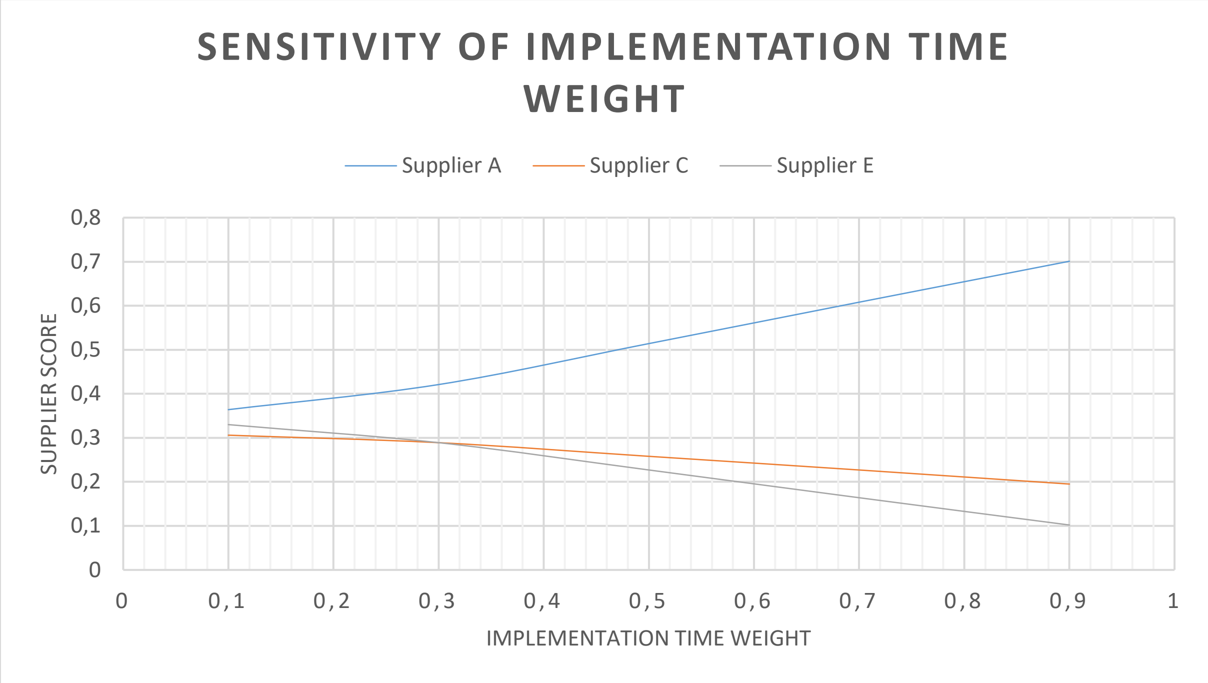


FIGURE J.1 SENSITIVITY OF THE ATTRIBUTE IMPLEMENTATION TIME

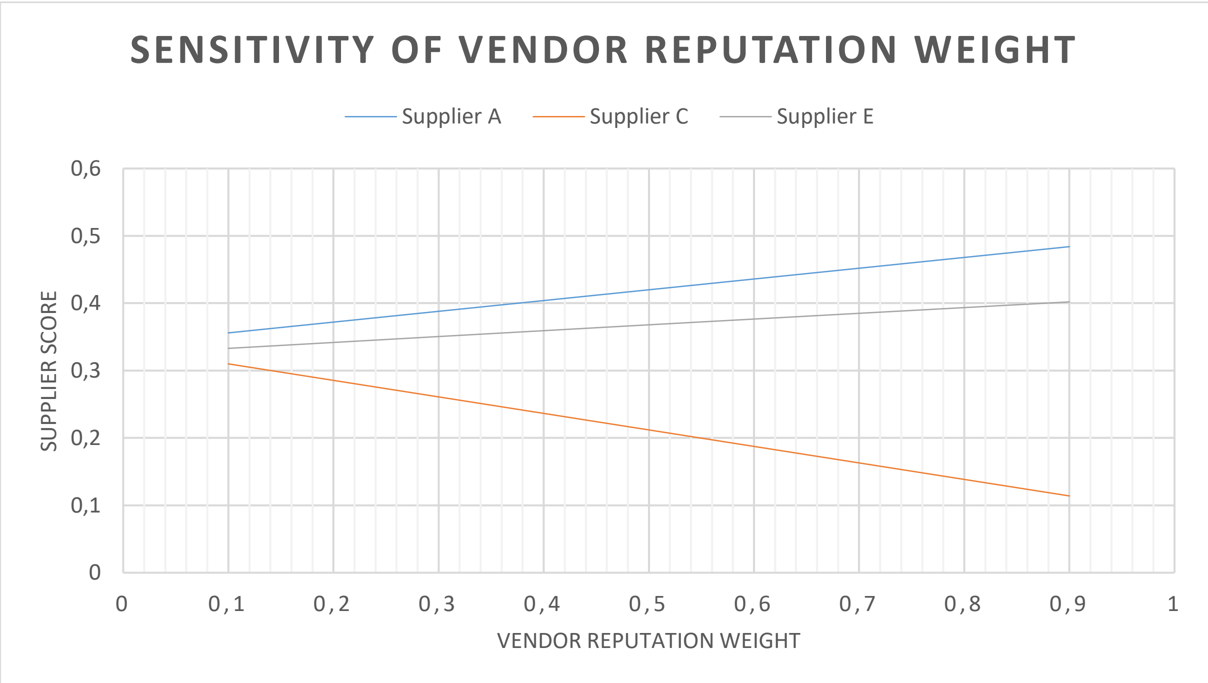


FIGURE J.2 SENSITIVITY OF THE ATTRIBUTE VENDOR REPUTATION

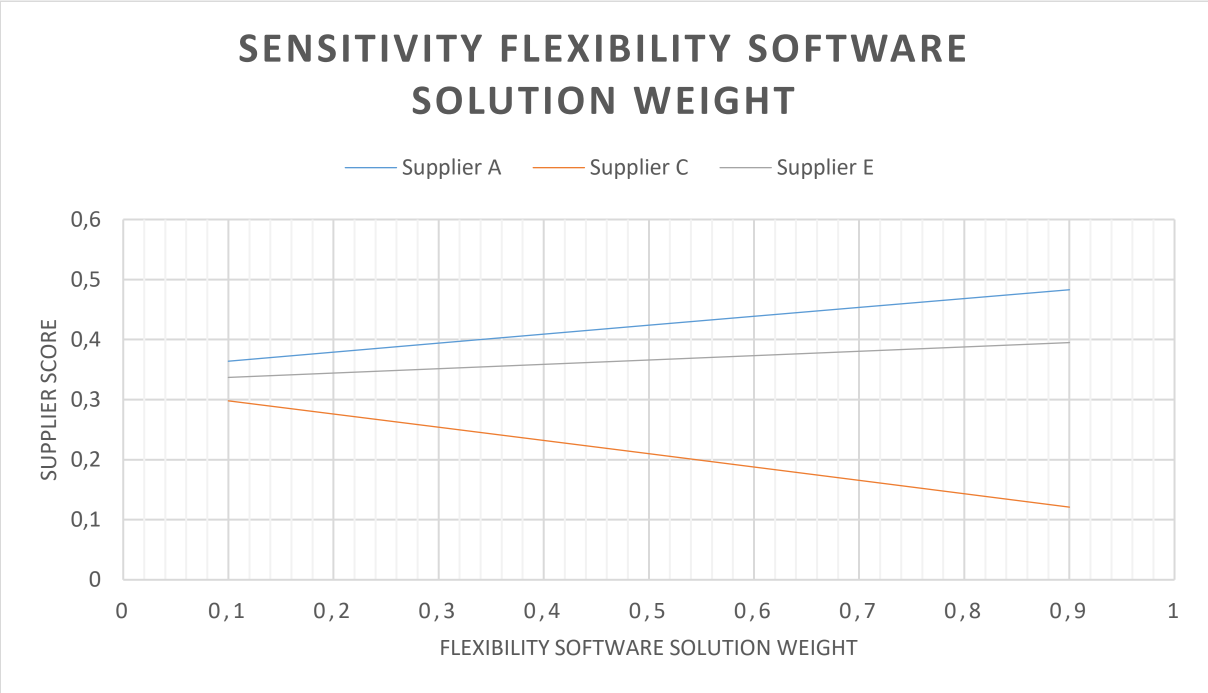


FIGURE J.3 SENSITIVITY OF THE ATTRIBUTE FLEXIBILITY SOFTWARE SOLUTION