Introducing data-driven decision-making to orchestrate a company's supply chain

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Introducing data-driven decision-making for the supply chain at Company X

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Preface

Dear reader,

This bachelor thesis, "Introducing data-driven decision-making to orchestrate a company's supply chain" marks my first independent research project and a significant learning experience.

First, I would like to thank my company supervisor for the practical insights and the other colleagues for welcoming me with open arms. During my time at Company X, I experienced a lot of valuable lessons and interactions that helped me to finish this thesis.

Secondly, a special thanks to my university supervisors, Ieke Schrader and Martijn Koot, for their invaluable guidance. Their encouragement and expertise were instrumental in the completion of this work.

Lastly, I would like to thank my family and friends. I am deeply grateful for their unwavering support.

This journey has been both challenging and rewarding, and I am excited to contribute to the field of supply chain management.

I hope this thesis is to your liking.

Gijs Niewzwaag

July 27, 2024

Management Summary

New intel to support supply chain decisions is discovered by introducing a data-driven decision-making tool in the form of two interactive draft dashboards with KPIs.

Company X makes many intuition-based decisions in the supply chain that leave them uncertain if a decision was the right choice. Therefore, the Supply Chain Manager struggles with making decisions. The Supply Chain Manager has to make decisions without information and cannot see the direct consequences of the decisions. Company X has data available, however, this data is unutilized to support decisions. To solve this problem, the research seeks to answer the following main research question:

"How can Company X create insight into transportation and order-picking to make data-driven decisions in the supply chain?"

Crisp-DM a methodology for data analytics is used as an approach for the research. The research starts with a Business Understanding by conducting interviews with order-pickers and trucks to understand the working steps and methods and creating a cost overview to clarify the financial situation of the order-pick trucks and transport trucks. Thereafter, in the Data Understanding, the available data set is identified. Based on this data set fleet performance related KPIs are developed, followed by a Data Preparation to fill the KPIs with data. In the Modelling phase, the KPIs are used to make two draft dashboards, the Driver Performance Dashboard and the Fleet Performance Dashboard. These draft dashboards give information on the performances of the truck driver, the transport truck, the supplier and the fleet as a whole.

The draft dashboards give new intel on transportation performances in the supply chain of Company X. This intel is a data-driven basis that can serve as a support for the Supply Chain Manager to make decisions. Moreover, the Supply Chain Manager can see the direct consequences of the decisions with KPIs in both dashboards. Additionally, a deployment plan is set up to serve as a guide for the practical implementation at Company X. Finally, a list of recommendations based on the results of the research is offered and ideas for further research to extend and improve the draft dashboards are given.

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1. Introduction

This Chapter will give the required information to understand the problem with the necessary background information. A problem approach will be given with a research design. To clarify the problem, in Section 1.1 until 1.3 background information, a thorough problem statement and the measure of the problem is given. Section 1.4 will explain the problem approach, divide the problem into multiple research questions and clarify the research design. Finally, Section 1.5 will offer the deliverables.

1.1. About Company X

Company X, founded over a century ago, is a wholesale company in cleaning products. Currently, the company has one facility and an additional production facility is being built. They deliver high-quality products for safety and hygiene at work and specialize in the sectors of Medical, Industry, Facility and Pharmacy & Food. These products are either from A-brands or from their line of products and the focus lies in the Netherlands. Company X has been given the predicate “Purveyor to the royal household”, which stands for their quality, solidity and continuity.

Company X struggles to make decisions and requires data analysis to find opportunities to decrease costs and evaluate the performance to support decisions. For this research, the process of Company X is viewed, which goes through a couple of steps to complete the wholesale process. Through the sales department, Company X gets an order from the customer. The customers can decide if they want their order completely delivered or partially. If they want their order complete this might take more time, if they want it partially they can get some articles faster. If all articles are in stock and the shipment is set on partially or fully picked the order-pickers can start picking with their order-pick truck see Figure 1-1. If some articles are in stock and the shipment is set on partially picked the order pickers can start picking right away, but if the shipment is set on fully picked the customers have to wait and the order is put on hold until all articles are in stock. If no articles are in stock the customers have to wait and the order is put on hold until articles arrive. The orders are either delivered on the next day, on fixed days, or the sales department can request an urgent order for the same day. The order picker takes on one whole order and picks all the articles with his truck. When the whole order has been collected, the order picker will indicate this through the system and prepare the order for transportation. The truck driver has a fixed line of transportation locations and loads the orders that are part of his line into the transportation truck. The truck driver delivers the order to the customer and makes them sign the papers of delivery with the transportation truck see Figure 1-2.

Figure 1-1: Order-pick truck

Figure 1-2: Transportation truck

1.2. Problem Statement

1.2.1. Problem Identification

Company X makes many decisions based on intuition in the supply chain. After making decisions Company X has no effective way to evaluate the impact of these decisions. Therefore, decisions that impact the costs and processes of the supply chain are difficult to make. The Supply Chain Manager wishes to have more information to improve the quality of the decisions. Currently, there is a lack of information to make quality decisions. Information can give insight and is the result of processing data through various techniques [1]. There are different forms of operational data gathered by Company X and available to Company X, however, it is unused and does not give any insight into the supply chain.

1.2.2. Problem Cluster – Core problem

In the problem cluster, multiple problems are given. Based on the problem cluster shown in Figure 1-3, the action problem can be derived. Our action problem is, *"The Supply Chain Manager struggles at making decisions."*. Owing to the fact that the supply chain decisions are made without information and based on intuition, and the Supply Chain Manager has no intel on the consequences of the decisions made.

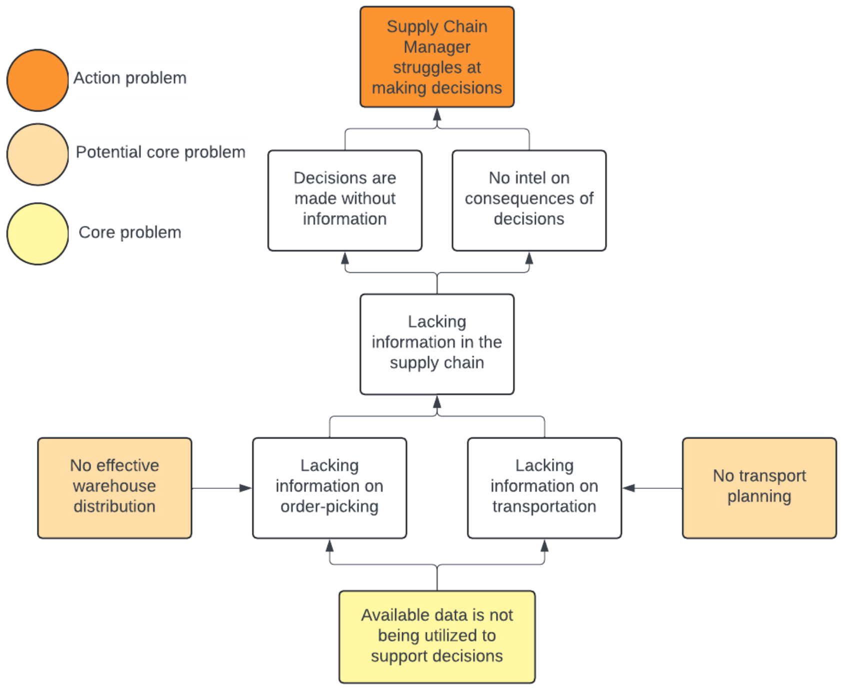


Figure 1-3: Problem cluster

Figure 1-3 shows that decisions are made without information and no intel is available on the consequences of decisions, because the supply chain lacks the information for this. This research only considers the order-picking and the transportation within the supply chain as the Supply Chain Manager voiced that these sections lack the most information whilst data is available.

For the order-picking, the Supply Chain Manager voiced that the warehouse distribution had many problems with the order-pickers. Handling this could improve the information on order-picking. This could have been a potential core problem, but this topic is handled by another intern at Company X. Therefore, information related to the distribution of products within the warehouse will be excluded from the order-picking field. For transportation, a potential core problem could be a lack of transport planning for Company X. Creating a new transport planning could offer information on the exact routes that are driven by the truck drivers. However, the supply chain manager and the IT department of Company X are currently working on a new transport planning system. For that reason, information related to the routing of the transport trucks will also be excluded from the research.

Finally, in Figure 1-3, the underlying core problem for lacking information on order-picking and transportation is:

"The available data from the order-picking and transportation is not being utilized to support decisions."

Since Company X has data available for both order-picking and transportation this data can help to extract information that supports the Supply Chain Manager when making decisions or to see the consequences of a taken decision.

The Supply Chain Manager voiced that the main difficulties arise in the following areas:

- Evaluating the employees, in this case, the order-pickers and the truck drivers.

Some order-pickers do more and bigger orders than others, require less time for their order or are better at handling their order-pick truck. This is because the working methods differ. The order-pickers can divide the weight differently, change the order of picking items or drive their order-pick truck differently. Currently, Company X cannot say which order-pickers perform better based on data. If they can see which order-picker performs best, the working methods of this order-picker can be compared to the others. The same goes for the truck drivers, some truck drivers take less time for deliveries than others, do the loading and unloading of pallets faster or have a better driving style.

- Determining how the trucks are performing individually, as a fleet and in terms of the suppliers, in this case, the order-pick trucks and the transport trucks.

The Supply Chain Manager considers some trucks more costly in terms of maintenance and capital costs than others. Capital costs are the initial costs Company X had to pay to buy the truck. These costs can be found in invoices that Company X gets from their truck suppliers when repairs have been done. However, more information is required to evaluate these costs and the differences between the trucks. For the transport trucks, other aspects of driving, like the sustainability of a truck and the ability to offer economical driving are also relevant when evaluating the truck's performance. To make decisions on the trucks, knowing if the trucks are still performing well based on the available data can support the Supply Chain Manager. Moreover, the suppliers can also be evaluated based on these aspects of the trucks and the costs to determine if the suppliers perform well or not.

Company X voiced their opinion that the lack of data-driven evaluation of performances in the order-picking field and transportation field, whilst data is available, is something they want to improve on. So this underlying core problem *"Available data is not being is not being utilized to support decisions"* will be the focus of this research. In the scope of this research, the order-pickers and truck drivers are added in terms of working methods and working performance, and driving methods and driving performance. The order-pick trucks and transport trucks are added in terms of cost performance and driving performance and the suppliers are added in terms of cost performance and performance differences between the trucks. Based on these aspects, the idea is to create new data-driven insight and offer data-driven decision-making.

1.3. Measure

This Section explains the "reality", which is the current situation that Company X resides in and the "norm", which is the future situation Company X wants to reach.

Reality: Company X makes many intuition-based decisions and is not data-driven. They cannot tell which suppliers are performing better based on data. They have no information on what order-pickers and truck drivers perform best. And they lack information on their truck's performances. Moreover, there is no intel on the consequences of the decisions. Thus, currently, "*the Supply Chain*

Manager struggles at making decisions X needs" which is our action problem and *"the Available data is not being utilized to support decisions"* is our core problem.

Norm: The future standard that Company X wishes for is data-driven decision-making. Through data-driven decision-making, the Supply Chain Manager can improve his decision-making. Company X has insight into the performances of the suppliers, order-pickers, order-pick trucks, truck drivers and transport trucks. Besides, the Supply Chain Manager can see the impact of the decisions within the data and act accordingly. In relation to our action problem, this research aims to offer the Supply Chain Manager support when making decisions through data-driven decisions and evaluations with performance management of the order-picking and the transportation to utilize the available data fitting to the core problem. The results are considered "good" when the solutions offer the Supply Chain Manager intel on these aspects and they can be used for data-driven evaluations and data-driven decisions.

1.4. Problem-Solving Approach

The following Section describes the problem-solving approach in connection with the knowledge problems, its research questions, and the research design.

For the research design, 'Business Intelligence' will be used as a discipline to conduct the data analysis. Business Intelligence combines data gathering, data storage and knowledge management with analysis to provide input to the decision process [3]. This applies to the research. So, the research design needs to consider how to conduct the research and what factors to take into account. For the problem-solving approach, the Cross-Industry Standard Process for Data Mining (Crisp-DM) is chosen, a widely recognized structured methodology with clearly defined phases for data mining projects [7]. Crisp-DM has more focus on understanding the business context with an available data set beforehand as part of the data analytics [9]. Comparable to this research it is clear that the company has unused data available, however, it requires exploration to get a clear picture of the data and the company's needs. After the available data is identified, based on this data KPIs will be developed. Although Crisp-DM is traditionally associated with data mining, its flexibility and comprehensive approach make it highly applicable to the development of KPIs and data analytic, which are central to this research.

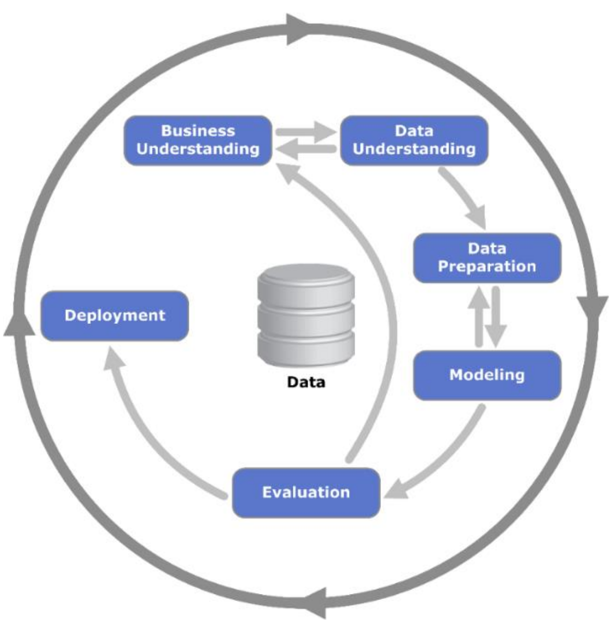


Figure 1-4: Crisp-DM Methodology [10]

1.4.1. Business Understanding

In , which are central to this research.

Figure 1-4, Crisp-DM starts with the 'Business Understanding' for the problem-solving approach. The needs of the company are the main focus, the company's objectives have to be determined, the situation has to be assessed and the goal of the data analysis has to be defined [8]. In this case, Company X wishes to improve the decision-making with the unused data based on the core problem *"Available data is not being is not being utilized to support decisions"*. The goal of the data analysis is to offer data-driven evaluations and information to support decisions. And, to find opportunities to improve performances and measure results. The decisions should relate to order-picking and transportation. Thus our main research question will be:

MRQ: How can Company X create insight into transportation and order-picking to make data-driven decisions in the supply chain?

The variables that will be included in this question are the working methods of the order-pickers and truck drivers in terms of picking methods, transport methods and driving style and the performances of the order-pickers and truck drivers in terms of working performance and driving performance. Relations between working methods and working performances will be researched when working methods differ and some employees have better working performances. Relations between driving styles and driving performances will be researched when driving styles differ and some employees have better driving performances. Finally, the variables suppliers performance and trucks performance are included. Here a relation can be researched between the different suppliers and the trucks performances in terms of costs and other aspects. To answer this question we need to consider sub-research questions to solve other knowledge problems.

For the 'Business Understanding' the research starts by understanding the supply chain of Company X. In Section 1.1 an explanation of the steps the order-pickers and truck drivers go through is given. However, since this research considers the relations between working methods and the performances of the employees, interviews will be conducted to get a clear picture of the different working methods that the employees have and to gain additional details on the working steps. These working steps and methods can be used to find causes for the different performances of the employees. So a sub-research question is:

- *RQ1: What are the different working steps and methods of the employees?*

The research strategy will be to conduct interviews on the working methods of the employees and gain knowledge on the differences between the employees. The interviews should offer more detail into the different steps taken by the employees in terms of picking and transportation but also in terms of driving style and how they use their trucks. The interviews also aim to explore opinions and reasons concerning their work and the working methods and driving styles. Finally, the interviews should offer opinions on their trucks and the suppliers to help in evaluating truck performances and supplier performances. Each order-picker and truck driver has their own truck that they use. Therefore, the results and opinions gathered from the interviews can be compared to operational data on the employee performances, truck performances and supplier performances. Interviews can be biased but comparing the interviews to each other and the operational data, the information can be confirmed or denied. Moreover, a thematic analysis will be applied to the interviews as a quantitative analysis measure to turn the interviews into less biased qualitative data.

With the action problem *"The Supply Chain Manager struggles at making decisions.",* one of the most important things is to have a clear picture of the costs. Decisions have to be made through an evaluation of the costs and the other performances. By creating an overview of the costs of the trucks and the suppliers, the picture becomes clearer on what information is relevant to support decisions based on data. In the scope of this research, an overview of the trucks costs is made, including the maintenance costs and capital costs. This concerns both order-pick trucks and transport trucks. A limitation is made when considering the truck fleet of Company X. Company X has a total of 8 order-pick trucks. Only 6 order-pick trucks will be considered because two trucks have been bought recently and did not inquire any maintenance costs and there is not yet historical operational data available for these two trucks. Moreover, reach trucks are excluded. Company X uses a reach truck to pick products from heights that are out of reach for the order-pick trucks. A reach truck is not used by one person only but by everyone, this makes it harder to evaluate a reach truck's performance and there is lacking operational data available. Finally, the transport fleet consists of 4 transport trucks and one small van. The van lacks measured data whilst driving and only delivers small packages. Thus, the research contains 6 order-pick trucks and 4 transport trucks. So, the next sub-research question is:

- *RQ2: What are the total costs of trucks in the supply chain in terms of maintenance costs and capital costs?*

The research strategy will be to gather all the invoices of the different suppliers and create an overview of all the maintenance costs and capital costs in the supply chain. For transportation, Company X gets their Mercedes trucks from BaanTwente, their Volvo truck from Nijwa. The invoices for their order-pick trucks are from JungHeinrich. The reparations are done by the dealer, the gasoline comes from Affia and the tyres are from Profile. The method of data gathering for RQ1 will be to transcribe the interviews, summarize the interviews and create an overview in Excel. For RQ2 the invoices will be summarized in a table in Excel.

1.4.2. Data Understanding

The next step is 'Data Understanding', as said before in Section 1.2.1 Company X has a lot of data available. Operational data is collected in their ERP software NAVision. Moreover, the suppliers offer measured data about the trucks. Company X has data available to start data-driven decision-making, however, for both the operational data and the measured data the exact attributes of this data and how it can be used are unclear. For this step, we need to consider one sub-research question:

- *RQ3: What data can be gathered at Company X in the supply chain considering the performances of order-pickers, order-pick trucks, truck drivers, transport trucks and suppliers?*

The data-gathering process aims to answer RQ3 and the data related to the performances of order-pickers, order-pick trucks, truck drivers, transport trucks and suppliers. To gather data, the suppliers have to be contacted for the measured data and the supply chain manager has to be contacted for the operational data from the ERP software. The result is an overview of a data set available to the research.

1.4.3. KPIs

Step three will be an additional Chapter on developing KPIs based on the data set of the Data Understanding Chapter. The 'KPIs' Chapter will be about the data analysis of different performances of the employees, trucks and suppliers. With this step we can improve the Business Intelligence of Company X. The data analysis as part of the Business Intelligence will be mainly descriptive to explain the relations and the costs. In the form of key performance indicators (KPI), we can evaluate the performances of employees, trucks and suppliers. For this, we need to consider KPIs about driving performances, working performances, truck performances and supplier performances. To find the right KPIs we ask two sub-research questions:

- *RQ4: What frameworks can be used to develop KPIs that evaluate the supply chain within a company?*
- *RQ5: What KPIs are important in the supply chain considering the performance management of order-pickers, order-pick trucks, truck drivers, transport trucks and suppliers?*

These two questions are important to conduct a proper data analysis and will be done through a literature review. With RQ4 we wish to increase our knowledge on a general methodology to create KPIs and find relations through KPIs. By researching multiple concepts about writing KPIs we can create a framework and apply it to Company X to create high-quality KPIs. RQ5 is the second aspect of the data analysis. We want to look into articles to find out about KPIs that others use or consider important. Variables that we need to consider for RQ5 are the working performance and driving performance of order-pickers and truck drivers, the truck performance and the supplier performance. Variables related to routing and locations will be excluded from the research when considering the performances. Moreover, only KPIs will be included that are viable with the data set from the Data Understanding Chapter. The result should be a list of KPIs for Company X.

1.4.4. Data Preparation

The fourth step is 'Data Preparation', which consists of five tasks. Select data, clean data, construct data, integrate data and format data [8]. The goal of this step is to prepare the data to fill the KPIs from the resulting list of the KPIs Chapter. For this Chapter, the sub-research question arises:

- *RQ6: What data transformations are required to make the data applicable to the KPIs?*

To answer this question, the Power Query Editor Excel will be used to transform the data and other Excel features will be used for additional integrations and formatting. For Company X the interest lies in making their current data more useful for new insights instead of collecting new data. A limitation can be the wish to consider a new data collection to support the data analysis, however, in the scope of this research introducing new data and collecting data over some time that it becomes reliable is not plausible. On that account, we have to limit ourselves to the available data.

1.4.5. Modelling

In the modelling phase of Crisp-DM, data will be analysed through different modelling techniques [8]. This 'Modelling' Chapter will be about creating a data visualization of the KPIs that can give information to the Supply Chain Manager on opportunities through data-driven decisions to reduce costs, improve performances and measure results in the supply chain. For this, we need to consider the aspects that are of importance to Company X when making the draft dashboard and ask the sub-research question:

- *RQ7: What aspects are important to Company X when creating a draft dashboard?*

This question requires contacting the Supply Chain Manager and discussing the wishes for the draft dashboard. For Company X an Excel draft dashboard suffices as data visualization if it can suffice as a suggestion to Company X. By answering this question we can create a useful draft dashboard for the manager.

1.4.6. Evaluation and Deployment

The 'Evaluation and Deployment' Chapter includes the final two steps. The evaluation step should prove that the action and core problems have been solved, and the MRQ has been answered. The following sub-research question to prove the solution arises:

- *RQ8: What examples of data-driven suggestions for decision-making and measurable results can be given?*

If examples of data-driven suggestions for decision-making and measurable results can be given with data-driven arguments, this would prove that the tool helps to make decisions for the Supply Chain Manager and that the available data is effectively utilized to support decisions. Therefore, improving the action problem *"The Supply Chain Manager struggles at making decisions."* and the core problem *"Available data is not being is not being utilized to support decisions"*.

The final step is the deployment of the KPIs and the draft dashboard. This part is about the actual implementation at the company. The model has to be converted to a data-driven decision-making tool for the company. Every company has its differences that require a different approach to the implementation. Thus, the following sub-research question is needed:

- *RQ9: What steps are required for the implementation of the KPIs and the draft dashboard at Company X?*

This question will be answered with an explanation of what steps need to be taken to apply the draft dashboard and KPIs to practical use at Company X in the supply chain.

1.5. Deliverables

After conducting the problem-solving approach in Section 1.4, the following deliverables are intended.

- Data analysis report
- KPIs for performances of order-picker and truck drivers
- KPIs for performances of trucks and the suppliers
- Draft dashboard for the Supply Chain Manager

In the data analysis report a deployment plan will be included to apply the draft dashboard and KPIs to Company X. Moreover, in the report evaluations will be given on the different performances of the employees, trucks, suppliers and costs and other opportunities will be explained. The KPIs will mainly be about the working performance of employees, driving performance of employees, truck performance and supplier performance. With the deliverables, the goal is to offer Company X a data-driven decision-making tool where results can be measured.

2. Business Understanding

The Business Understanding Chapter will start by introducing the thematic analysis methodology in Section 2.1.1 for the interviews to answer the research question *"What are the different working steps and methods of the employees?"*. This methodology will be applied to the research question in Section 2.1.2. Through answering this question the working methods in terms of picking methods and driving methods of the order-pickers are analyzed in Section 2.1.3. And delivery methods and driving methods of the truck drivers are analyzed in Section 2.1.4. Then, Section 2.2 will answer the research question *"What are the total costs of trucks in the supply chain in terms of maintenance costs and capital costs?"*. An overview of the 6 order-pick trucks and 4 transport trucks is given.

2.1. Interviews

To increase the Business Understanding of Company X an interview is conducted to answer the first sub-research question *"What are the different working steps and methods of the employees?"*. 6 order-pickers and 4 truck drivers are interviewed.

In general, there are three kinds of interviews, structured, unstructured and semi-structured. In the semi-structured, the interviewee is allowed to elaborate to a certain extent and give additional explanations with open-ended questions. The responses are more comparable and offer more depth [21]. For this research an overview of the topic is clear and the goal is to get more detail on the working methods. Thus, in-depth information is relevant, however, a comparison between each interviewee has to be made. For that reason, the interview is semi-structured. This allows for some in-depth answers but gives comparability between the interviews. The questions are related to the working methods and the usage of trucks. In consultation with the Supply Chain Manager, a combination of closed and open-ended questions have been made. The order-picking questions are about picking methods and problems, opinions on their truck and truck problems, the driving and other suggestions. The truck driver questions are about delivery methods and problems, opinions on their truck and truck problems, the driving and other suggestions. A list of the questions for the order-pickers is shown in Appendix Figure 0-1 and the truck drivers in Appendix Figure 0-2.

2.1.1. Thematic analysis methodology for the interview

In general, data can be categorized as quantitative and qualitative data. Quantitative data uses numeric values, and qualitative data uses both nominal and ordinal data, it is also called categorical data [20]. The transcriptions are the qualitative data, however, to make the qualitative data useful we need to conduct a qualitative analysis to make sense of the transcriptions. A technique that can be applied to qualitative analysis is the thematic analysis. The thematic analysis is described as a descriptive method flexibly reducing data to find patterns and explanations in the findings [22]. It can be outlined in five steps: compiling, disassembling, reassembling, interpreting and concluding [22]. Compiling consists of transforming the interviews into usable transcriptions. Disassembling is about coding the data, coding is defined as "the process by which raw data are gradually converted into usable data through the identification of themes, concepts, or ideas that have some connection with each other." [31]. The data is separated and meaningful categories are made. The codes serve as tags to retrieve and categorize similar data [22]. During the reassembling, the codes are put into context and a theme is given as a pattern. These themes can also have sub-themes and the themes should be checked by asking questions like:

- What is the quality of this theme? (is it important in relation to the research question?)
- What are the boundaries? (inclusion and exclusion criteria?)
- Is there enough data to support this theme? (are there multiple statements of this idea?)

These questions can validate useful themes or patterns [22]. The fourth and fifth steps are to interpret and conclude the qualitative thematic analysis. The research question is answered and the results are given and explained.

2.1.2. Thematic analysis application to the interviews

The compiling step is done by transcribing the recorded audio of the 6 order-pickers and the 4 truck drivers and translating the interviews into English. The qualitative thematic analysis is done twice, once for the order-pickers and once for the truck drivers.

The disassembling step is done in Excel, and based on the answers categories are assigned to the type of answers. For the order-pickers 21 categories (codes) are found to separate the answers listed in the Table 2-1. For the truck driver, 21 categories are found to separate the answers listed in the Table 2-2.

Codes
General difficulty of work
Challenges of work
Working methods to reduce order-picking time
Truck problems
Reason of truck problems
Truck satisfaction
Difficulty of truck usage
Truck repairs
Trainings
Opinion of Trainings
Sort of orders
Problematic conditions
Ideas to decrease order-picking time
Time to find items
Multiple parts opinions
Multiple parts fixes
Warehouse space
Warehouse organisation
Warehouse organisation fixes
Breaking of items
Pick errors

Table 2-1: Order-picker interview categories

Codes
General difficulty of work
Challenges of work
Working methods to decrease delivery time
Route description
Route variety
Opinion on high variation
Brake usage
Highway usage
Driving style
Reason for driving style
Fines
Frequency of customer problems
Sort of customer problems
Waiting time at customer
Stop time
Variation stop time per customer
Loading time
Point of sign off
Trainings
Opinion on trainings
Repairs

Table 2-2: Truck driver interview categories

The reassembling step is applied by searching for patterns in the answers to each category. In Appendix Table 0-5 the analysis is done for the order-pickers and Appendix Table 0-6 the analysis is done for the truck drivers. For instance, multiple statements are generalized to one theme if they mean the same thing, if an order-picker answer fits this statement the box is checked. In the final column, the frequency of employees agreeing on a theme is given to offer strength to a certain theme and offer more validity. The order-pickers identify from O1 to O6 and the truck drivers identify as V1, V2, M3, and M4. V stands for Volvo and M for Mercedes because the difference in trucks needs to be considered.

The interpretation and conclusion of the thematic analysis are applied by analyzing the differences in answers of order-pickers in picking methods and problems, opinions on their truck and truck problems, the driving and other suggestions in Section 2.1.3. And of truck drivers in delivery methods and problems, opinions on their truck and truck problems, the driving and other suggestions in Section 2.1.4.

2.1.3. Thematic analysis results of order-pickers

Only the main results have been included that best relate to differences and opinions on picking methods, driving style and the order-pick truck.

Table 2-3 shows results related to picking methods and problems. Firstly, the order-pickers, with a frequency of 5 out of 6, the order-pickers consider the difficulty of their work as easy shown in Table 2-3. O6 is the newest employee stating "I currently work quite slow and want to be as fast as the others, which puts a lot of pressure on me". Table 2-3 shows that the main challenges for the order-pickers are knowing the items before picking and determining the criteria to sort the order, both with a frequency of 3 out of 6. Since the warehouse has many different products and the list is not sorted, mainly newer order-pickers state themes in Table 2-3 like having trouble determining the criteria and knowing the products beforehand to stack the pallet efficiently with having to repack the pallet. O1 and O5 are employed the longest and did not state any real challenges. Working methods to reduce picking time by O1 and O5 in Table 2-3 are checking the order beforehand, using the reach truck at the very end when required multiple times and picking large, heavy and stackable items first to pack more efficiently. The reach truck is required for products that are located higher up where the order-picker cannot reach, if the order-picker sees multiple products and knows that it requires the reach truck, these products will be picked last so the reach truck can be used in one go. By checking the order beforehand, the order-picker can determine to pick heavy, large and stackable items before smaller and lighter items.

Codes	Themes	Order-pickers						Frequency
		O1	O2	O3	O4	O5	O6	
General difficulty of work	Easy	x	x	x	x	x		5
	Hard						x	1
Challenges of work	Knowing the items before picking to decide on an order			x	x		x	3
	Determining the criteria to sort the order				x		x	3
	Busy period		x					1
Working methods to reduce order-picking time	Checking the order beforehand	x	x		x	x		4
	Use the reach truck at the very end if it is by required multiple times	x						1
	Larger boxes on the bottom and smaller ones on the top				x	x		2
	Heavy items on the bottom and lighter items on top	x	x		x	x		4
	Stackable items on the bottom	x	x			x		3

Table 2-3: Picking methods frequency results

The spider chart Figure 2-1 relates to driving and truck usage with the frequencies given on the axis. To consider the truck in relation to the working methods, the spider chart shows 5 out of 6 order-pickers have little to no problems with their truck and find the usage of the truck easy. Only O6 has had problems and finds using the truck harder but states that he/she always had problems with driving. Moreover, Figure 2-1 shows that all order-pickers are highly satisfied with the trucks. Truck repairs have been limited in the past months to two employees having no repairs, three employees having small repairs that were quickly handled by the technical department and as shown in Figure 2-1 only one significant repair was due where the supplier was required to step in. O1 stated "The last repair was three months ago due to a worn wheel." and viewed it as a result of long usage and ageing and nothing significant.

Figure 2-1: Spider chart of order-picker truck information frequencies

To conclude the interviews of the order-pickers and answer the research question, the main differences in working steps and methods are, that employees with more experience have more product knowledge and check the order beforehand to determine a picking order that makes stacking easier. In general, these order-pickers state that picking heavy, larger and stackable items first is beneficial. And using the reach truck only at the end helps to reduce the time. Comparing these working methods by identifying the fastest order-picker can offer relevant insights on the best working methods. Noticeable in the answers, working methods lacked relation to driving styles when considering truck usage. Overall, the order-pickers stated that the truck usage is simple and they find it easy, O3: "I find it easy." and O1: "Yes, I find driving the truck easy.", and that truck satisfaction is high, O2: "Yes, it functions well." and O4: "Yes, no problems.". In the context of the research, this contradicts different driving styles and proves that driving the order-pick truck is a simple method.

2.1.4. Thematic analysis results of truck drivers

Only the main results have been included that best relate to differences and opinions on delivery methods, driving style and the transport truck.

Table 2-4 shows results related to delivery methods and problems. The truck drivers, in Table 2-4, 4 out of 4 truck drivers consider the general difficulty of their work easy, stating things like V1: "The tasks are straightforward". Nevertheless, in Table 2-4, the truck drivers encounter some challenges at work. Themes like, some customers require special attention, signing off when delivering the products, being too busy, backwards driving and having new customers are stated. Special attention is needed in cases like delivering to a prison or American companies and requiring pre-registration or having to deliver in special locations in the building. These tasks are often time-consuming. Backwards driving can be difficult, due to the size of the vehicle, V1: “Backwards maneuvring requires precision and can be challenging due to space constraints.”. Signing off can take time when the customer is not present or cannot be reached, M3 does the signing off later occasionally without the customer which makes it invalid. M3 uses the signing off by him/herself to save time. Other methods to decrease delivery time shown in Table 2-4 are, knowing the customer and its instructions beforehand, this is considered relevant by all 4 truck drivers. And M4 brings a hand truck that offers him support to unload sometimes. In general, the truck drivers report to rarely have customer problems with a frequency of 3 and M3 reports to sometimes have problems given in Table 2-4. Themes stated in Table 2-4 are the long waiting time or the customer does not accept goods. Reasons stated in Table 2-4 for a long waiting time are, waiting queues at the customer, no customer present, delivery to a specific location, new customers and no allowance to unload. The general case is that the truck driver does not know where to unload and needs the customer to sign off. V2 explains that he/she waits in the queue or searches for the customer. V1 explains that he/she tries to call Company X to arrange that he/she can skip the line, or calls the customer to arrange a location to unload without the customer being present. M3 signs off later to save time when no location is specified and no customer is present or when the waiting queue is too long. Signing off later without consultation with the customer should not happen according to Company X. M4 does not encounter customers with these problems and if no customer is present a location is agreed upon with the customer.

Codes	Themes	Truck drivers				Frequency
		V1	V2	M3	M4	
General difficulty of work	Easy	x	x	x	x	4
Challenges of work	Special attention customers	x	x			2
	Busy				x	1
	Signing off			x		1
	Backwards driving		x			1
	New customers		x	x		2
Working methods to decrease delivery time	Knowing the instructions		x			1
	Knowing the customers	x	x	x	x	4
	Signing off myself			x		1
	Bring a hand truck				x	1
Frequency of customer problems	Sometimes			x		1
	Rarely	x	x		x	3
Sort of customer problems	Long waiting time	x	x	x	x	4
	Customer does not accept goods	x	x			2
Waiting time at customer	Waiting queue	x	x	x	x	4
	No customer present	x	x	x	x	4
	Delivery to a specific location	x	x	x		3
	New customers		x	x		2
	No allowance to unload	x	x	x		3

Table 2-4: Delivery methods frequency results

The bar chart in Figure 2-2 offers results related to driving and truck usage with the frequencies on the y-axis. The bar chart shows with a frequency of two, that V1 and V2 state having many long distances with highways in their routes, with a frequency of one, M3 states having a mix of longer distances with highways but also more residential areas and short distances with highway and M4 only suggests to have short distances with highway and residential areas. Figure 2-2 shows with a frequency of 3, that V1 to M3 consider a high variety in their routes going to many different locations in the Netherlands. M4 is mainly located in the region around the company with less variety. The driving style of V1 and V2 is stated as economical and automatic with a frequency of 2 in Figure 2-2. Both truck drivers explain that their truck is very limited, it accelerates slowly and offers many settings that can support driving more economical. In comparison, the bar chart in Figure 2-2 shows that the other two truck drivers, M3 and M4 state to drive calm and controlled but they make less use of the settings to support driving more economical. Figure 2-2 shows the brake usage of two drivers to be little, this is V1 and V2. Whereas, M3 states sometimes and M4 states to use it a lot. This is also dependent on the route since M4 is mainly in residential areas.

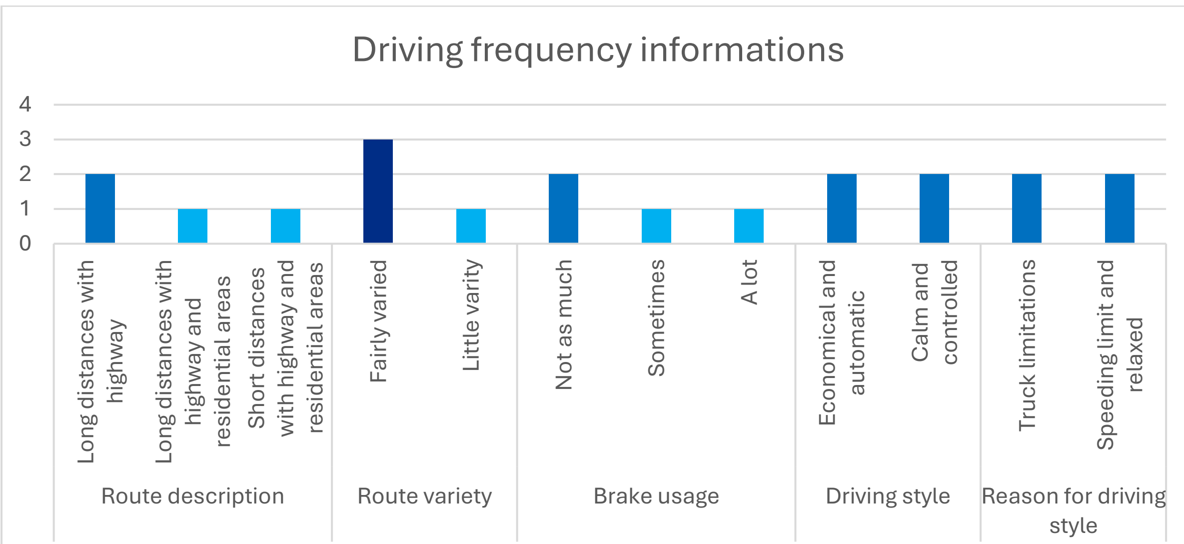


Figure 2-2: Bar chart of driving information frequencies

In conclusion, the main differences in working steps and methods between the truck drivers are the driving styles and the handling of customers. V1 and V2 claim to "Let it coast a lot" and drive "Economical". M3 and M4 claim to drive calmly and to "Sometimes let the vehicle coast", cruise control is used occasionally but the automatic system of Mercedes is used less by M3 and M4 since they want to be in control by themselves. V1 and V2 like the automatic system of Volvo and claim to use it a lot. Different from the order-pickers, the transporters do relate to more aspects when it comes to a driving style. This is a relevant difference and can be compared to the operational data and measured data in the Modelling Chapter. Important differences in handling the customers are, that V1 just waits in the queue, V2 takes action to avoid the queue and calls the customer when not present, M3 signs off him/herself sometimes and M4 claims to not require these measures. These differences can also be compared to the operational data in the Modelling Chapter to see whether some truck drivers have a smaller delivery time than others.

2.2. Costs overview

This Section aims to answer the sub-research question *"What are the total costs of trucks in the supply chain in terms of maintenance costs and capital costs?"*. This is done by collecting the invoices of the suppliers and creating an overview of the maintenance costs from the transport trucks and order-pick trucks. The overview of the maintenance costs is added to the capital costs for the complete overview. The overview helps to have a clear picture of the costs made by each truck.

Table 2-5 presents the cost overview for order-pick trucks and Table 2-6 for the transport trucks. Order-pick trucks are designated O1 to O6 to the order-pickers, and transport trucks are assigned to drivers V1, V2, M3, and M4. Each truck is exclusively used by its assigned operator. The overviews include both repairs and maintenance instances. Maintenance is planned and preventive, repairs are unplanned and necessary because the truck came to a standstill. The first column shows the number of maintenance and repair instances. The next columns represent each truck and subsequent rows detail each truck's total maintenance costs, capital costs, any extra costs, maintenance frequency, construction year and age. Maintenance records and age span from each truck's construction year to May 31, 2024.

In Table 2-5, the construction year of the order-pick trucks is 2021 and all 6 are the same age. Company X has two more order-pick trucks with a construction year of 2024 with no maintenance records yet. For that reason, they have been excluded from the research. The order-pick trucks show a similar frequency of maintenance and repairs ranging from 3 to 6 records. The general costs range from €1078,57 to €1630,36 with one outlier O1 €2674,19. This outlier can be explained with the repair from €908,20, this repair happened due to external use by another employee and not by the order-picker O1. Distracting this repair from the costs would create a new range from €1078,57 to €1765,99 for all order-pick trucks and a frequency ranging from 3 to 5 records. The capital costs of the 6 order-pick trucks are also the same.

Number of maintenance and repairs	Order-pick trucks					
	O1	**O2**	**O3**	**O4**	**O5**	**O6**
1	€ 284,15	€ 284,15	€ 601,19	€ 284,15	€ 335,78	€ 425,02
2	€ 321,00	€ 51,63	€ 309,96	€ 478,98	€ 449,64	€ 140,31
3	€ 432,62	€ 223,06	€ 222,03	€ 564,40	€ 293,15	€ 51,63
4	€ 435,07	€ 372,47	€ 51,63	€ 9,68		€ 460,88
5	€ 908,20	€ 293,15	€ 293,15	€ 293,15		€ 293,15
6	€ 293,15					
Total maintenance costs	€ 2.674,19	€ 1.224,46	€ 1.477,96	€ 1.630,36	€ 1.078,57	€ 1.370,99
Capital costs	€ 15.250,00	€ 15.250,00	€ 15.250,00	€ 15.250,00	€ 15.250,00	€ 15.250,00
Total costs	€ 17.924,19	€ 16.474,46	€ 16.727,96	€ 16.880,36	€ 16.328,57	€ 16.620,99
Total maintenance frequency	6	5	5	5	3	5
Construction year	2021	2021	2021	2021	2021	2021
Years of age	3	3	3	3	3	3

Table 2-5: Order-pick truck costs overview

In Table 2-6, the construction year of the transport trucks shows a lot more variance. V1 is from 14 July 2022, V2 is from 6 January 2023, M3 is from 7 December 2023 and M4 is from 9 January 2020. V1 is 1,88 years, V2 is 1,40 years, M3 is 0,48 years and M4 is 4,39 years. The transport trucks also show a lot more variance in the frequency of records, ranging from 1 to 25 records. There is also more variance in the maintenance costs ranging from €300 to €19089,42. An important consideration is that the M4 is a lot older than the other vehicles of the fleet and has more records and costs accordingly, however, the difference in costs is high to an extent where further research is required. Moreover, V1 has a total maintenance cost of €2084,94 and V2 has €2314,41 whilst being younger. M3 is new and only has €300 in terms of maintenance costs. Besides, the frequency of repairs also results in downtime of the vehicles that can reduce efficiency and for the Volvo trucks, extra costs of €150 are added to lend another vehicle. This has happened once for each Volvo truck so far. Finally, the trucks differ highly in capital costs, with V1 and V2 €96494,00, M3 €101950,00 and M4 €84000.

Number of maintenance and repairs	**Transport trucks**			
	V1	**V2**	**M3**	**M4**
1	€ 63,83	€ 16,19	€ 300,00	€ 207,07
2	€ 1.486,11	€ 80,51		€ 125,82
3	€ 56,31	€ 45,05		€ 539,15
4	€ 478,69	€ 251,91		€ 38,39
5		€ 1.897,07		€ 1.188,55
6		€ 23,68		€ 1.299,74
7				€ 35,00
8				€ 1.660,85
9				€ 923,71
10				€ 91,12
11				€ 675,20
12				€ 901,62
13				€ 1.320,93
14				€ 84,19
15				€ 197,29
16				€ 2.239,14
17				€ 29,67
18				€ 2.576,64
19				€ 2.301,07
20				€ 87,55
21				€ 81,82
22				€ 59,20
23				€ 43,35
24				€ 2.338,49
25				€ 43,86
Total maintenance costs	€ 2.084,94	€ 2.314,41	€ 300,00	€ 19.089,42
Extra costs	€ 150,00	€ 150,00	€ 0,00	€ 0,00
Capital costs	€ 96.494,00	€ 96.494,00	€ 101.950,00	€ 84.000,00
Total costs	€ 98.728,94	€ 98.958,41	€ 102.250,00	€ 103.089,42
Total maintenance frequency	4	6	1	25
Construction year	14-7-2022	6-1-2023	7-12-2023	9-1-2020
Years of age	1,88	1,40	0,48	4,39

Table 2-6: Transport trucks cost overview

To compare the differences in maintenance between the order-pick trucks and transport trucks, Table 2-7 and Table 2-8 have been constructed with the maintenance frequencies and the maintenance costs to calculate the *Standard Deviation*, the *Mean* and the *Coefficient of Variation (CV)*. The formula to calculate the CV is:

$$CV = \frac{Standard\ Deviation}{Mean}$$

A high CV indicates more variability in relation to the mean and more uncertainty, and a low CV indicates less variability in relation to the mean and less uncertainty [38]. Referring to Table 2-7 the maintenance frequency and the maintenance costs of the order-pick trucks show a low CV of 17.50% and 17.88% respectively. On the other hand, Table 2-8 shows a very high CV for the maintenance frequency and costs. This shows that there is less variability between the order-pick trucks and more variability between the transport trucks proving that the transport trucks require further research in terms of costs.

Order-pick trucks	Maintenance frequency	Maintenance costs
Standard Deviation	0,82	€ 254,71
Mean	4,67	€ 1.424,72
Coefficient of Variation	17,50%	17,88%

Table 2-7: Order-pick trucks maintenance variation

Transport trucks	Maintenance frequency	Maintenance costs
Standard Deviation	10,86	€ 8.807,63
Mean	9,00	€ 5.947,19
Coefficient of Varation	120,70%	148,10%

Table 2-8: Transport trucks maintenance variation

In conclusion, comparing order-pick trucks to transport trucks, the variance in maintenance frequency, costs, and age is much higher for transport trucks. This presents opportunities for insight through data analysis in the Modelling Chapter, potentially revealing relationships with truck and driver performance and supplier differences. Earlier, the interviews indicated minimal differences in order-pick truck usage, with drivers finding them easy to operate and experiencing few issues. The order-picker interviews offered no variables to evaluate the driving style. This Section resulted in a low variation in maintenance frequency, costs and age of the order-pick trucks. This questions the relation between order-pick truck costs and truck usage and driving styles. Besides, the supplier for all order-pick trucks is the same, therefore it becomes more difficult to evaluate the supplier. These considerations will be taken into account in the Data Understanding Chapter. If data cannot be found that offers insight into the order-pickers in terms of driving styles, truck performances and supplier performances, including order-picking must be reconsidered. For transport trucks, the identified differences indicate areas for analysis. Successful data gathering in the Data Understanding Chapter will enable the creation of KPIs to evaluate these differences through the draft dashboard.

3. Data Understanding

In this Chapter, the aim is to explore data and gather data from Company X. The research question *"What data can be gathered at Company X in the supply chain considering the performance management of order-pickers, order-pick trucks, truck drivers, transport trucks and the suppliers?",* will be answered in Section 3.1 for the order-picking and in Section 3.2 for the transportation. In these sections, the resulting list of data available at Company X will be explained and discussed.

3.1. Order-picking data identification

This Section involves the data collection related to order-pickers, order-pick trucks and the supplier.

Initially, the IT department indicated they could provide operational data on order-pickers, including order specifications (weight, number of items, volume) over two years. However, due to time constraints and data extraction difficulties, Company X could not provide this data through their ERP software.

Subsequently, discussions with the Supply Chain Manager led to requesting truck specifications and performance data from the order-pick truck supplier, Jungheinrich. While the supplier provided many truck specification variables, they could not offer historical operational data. They proposed a contract to collect future data, which required an investment without a proven basis for cost reduction or performance improvement.

Based on the Business Understanding and Data Understanding chapters, a key conclusion emerged. Interviews in Section 2.1 indicated minimal differences in driving styles and performances, as order-pick trucks were found to be easy to operate. Additionally, the cost overview in Section 2.2 showed low variance in maintenance costs and frequencies for order-pick trucks compared to transport trucks, complicating supplier and truck performance analysis. Due to the limited availability of operational data from both the IT department and the supplier, the research focus shifted away from order-picking to transport trucks and drivers. Nevertheless, two recommendations arose: (1) Company X should use their ERP data related to order-picking to gain insights into order-picking performances if they pursue data-driven decisions in the future. Differences in picking methods identified in interviews can be analyzed using operational data to identify best practices and improve performances. (2) If truck costs increase and satisfaction decreases, consider JungHeinrich's contract for measurable data to evaluate order-pick truck performances.

3.2. Transportation data identification

This Section involves the data collection related to truck drivers, transport trucks and suppliers.

For transportation, discussions with the Supply Chain Manager and IT department revealed that the ERP data could be offered including the weight of delivery, the quantity of deliverables, and the delivery time of sign-off at a customer. Using these variables, truck driver performances can be assessed based on weight, delivery time and customers per delivery. Aspects like street and type of road are currently not available at Company X. Without these variables showing the exact routes driven is difficult to identify for this research. Therefore, route-related aspects are excluded from the research, and the assumption is made that the truck drivers drive identical routes. After several meetings with the IT department, the ERP data for the transportation from 1 January 2023 until 31 May 2024 was provided. The resulting ERP data is shown in Table 3-1 in the left column.

Another conversation with the Supply Chain Manager revealed that the two transportation truck suppliers could provide monthly measurements of the trucks. After multiple requests, the Mercedes supplier could deliver monthly driving reports in PDF format and the Volvo supplier provided a website with data measurement reports where Excels can be exported. The reports of both suppliers could be provided from the construction date given in Section 2.2 until 31 may 2024 for each truck V1, V2, M3 and M4. The reports from Volvo offer more diverse data since the Mercedes reports are limited to driving reports. Driving style-related variables like coasting, brake usage, fuel consumption and other driving-related aspects were provided by both suppliers and shown in the second column of Table 3-1. Individual Mercedes data that could be gathered is shown in the third column of Table 3-1 and the individual Volvo data is shown in the fourth column of Table 3-1.

ERP Data	Combined Supplier data	Individual Mercedes data	Individual Volvo data
TR Nr.	Total distance (km)	Wear-free braking (km)	Distance uphill (%)
Customer Nr.	Average speed (km/h)	Kick down usage	Distance flat (%)
Type of deliverable	Stationary time(engine running)	Distance > 85 km/h (km)	Distance downhill (%)
Amount of deliverables	Stationary time(engine off)	EcoRoll rate	Transport work (t-km)
Weight of deliverables	Total stationary time	PPC rate	Total pedal brake usage (Number)
Delivery time	Stops	Economy program rate	Total brake usage (Number)
Delivery date	Fuel consumption driving (l)	Manual program rate	Fuel consumption with cruise control (l)
DriverID	Fuel consumption stationary (l)	Standard program rate	Fuel consumption during engine load
City	Total fuel consumption (l)		Engine revolutions (Number)
	AdBlue® consumption (l)		Economy time
	CO_2-emission (kg)		Speed under engine load (km/h)
	Roll out (km)		Economy mode (km/h)
	Roll out time		Coasting speed (km/h)
	Cruise-control (km)		Speed with cruise control (km/h)
	Average weight (t)		Speed at too high speed (km/h)
	Braking (km)		Speed in highest gear (km/h)
			I-Shift automatic time

Table 3-1: Transportation operation data list

In Table 3-1 the final data set is given. First, the ERP data is considered, the data set has 19248 rows and 9 columns. The data variables are as following:

- TR Nr. is the unique identifier of one complete delivery.
- Customer Nr. is a unique identifier for each customer.
- Type of deliverable includes the sort: pallet, box, half pallet, block pallet or roll container.

- Amount of deliverables is a number of a deliverable type ranging from 0 to 25.
- Delivery time which is the time of the day that the delivery of one customer is signed off after the unloading is finished.
- Delivery date is the day of the delivery.
- DriverID is the identifier of the driver, in the context of this research V1, V2, M3 and M4.
- City is excluded in this research since the route is not taken into account.

A limitation of this data set is that the activities are registered by the drivers, if drivers sign off later or set the activities as finished a day later this can harm the correctness of the data. The time frame of one year and five months can help to make the mistakes neglectable if mistakes are not too many.

The supplier data sets in Table 3-1 have many data variables that are a sum of the month or averages of the month. The Volvo data set has 33 columns for V1 and V2, V1 has 18 rows and V2 has 16 rows due to the difference in construction date. The Mercedes data set has 24 columns for M3 and M4, M3 has 5 rows and M4 has 24 rows. To generalize the data variables:

- Fuel-related variables are a monthly sum in liters.
- Distance-related variables are a monthly sum in kilometers.
- Time-related variables are a monthly sum of the total time in hh:mm:ss.
- Speed and weight-related variables are monthly averages in km/h and t.
- CO_2 emissions are a monthly sum in kilograms.

The data is dependent on the measurement system of the suppliers, and at first sight, it is difficult to determine the correctness, however, the values seem to be comparable with no significant outliers for each truck driver. A decision is made that only the most recent 5 months of each truck driver is used since M3 only has 5 months available, and using more past months would make it less comparable to M3. For Company X over time these months will increase to support the validity.

The research question *“What data can be gathered at Company X in the supply chain considering the performance management of order-pickers, order-pick trucks, truck drivers, transport trucks and the suppliers?”* is answered for the transportation, in the interviews Section 2.1 different delivery methods and driving styles are shown. The costs are shown in Section 2.2. The ERP data variables are given in Table 3-1, this data relates to the truck driver delivery performance in terms of variables like delivery time, weight and number of deliveries. If a truck driver's performance is high this can be compared to the delivery methods mentioned in the interviews. Finally, the transportation also has supplier data available shown in Table 3-1. Many data variables relate to truck drivers driving style performance, this can be compared to the driving styles mentioned in the interviews. These data variables also relate to the transport truck performance in terms of economical driving, emission and costs and the variables relate to the supplier performance in terms of costs, economical driving trucks and low emission trucks. At this point of the research, a first evaluation of the transport truck suppliers can be made. The Volvo suppliers offer more data variables and it can be exported with more ease than the PDFs of Mercedes. Based on the gathering Volvo performs better than Mercedes. In the next Chapter KPIs, the data set in Table 3-1 is used to find relevant KPIs accordingly.

4. KPIs

The KPIs Chapter will include data analysis through the use of KPIs. Section 4.1 will be about the research question *“What frameworks can be used to develop KPIs that evaluate the supply chain within a company?”*, after answering this research question by providing a theoretical framework. This framework will be applied to the research. Then in Section 4.2 the research question *“What KPIs are important in the supply chain considering the performance management of order-pickers, order-pick trucks, truck drivers, transport trucks and the suppliers?”* will be answered based on the available data of Company X. A list of KPI suggestions is made. The theoretical framework will be applied to this list to conclude a final list of KPIs in sections 4.2 to 4.5 that is filled with data of Company X.

4.1. Theoretical framework

A theoretical framework will be created with a systematic literature review of the sub-research question “*What frameworks can be used to develop KPIs that evaluate the supply chain within a company?”*. The theoretical framework will be about a given framework for creating KPIs. The idea is to find a theory on a general framework that can be applied to KPIs. This can then be applied to the research in the next part of the KPIs Chapter. The theoretical framework serves as a guide to develop useful KPIs for Company X by going through steps gathered through a literature review. The KPIs should relate to the delivery performances, driving performances, cost performances and supplier performances to create insight into the transportation of Company X.

4.1.1. Introduction KPI

Key performance indicators, in short KPIs, are measures to quantitatively or qualitatively assess the performance of critical factors over time [14]. The performance indicator is a numeric value that represents a complex empirical phenomenon [12]. Creating KPIs can enable the companies to establish a point of reference for periodic improvements and help identify areas that can directly affect the total business costs [12]. To our research goal, we aim to increase insight to improve the quality of the decision-making in terms of cost performance, truck driver performance, truck performance and supplier performance.

A systematic literature review has been done on the research question *“What frameworks can be used to develop KPIs that evaluate the supply chain within a company?”* and a framework is made to create KPIs, the SLR protocol is given in Appendix I. First criteria are identified for exclusion and inclusion like “Written in English”, “Peer-reviewed” and “Published before the year 2000” to improve the quality of the literature. The SLR is done by using the keywords, “KPI, Framework, Develop, Supply Chain and Company” to find articles in the scope of the research. The search terms are narrowed down in a search log to find more specific articles by adding relations or adding words like “supply chain”, “performance” and “framework into one string. This process is repeated until useful articles are found that help in developing KPIs and validating them. Then concepts are derived from the articles and turned into a Conceptual Matrix in the Appendix Table 0-4. This conceptual matrix is used to create the conceptual framework by comparing concepts to develop KPIs of different sources to find concepts that can be added to the framework. In the following, the resulting conceptual framework with steps to conduct to develop useful KPIs for Company X is given.

4.1.2. KPI Identification

The initial step is to identify KPIs. Based on [15], the sampling of KPIs can be done through two procedures. First, one can start by doing an SLR about relevant KPIs regarding the research topic [15]. The keywords that are related to this research topic and narrow the search if we get too many results. Keywords like truck driver, transport truck, logistics, maintenance, costs and supply chain can be considered. In addition to these keywords, we need to add KPIs and/or Metrics and/or performance indicators to find sources with KPIs. KPIs can be picked if they are found in multiple articles or match the data variables that the research has access to [12].

The second procedure to collect KPIs can be done through consultations in the form of meetings, surveys and interviews with experts methods like questionnaires given to experts [15], like the truck drivers, the supply chain manager and the suppliers. These experts can suggest performance indicators that relate to the research. Through these questionnaires, another set of KPIs can be found.

4.1.3. Filter the KPIs

This step helps to understand the sets of KPIs and filter them based on certain criteria. To develop proper KPIs, three principles are considered important: cause-and-effect relationships, availability of key performance drivers and linkage to financial measures [13]. The KPIs need cause-and-effect relations between the perspectives and between each other. Moreover, it is important to have performance drivers as KPIs that can explain how the outcome KPIs are to be achieved [13]. The general aim is to improve the transportation performance, in this case, improve the driving performance, financial performance, delivery performance, supplier performance and truck performance. Other principles to filter the KPIs are, the availability of data to set baselining and target, measurement criteria and measurement results set, and KPIs are linked to goals and objectives of the research [16]. Based on the principles of developing proper KPIs we create questions to evaluate KPIs and exclude KPIs that cannot be answered through the following questions:

I. Does the KPI offer a cause-and-effect relationship with another perspective or another KPI?

II. Does the performance driver KPI connect with an outcome KPI or does the outcome KPI have a performance driver KPI?

III. Is sufficient data available for the KPI?

IV. What are the measurement criteria?

V. Can useful measurement results be achieved?

VI. Does the KPI help in reaching the research objective?

4.1.4. KPI Sorting through a Balanced Scorecard and Three Hierarchical Levels

The next step contains a sorting process based on two methodologies, the Balanced Scorecard (BSC) and the Three hierarchical levels (strategical level, tactical level and operational level).

The BSC, introduced by Kaplan and Norton in 1992, is one of the first performance measurement models to represent the efficiency and effectiveness of activities inside a complex organization [12]. BSC means to evaluate corporate performance from four different perspectives:

The Financial perspective indicates whether strategy, implementation and execution effectively contribute to financial success like cost reduction [13]. The Internal Business Process Perspective represents the employees' skills with the usage of the trucks [13]. The Customer Perspective is about factors that matter to the customer [13]. The Innovation and Learning Perspective is about efficiency and cost reduction through innovation considering the maintenance and usage of trucks [13].

Based on [15], the Customer Perspective is limited to the customer only and misses the identification of all stakeholders, including employees and the company itself. In the scope of this research, the customer perspective is replaced with a Stakeholder Perspective to include suppliers, the supply chain manager and the company itself, excluding customers

Through the BSC the financial part of the transportation and its costs can be taken into account whilst considering non-financial measures. Moreover, the BSC is a widely known methodology that helps in focusing on the business objectives considering each perspective. The objectives can be represented with KPIs for each perspective.

Figure 4-1: Anthony's pyramid [12]

The Three Hierarchical Levels are based on Anthony's pyramid structure. In Figure 4-1, the highest level is strategic, it is about aggregating information for long-term decision-making processes. The middle level is tactical and controls if the goals set by the higher level are attained efficiently and effectively, decisions for these KPIs are the mid-term. The lowest level is operational, it contains very detailed information mainly used for frequent, short-term and not very incisive decisions [12]. This is to be included in the framework to construct hierarchical relationships between KPIs to identify influences among indicators. The sorting of KPIs will be done by combining the BSC and hierarchical levels into sorting tables for the KPIs. Tables will be made where the KPIs are sorted into the four perspectives of the BSC and sorted into the three levels of Anthony's pyramid.

4.1.5. Define and Finalize the KPIs

At this point, the BSC is reduced to effective KPIs. Nevertheless, the KPIs need to be clearly defined. With the company's objectives, define the KPIs and give its characteristics [14]. The necessary explanations and definitions of the most important KPIs will be given. Finally, a consensus is to be reached for the BSC. To reach a consensus for the BSC, we communicate the BSC to all stakeholders, comments and feedback can be received and the BSC can be revised accordingly [13]. To do this the BSC with the explained KPIs will be presented to the stakeholders or the experts who give feedback on the KPIs [15]. This process until a consensus for the BSC has been reached. If a consensus has been reached and the list of KPIs fits the four perspectives and the three levels, the KPIs can be applied to the data.

4.2. KPI Identification - Literature review on KPIs

Based on the theoretical framework, this Section includes the initial step to identify KPIs that apply to Company X through a literature review of the sub-research question *"What KPIs are important in the supply chain considering the performance management of order-pickers, order-pick trucks, truck drivers, transport trucks and the suppliers?"*. This literature review takes transportation performances into account. The KPIs should offer insight to the supply chain manager considering the costs of trucks, the truck performance and the truck driver performance. If articles relate to these aspects and fit the data of Company X that are in the scope of this research they are picked and evaluated.

The first article [26], discusses an evaluation of a vehicle fleet through maintenance management indicators. Since this research also considers the fleet of four transport trucks and requires KPIs to be evaluated, the indicators suggested in this article can offer suitable insight. The second article [25], considers an optimal allocation of delivery trucks through lifecycle-based criteria. With our research, the fleet ranges from more than 4 years (M4) to less than half a year (M3) in age. Therefore, this article is added. The third article [31], tries to evaluate driver performances through the use of driving measurements. This research also aims to gain insight into driver performances with the Mercedes and Volvo suppliers giving monthly reports on driver measurements to Company X. The fourth article [33], creates a framework of KPIs for autonomous shipping in Europe. Company X does not offer autonomous shipping, however, it does offer manual shipping by the truck drivers. Furthermore, KPIs in the article relate to the transportation shipping process which is suitable for this research. Finally, the fifth article [34], discusses a freight transportation company and evaluates its performance through metrics. Freight transportation is the movement of goods from one place to another. This is the main task for the fleet of Company X. The metrics offered about freight transportation can show interesting factors that can help to gain insight into the transport trucks and the suppliers.

KPIs	Explanations	[26]	[25]	[31]	[33]	[34]
Capacity utilization	The volume of the truck divided by volume used	x	x			x
Maintenance costs	All the maintenance costs summed per truck	x	x	x	x	
Time between failures	The time between repairs of a truck	x				
Fuel consumption	The diesel consumption per truck		x			
CAPEX	The capital cost of the truck		x		x	
Lifetime kilometres	The total kilometers driven by a truck		x			x
CO_2 emission	The CO_2 emission per truck for a certain time period		x		x	
Total life cycle costs	All the costs combined the truck has made		x			
Age of truck	The current age since the truck has been bought		x			
Idle duration	The time with engine on without driving			x		
Fuel costs	The fuel cost multiplied with the driven kilometers for a time			x	x	
Average speed	The average km/h driven by a truck for a certain time period			x		x
Average loss cost of fuel	The average costs made during idle duration			x		
Net difference CO emissions	The difference in emissions between the trucks or suppliers				x	
Weight per delivery	The total starting weight carried for one complete delivery				x	
Average distance traveled	The average distance for a certain time period per truck					x
Delivery time per driver	The total delivery time per complete delivery per driver					x
Complete deliveries per supplier	The total complete deliveries in a time period per supplier					x
Complete deliveries per driver	The total complete deliveries in a time period per driver					x

Table 4-1: Literature KPI list

In Table 4-1, a suggestion list of KPIs is collected. Whenever an article offers a KPI the box is checked, some KPIs are offered by multiple articles and have multiple checks. KPIs are included if they relate to driving performance, delivery performance, suppliers performance, truck performance and cost performance and if the KPIs are feasible with the final data set from Table 3-1.

The identified KPIs cover critical aspects of fleet performance, from utilization and maintenance to fuel consumption and emissions. These indicators provide comprehensive insights into both financial and operational performance, allowing for a balanced evaluation of the fleet. By comparing the performance data across these KPIs, areas of improvement can be identified to support the decision-making process.

The Table 4-1 shows the finalized list of KPIs gathered from the chosen articles through a literature review. Based on the theoretical framework, the next procedure for KPI identification is to consult the list with experts and review the list with the questions from the theoretical framework.

4.3. KPI Experts consultation and filtering

This Section identifies additional KPIs through consultation with experts, and filters KPIs based on the questions from Section 4.1.3.

The second procedure for KPI identification is done with the experts. In this research the main expert is the Supply Chain Manager of Company X. Moreover, the truck suppliers are viewed as experts and the truck drivers are viewed as experts. The answers given in the interviews by the truck drivers are taken into account to evaluate the list of KPIs. Consultations with the suppliers have been done through mail messaging, calls and a meeting. Finally, to review the list, close ties have been kept with the Supply Chain Manager to consistently consult about the data and the KPIs. Based on these interactions 13 KPIs have been added shown in Table 4-2 below. Table 4-2 gives additional KPIs to evaluate the driver performance, the cost performance, the delivery performance and the overall fleet performance. These KPIs were approved by the Supply Chain Manager and can support the decision-making process by offering new insights.

KPIs name	Explanations
Roll out (%)	Distance of coasting the truck divided by the total distance.
Cruise-control (%)	Distance of using cruise-control divided by the total distance.
Braking (%)	Distance of braking divided by the total distance.
Driver Performance	Scores each driver from 1 to 4 based on their performance in four areas: Idle (%), Braking (%), Roll out (%), and Cruise-control (%). For each KPI, the best-performing driver gets 1 point, and the worst-performing driver gets 4 points.
Residual value	The truck's current value based on 15% straight-line depreciation.
Total Cost of Ownership (TCO)	Total cost of a truck, including all maintenance and capital costs, minus the truck's current value.
TCO (fuel incl.)	TCO but with all-time fuel included as cost.
Cost per Kilometer	TCO divided by the lifetime kilometers.
Cost per Kilometer (fuel incl.)	TCO (fuel incl.) divided by the lifetime kilometers.
Customers per driver	Average monthly customers per complete delivery per driver.
Average fleet age	The total fleet age divided by the number of trucks in the fleet.
Average lifetime kilometers	The total lifetime kilometers divided by the number of trucks in the fleet.
Maintenance frequency	All the maintenance and repairs counted per truck.

Table 4-2: Experts consultation KPI list

The next step is to evaluate the literature and expert KPIs by applying the questions from Section 4.1.3. to the literature KPIs and the experts KPIs. The questions are answered in Table 4-3 through a checklist where the KPIs go through the six questions. In the Table 4-3 questions I. and II. are combined since the Cause-and-effect relationship and the KPI connection correlate with each other. Question III. is about the data availability, question IV. is about what the measurement criteria are and if they are clear, question V. is about whether the results are useful and question VI. Is about whether the KPIs help in reaching the research objective. Table 4-3 only shows the KPIs that have a least one unchecked box since these are relevant for the filtering process. The complete version is in the Appendix Table 0-7, where a total of 32 KPIs have been evaluated based on the questions.

In general, for I. and II. all boxes are checked since all KPIs serve as either a Driver KPI or an Outcome KPI and each KPI is affected by or affects another KPI, except for *Complete deliveries per supplier* because this KPI is about the delivery performance of the drivers and not the suppliers in this research. III. is checked for almost all boxes since the KPI identification is based on the available data resulting from the Data Understanding Chapter except for *Complete deliveries per supplier* because the supplier does not do the deliveries and for *Time between failures* because the maintenance records lack the labor time of the repairs. IV. is also checked for almost all boxes since for all KPIs the measurement criteria are clear and shortly explained in Table 4-3, except for *Complete deliveries per supplier*. V. and VI. are checked for many KPIs since they offer useful intel on efficiency, costs, trucks, drivers and the fleet and these KPIs support decisions, offer relevant information and support evaluations. However, the following KPIs are not checked for V. and VI.:

- *Total life cycle costs* is excluded as it fails to account for the residual value of a truck.

- *Average speed* is prone to routing variations and speed limitations on the trucks, making it less reliable as a KPI.
- *Net difference CO_2 emissions* is redundant and covered by the *CO_2 emissions* KPI.
- *Average distance travelled* lacks significance as a standalone KPI and is better suited as a data variable to be used as a basis for other KPIs.
- *Complete deliveries per supplier* is again not applicable.

Thus, all KPIs with unchecked boxes are excluded, ensuring only high-quality KPIs are advanced. Those KPIs that meet all criteria will proceed to the next step, where they will be sorted based on the Balanced Scorecard (BSC) and the Three Hierarchical Levels.

KPI Name (green:literature, yellow:experts)	I. and II. Cause-and Effect Relationship of KPI		III. Data	IV. Measurement Criteria		V. Useful Results		VI. Research Objective	
Time between failures	✓	Outcome KPI affected by Maintenance frequency	✗	✓	Time between repairs	✓	Intel on efficiency	✓	Gives information
Total life cycle costs	✓	Outcome KPI affected by Age of truck	✓	✓	Sum all costs over truck's life	✗	Lacks residual value	✗	Not complete
Average speed	✓	Driver KPI affects Fuel costs	✓	✓	Distance / time	✗	Speed is limited	✗	Not applicable
Net difference CO_2 emissions	✓	Outcome KPI affected by Average speed	✓	✓	Net difference between trucks	✗	Already covered	✗	No new intel
Average distance travelled	✓	Driver KPI affects Fuel costs	✓	✓	Kilometers per month	✗	More a data variable	✗	Not as KPI
Complete deliveries per supplier	✗	No impact, deliveries are not done by suppliers	✗	✗	Not done by suppliers	✗	Not by suppliers	✗	Not applicable

Table 4-3: KPI excerpt checklist evaluation

4.4. KPI Sorting – Application

This Section applies the theoretical framework of Section 4.1 to the list of KPIs from the literature review and the extra KPIs from the experts consultation. The KPIs are sorted based on the Balanced Scorecard and the Three hierarchical levels.

The Table 4-4 shows the four perspectives of the Balanced Scorecard. In the context of this research, the **Financial Perspective** is KPIs related to the general costs of the trucks individually and in terms of the fleet. The **Stakeholders Perspective** are KPIs related to the evaluation of the suppliers. In other circumstances, customers would be included as the stakeholders but this research limits the stakeholders to the suppliers. The **Internal Business Perspective** are KPIs related to the evaluation of the individual truck drivers and the driving process itself. Finally, the **Innovation and Learning Perspective** contains opportunities for Company X to improve and keep track of.

The **Operational Level** includes short-term decision-making KPIs and operational measurements [12]. Table 4-4 shows measurements like the *Maintenance frequency*, *Average monthly weight per driver*, *Lifetime kilometers* and so on. These measurements provide a basis for evaluating daily operations. These KPIs are crucial for monitoring immediate performance but do not directly influence long-term decisions.

The **Tactical Level** contains indicators that show performance and efficiencies and can support mid-term decision-making [12]. These indicators are mainly drivers for the strategic KPIs. For instance, financial KPIs like *Total maintenance costs per truck* and *Residual value* are essential for evaluating mid-term financial health and guiding long-term investment decisions. Similarly, supplier-related KPIs like *Average monthly fuel consumption per supplier* and *Total maintenance costs per supplier* offer valuable insights for supplier performance evaluation and relate to the strategic long-term decision KPIs. Driving performance percentages, such as *Braking (%)* and *Cruise-control (%)* offer insight into the drivers and comparisons between the drivers. These KPIs combined are the drivers of the strategic KPI *Driver Performance*. To improve control of the whole fleet knowing tactical KPIs *Average fleet age* and *Average lifetime kilometers* help to keep track of the trucks.

The **Strategic Level** are KPIs for the long-term decision-making process [12]. These KPIs reflect the overall performance across BSC perspectives. Financial KPIs such as *Capital costs per truck*, the *TCO* and *Cost per kilometer* provide a comprehensive view of the cost-effectiveness of the fleet, the individual truck and the supplier. Thus, enabling the Supply Chain Manager to make informed investment decisions considering the trucks and the suppliers. The *Driver Performance* KPI scores the truck drivers based on the four tactical KPIs of the Internal Business Perspective. This KPI indicates the best-performing and worst-performing driver to the Supply Chain Manager, enabling data-driven evaluations. Finally, Innovation and Learning KPIs, including *Capacity Utilization*, *Monthly CO^2 emission* and *Monthly idle fuel costs* highlight potential growth areas, guiding strategic initiatives for sustainability and efficiency.

	Financial perspective	Stakeholders	Internal business	Innovation and learing
Level	KPI	KPI	KPI	KPI
Strategic	Capital costs per truck	Capital costs per supplier	Driver performance	Capacity Utilization
	TCO	TCO per supplier		Monthly CO^2 emission
	TCO (fuel incl.)	TCO (fuel incl.) per supplier		Monthly Idle fuel cost
	Fleet fuel Cost per Kilometer	Fleet fuel Cost per Kilometer per supplier		
	Cost per Kilometer	Cost per Kilometer per supplier		
	Total cost per kilometer	Total cost per kilometer per supplier		
Tactical	Total Maintenance costs per truck	Average Monthly fuel consumption per supplier	Roll out (%)	Average fleet age
	Total fleet costs	Average Monthly CO^2 emission per supplier (g/km)	Cruise-control (%)	Average lifetime kilometers
	Residual value	Total maintenance costs per supplier	Idle (%)	
			Braking (%)	
Operational	Maintenance frequency	Total maintenance frequency per supplier	Average monthly weight per driver	Age of each truck
			Average monthly customers per driver	Lifetime kilometers of each truck
			Average monthly complete deliveries per driver	
			Average monthly delivery time per driver	

Table 4-4: KPI list sorted

4.5. Define and Finalize the KPIs

This Section defines the KPIs and explains how the KPIs have been achieved. At the end, the sorted list of KPIs is taken to the Supply Chain Manager until a consensus is reached.

First, the strategic KPIs are defined and explained on how to achieve the KPI:

- *Capital costs per truck* = Initial truck investment cost found in cost records.
- *TCO* = Total Maintenance costs + Capital costs – Residual value of the truck
- *Cost Per Kilometer* = TCO divided by the Lifetime kilometers.
- *Driver Performance* = A scoring from 1 to 4 based on their performance in four areas: Idle (%), Braking (%), Roll out (%) and Cruise-control (%). For each KPI the best-performing driver gets 1 point, and the worst-performing driver gets 4 points. The total score shows the overall performance, with a lower score indicating better performance.
- *Capacity Utilization* = Each type of deliverable (pallet, half pallet, block pallet, roll container and box) is converted to a ratio in pallets and the resulting deliverables are summed. The sum of deliverables is divided by 26 which is an assumption of the maximum capacity. If the value is close to 0 the truck is underutilized and if it is close to 1 the truck is well-utilized.
- *Monthly CO_2 emission* = The total monthly CO_2 emission of all four trucks.
- *Monthly Idle fuel costs* = The total monthly stationary fuel consumption multiplied by the fuel price of all four trucks.

The tactical and operational KPIs are explained in the Appendix III. With these explanations of the strategic KPIs, the main KPIs are now defined and require the final approval of the Supply Chain Manager to be finalized.

After multiple meetings with the Supply Chain Manager, the KPIs were considered good for the cause of the research. The Supply Chain Manager approved that these KPIs would support offering data-driven decision-making. In Section 4.3, the KPIs suggested by the suppliers and the Supply Chain Manager have been included and the Supply Chain Manager and suppliers agreed with the resulting KPIs in Table 4-4. This list will be applied to the Data Preparation Chapter to fill the KPIs with data and then create a dashboard in the Modelling Chapter. The research question "*What frameworks can be used to develop KPIs that evaluate the supply chain within a company?*" is answered with the theoretical framework explained in Section 4.1 that effectively helped to develop high-quality KPIs fitting to the research. Moreover, the research question *"What KPIs are important in the supply chain considering the performance management of order-pickers, order-pick trucks, truck drivers, transport trucks and the suppliers?"* is answered with the Table 4-1 showing relevant KPIs from the literature that help in evaluating the performances for these aspects. The final list in Table 4-4 is the list of developed KPIs that are important to support the decision-making of the Supply Chain Manager in terms of transportation performances.

5. Data Preparation

This Chapter aims to prepare the data for data analysis and data visualization. The five tasks Select data, clean data, construct data, integrate data and format data are conducted in this Chapter considering the KPI list in Table 4-4.

5.1. Selection and cleaning of data

This Section goes through the selection and cleaning of the transportation data.

The first two tasks are the selection and cleaning of data. This is partially done in Section 3.1 where all the data sets for the performance management of transportation have been gathered. Indirectly whilst exploring the data sets of Mercedes and Volvo data variables with only 0 values and empty values were excluded. At this stage, the list of KPIs is used to exclude unused data variables.

First, the ERP data set. The data set exported by the IT-Department still included variables like ShippingName, ShippingPostalCode and ShippingCity. These variables relate to locations and routing. This is not included in the scope of this research. Finally, the OrderCustomerID can be removed since this research does not look at the customers individually but focuses on the deliveries. This results in the Cleaned ERP data set in the left column of Table 5-1.

Cleaned ERP data set	**Cleaned Suppliers data set**
DriverID	Total distance (km)
TR Nr	Total time (hh:mm:ss)
TypeDeliverable	Stationary time(standstill, engine running)
DeliveryDate (dd/mm/yyyy)	Total stationary time (hh:mm:ss)
DeliveryTime (hh:mm:ss)	Brake distance (km)
NrDeliverables	Fuel consumption (l)
Weight (kg)	Fuel consumption driving (l)
	Fuel consumption stationary (l)
	CO_2- emission (kg)
	Roll out (km)
	Cruise-control time (hh:mm:ss)

Table 5-1: Cleaned transportation data set

In Chapter 4 the final list of KPIs in Table 4-4 has only KPIs with data variables that both Volvo and Mercedes have available. The KPIs take out a lot of the data variables that were given in Chapter 3 the data set in Table 3-1. Since the data variables are not relevant to the KPIs, they are taken out at this stage. The data variables that were necessary for the driving performance KPIs are Total stationary time, Brake distance, CO_2 emission, Roll out and Cruise-control time. The distance and time data variables are necessary to calculate the rates for these variables and the fuel consumption-related variables help to offer insight for the Fuel KPIs. This results in the Cleaned Suppliers data set in the right column of Table 5-1.

5.2. Construction, integration and formatting of data

This Section constructs the data by transforming all the data sets with the use of the Power Query Editor into one Excel. New variables are constructed with the existing data sets to prepare the required data for the KPIs from Chapter 4. Moreover, this Section offers an additional integration of the supplier's data and formats all the resulting data sets.

To clarify the Data Preparation process an illustration has to be added. A flowchart is a graphical representation of a process [41]. In Figure 5-1, the data process flow chart is given. It starts with the sources for the Data Preparation. As said in Section 3.2, the measurable data of Mercedes comes in PDFs as a report for each truck each month, the Volvo export comes in Excel for each truck with all months and the ERP export comes as big data in Excel for the complete period. Each truck is assigned one map where the files can be added and the ERP export is assigned its map resulting in five maps. With the Power Query Editor, a querying tool from Excel the maps are exported and all connected to one specific Excel file. As shown in Figure 5-1, the Power Query Editor is the main tool used for Data Preparation, through queries the PDFs are reconstructed to effective tables and transformed to the same format for each truck with its table. For more detailed steps see Appendix IV. Furthermore, the ERP data is transformed in the Power Query Editor. With these transformations, the result is the Excel Data Warehouse, see Figure 5-1.

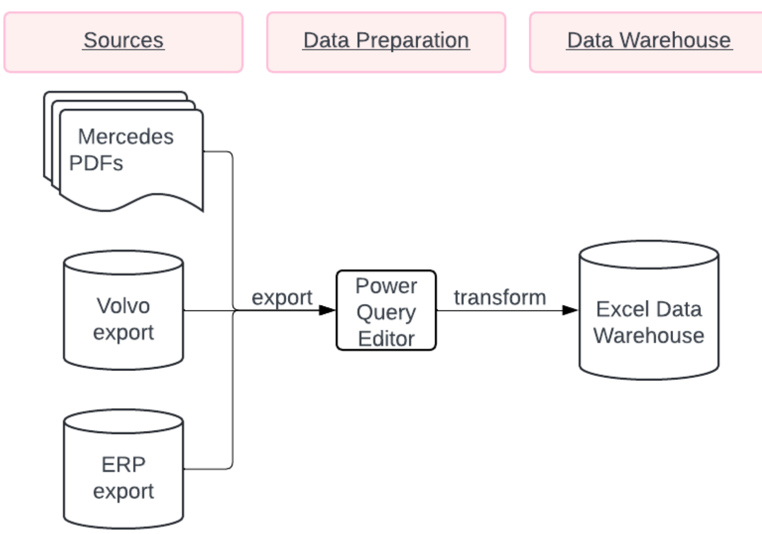


Figure 5-1: Data process flow chart

With the Excel Data Warehouse, some additions were required to make it applicable to the KPIs given in Table 4-4. An Entity-Relationship (E-R) diagram is a graphic tool to support the design of database systems [40]. In Figure 5-2 an E-R diagram is given to show the final database with additions. The ERP table is used to make additional Helper Variables, given in green, these are calculations done in Excel to create pivot tables that serve as a basis for the KPIs. Five additional pivot tables have been constructed with Helper Variables, Capacity Utilization, Monthly Deliveries, Customers, Total

Weight and Total Delivery Time see Figure 5-2. Moreover, a Costs table is added taken from Section 2.2. Finally, the measured truck data tables from the supplier are integrated into one table for all four trucks with the same data variables see Figure 5-2.

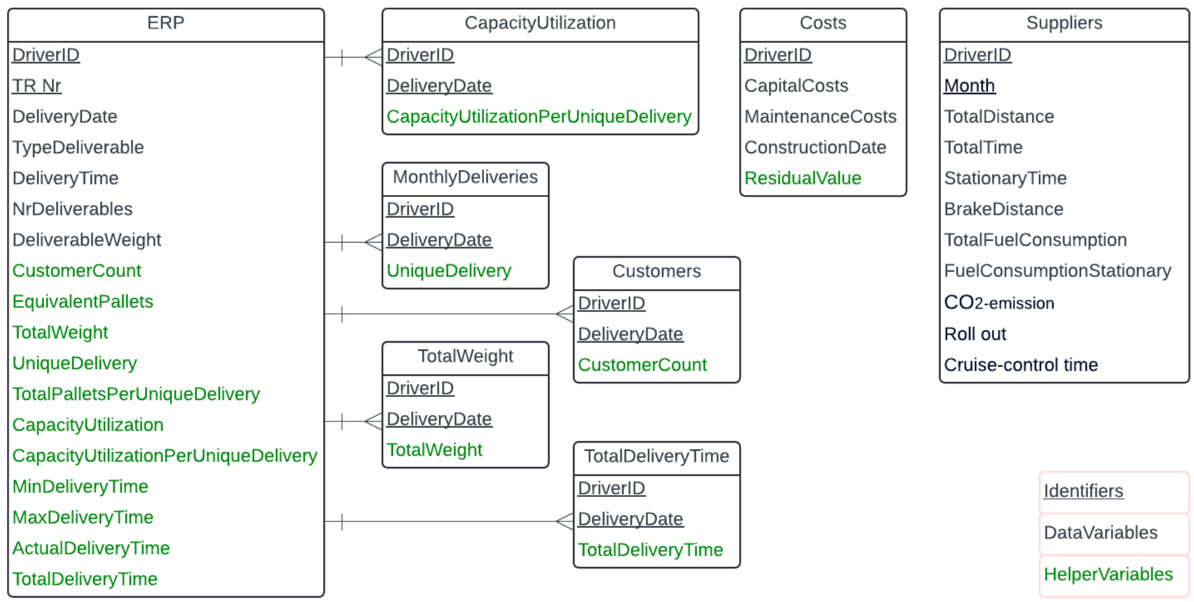


Figure 5-2: ER-diagram of the final database

To conclude the 'Data Preparation' Chapter Figure 5-2 shows all the resulting tables that have been prepared for the 'Modelling' Chapter 6. In this Chapter, the final database will be used to fill the KPIs from Table 4-4 with the data accordingly to then create a dashboard with the KPIs.

6. Modelling – Draft Dashboard

The data will be analyzed through the KPIs and the KPIs will be used to create a data visualization through a draft dashboard. To offer a data visualization that is useful to Company X, the research question *“What aspects are important to Company X when creating a draft dashboard?”,* is answered.

First, to consider the research question *“What aspects are important to Company X when creating a draft dashboard?”,* a small list of mentioned requirements or interests by the Supply Chain Manager is given:

- Draft Dashboard in Excel is sufficient as a deliverable for the research.
- The Supply Chain Manager is interested in the *Capacity Utilization* KPI.
- The Supply Chain Manager is interested in delivery performance and driving performance related KPIs.
- Company X values an environmentally friendly status.
- The Supply Chain Manager is interested in the cost performances of the trucks individually, the suppliers and the fleet as a whole.

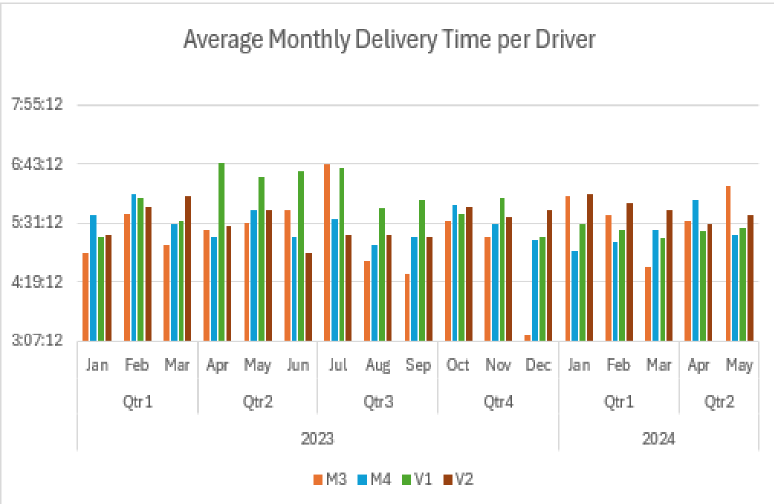
Based on these requirements, a draft dashboard is made in Excel. The KPIs are separated across two dashboards, the Driver Performance Dashboard, focusing on the driving performance and delivery performance and the Fleet Performance Dashboard, focusing on the supplier performance, the truck performance and the fleet performance. No design requirements were given, however, the aim is to offer dashboards that quickly give intel to the Supply Chain Manager to support decisions and see the consequences of decisions.

Since the Supply Chain Manager showed interest in seeing the delivery performances over a longer period, in Figure 6-1 the Driver Performance Dashboard, the operational Internal Business KPIs that relate to the delivery performances have been included in the form of bar charts and line charts. With this, the Supply Chain Manager can vastly see the development of the operational KPIs considering the truck drivers. The other truck driver-related values have been given in a static value format. With this, the Supply Chain manager also gets clear indicators on which truck drivers are performing better. In the middle, the strategic KPI *Driver Performance* is shown to instantly get an idea of the truck driver with the best driving performance based on the monthly averages. From there on the Supply Chain Manager can look into the percentage below to see the difference in the tactical KPIs to find the basis of the difference in driving performance. The charts all offer a timeline slider to increase the interactivity of the dashboard for the Supply Chain Manager. With the sliders, all charts can be shown in terms of months, quarters and years.

In Figure 6-2, the *Capacity Utilization* KPI is included in the center of the dashboard in the form of a bar chart to be able to see the values quickly. The verticle axis is set up to go from 0 to 1 to easily see the capacity left in the truck. Moreover, a timeline slider is included so that the Supply Chain Manager can see the *Capacity Utilization* in months, quarters and years. Above the *Capacity Utilization* chart, 4 KPIs are given that relate to the Innovation and Learning Perspective. These values can offer quick updates on the *Average fleet age*, *Average lifetime kilometers* and show Company X how their fleet is performing in terms of lost fuel costs and emissions to consider the environmental importance of Company X. The left section is the Financial Perspective and the right section is the Stakeholder (suppliers) Perspective. For both of these sections, the strategic KPIs which are mainly cost-related are placed at the top of the draft dashboard in a slightly bigger size to ensure that the manager easily sees these KPIs. Below the first table in the left section, the KPIs *Maintenance frequency*, *Residual value and Maintenance costs* are shown in Figure 6-2 because with these KPIs the Supply Chain Manager gets information on the leftover value of the truck and the quantity of maintenance records and costs after seeing the cost performances beforehand. These can help to decide whether to invest in a new truck if the cost performances prove to be bad. Finally, the *Total fleet costs* and *Total maintenance costs* of the fleet are given on the bottom left of the draft dashboard to have additional information on the actual costs of the fleet. The supplier section on the right gives a table below the main strategic KPIs for additional information to compare the supplier performances in terms of *Monthly fuel consumption*, *Monthly CO_2 emission*, *Total maintenance costs per supplier* and *Total maintenance frequency per supplier*.

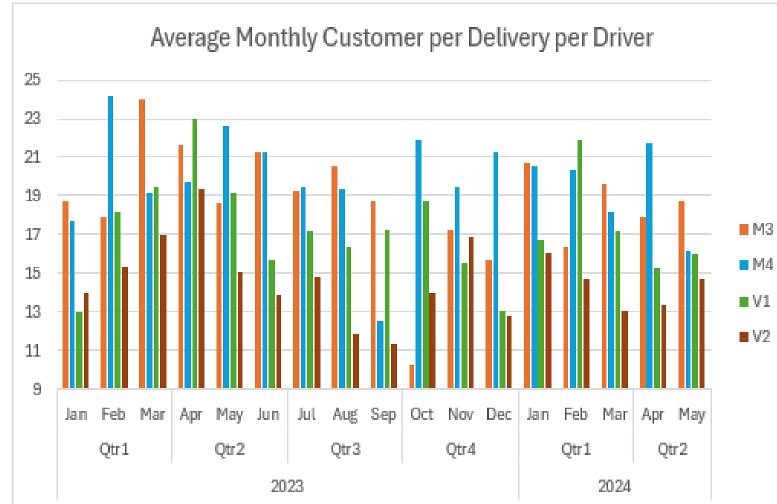
The conclude, the research question of the Modelling Chapter *"What aspects are important to Company X when creating a draft dashboard?"* is answered by offering two draft dashboard designs in Figure 6-1 and Figure 6-2 based on the small selection of requirements. KPIs like *Capacity Utilization* that were of interest to the Supply Chain Manager have been included. Moreover, interactive features have been included to give options to dig deeper into the variables. Finally, economic, sustainability and cost-related KPIs are included since Company X always aims to perform well in these aspects.

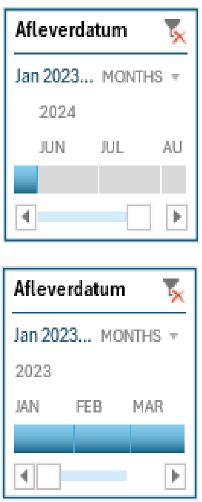
Driver Performance Dashboard

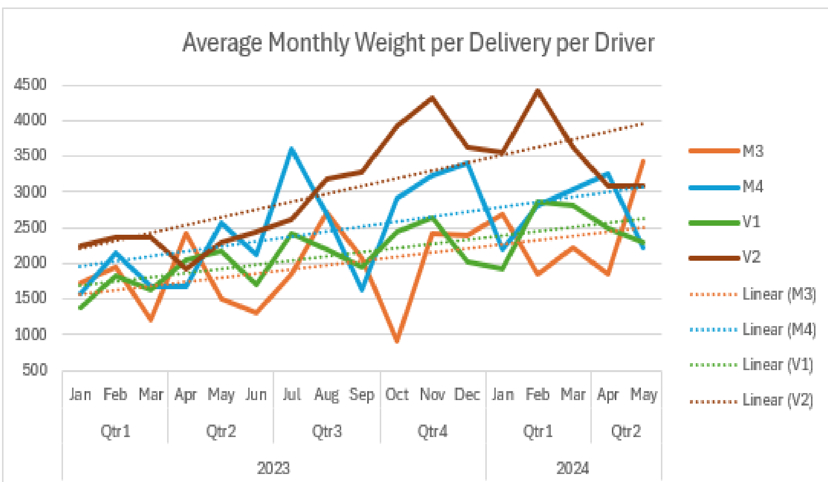


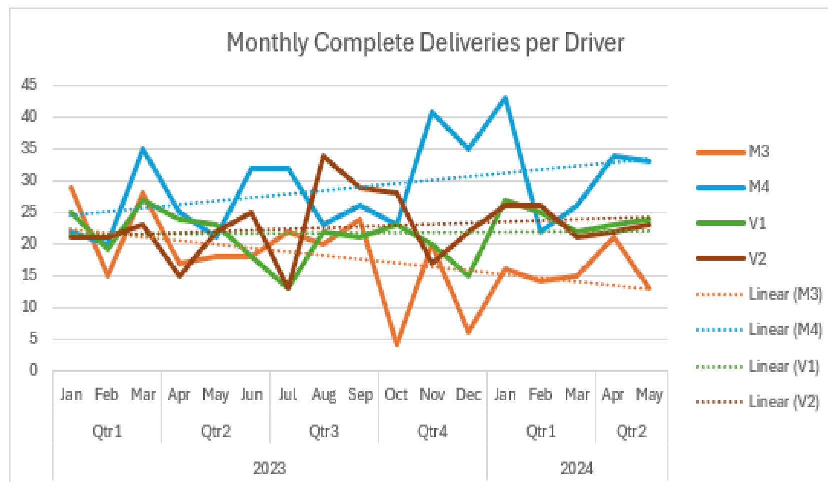
	Driving performance
V1	7
V2	6
M3	12
M4	15

	Roll out (%)	Cruise-control (%)	Idle (%)	Braking (%)
V1	10.56%	65.52%	8.72%	6.31%
V2	7.42%	78.31%	5.27%	5.76%
M3	7.42%	50.52%	14.54%	8.20%
M4	5.16%	11.94%	22.23%	6.66%









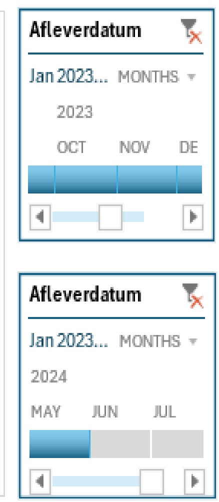


Figure 6-1: Driver Performance Dashboard

Fleet Performance Dashboard

Costs performance

	M4	M3	V1	V2
TCO	€74,423.61	€7,669.02	€29,459.88	€22,714.70
TCO (fuel incl.)	€159,747.51	€17,137.77	€81,553.71	€62,242.93
Cost per Kilometer	€0.34	€0.31	€0.20	€0.20
Fuel Cost per Kilometer	€0.39	€0.39	€0.35	€0.35
Total Cost per Kilometer	€0.73	€0.70	€0.55	€0.55
Capital costs	€84,000	€101,950	€96,494	€96,494

Maintenance frequency	25	1	4	6
Residual value	€28,665.80	€94,580.98	€69,269.06	€76,243.71
Maintenance costs	€19,089.42	€300.00	€2,234.94	€2,464.41

Total Maintenance costs	Total fleet costs
€24,088.77	€403,026.77

Fleet age (years)	Lifetime kilometers	Monthly CO_2 emission (t)	Monthly Idle fuel cost
2.04	126175	14.80	€ 127.78

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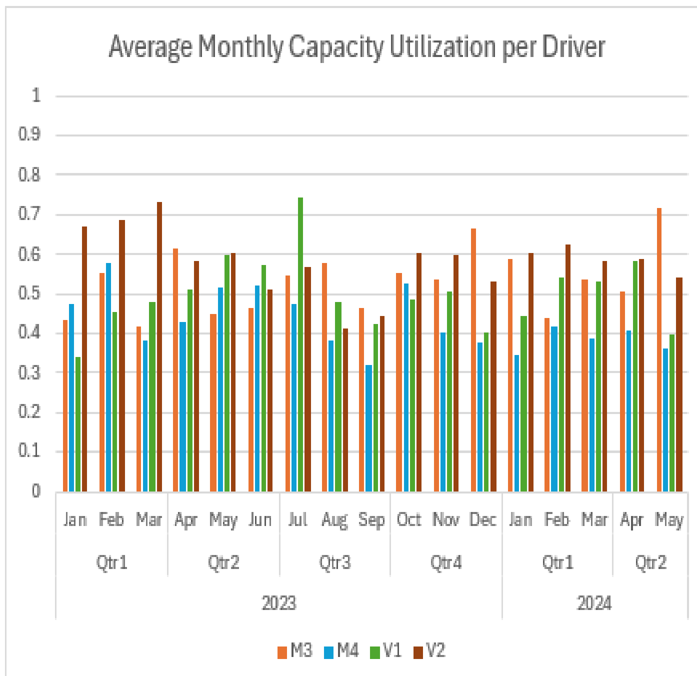

Suppliers performance

	Mercedes	Volvo
TCO	€82,092.64	€52,174.58
TCO (fuel incl.)	€176,885.28	€143,796.65
Cost per Kilometer	€0.652	€0.400
Fuel Cost per Kilometer	€0.775	€0.701
Total Cost per Kilometer	€1.428	€1.101
Capital costs	€185,950	€192,988

Monthly fuel consumption (l/100km)	26.09	23.59
Monthly CO_2 emission (g/km)	697.14	582.53
Total maintenance costs per supplier	€19,389.42	€4,699.35
Total maintenance frequency per supplier	26	10

Figure 6-2: Fleet Performance Dashboard

7. Evaluation and Deployment

This Chapter answers the research question "*What examples of data-driven suggestions for decision-making and measurable results can be given?*" in Section 7.1 to prove the solution. And in Section 7.2 the research question "*What steps are required for the implementation of the KPIs and the draft dashboard at Company X?*" to give an implementation plan to Company X.

7.1. Evaluation

This Section answers the sub-research question "*What examples of data-driven suggestions for decision-making and measurable results can be given?*".

The idea of answering this research question is by giving examples of data-driven suggestions that can be made and measurable results that can be shown with the draft dashboard and the KPIs. The first example can be offered with the *Driver Performance* KPI in Figure 6-1. The strategic KPI instantly shows that V2 is performing best with 6 points and M4 is performing the worst with 15 points. M4 has the worst percentage for every tactical KPI except *Braking (%)*. In the interviews in Section 2.1 the Mercedes drivers considered their driving methods to be calm and relaxed and wanting to be in charge. Mainly for M4, this shows since the cruise-control is barely being used with a percentage of only 11.94% which is extremely low in comparison to the other truck drivers. In the interviews the Volvo drivers mentioned not minding using the Volvo systems as much as possible, this confirms the results of the driving performances. Based on this example the Supply Chain Manager can give points of improvement to M4, like using more cruise-control and letting the car roll out more.

An example of a measurable result with the dashboard in Figure 6-2 can be shown with the strategic KPI *Capacity Utilization*. The average *Capacity Utilization* is around 0.55 and is quite consistent over time. Here the question arises if this value cannot be higher. After showing this to the Supply Chain Manager, the reply was that Company X aims to have an average of around 0.75 and considered this measurable result as valuable to take action to improve this value. The Supply Chain Manager can introduce new ideas, test them and find new measured results in the draft dashboard to find out whether these ideas have been effective and adjust accordingly.

Another similar example can be given. The Fleet Performance Dashboard in Figure 6-2 shows that the fleet has a *Monthly CO_2 emission* of 14.8 tons and *Monthly Idle fuel costs* of €127.78 which is lost while trucks are stationary and not turning the engine off. These KPIs relate to the environment and costs which are considered important to Company X. The measures can be tested by introducing new ideas of driving, changing trucks and loads to see if the values go down or up. By using the tool to test ideas Company X can find opportunities to reduce these values.

Additional proof can be given to show that the draft dashboard helps in making decisions. Currently, Company X has the policy of replacing a truck at the age of 5 years, however, this value is not based on data from the truck's performance. In Figure 6-2 on the left side, M4 has the highest *TCO* of €159747.51, the highest *Total Cost per Kilometer* of €0.73 and an exceptionally high *Maintenance* *frequency* of 25. Moreover, the *TCO* exceeds €100000 which is around the price of a new truck based on the supplier's information. In the costs overview Section 2.2 the age of M4 is 4.39 years. Based on these values replacing the truck M4 with a new one is suggested even if the truck is not 5 years old yet. Then, the question could arise from which supplier to buy a truck. The supplier performance can be evaluated based on the right section in Figure 6-2. Overall, Volvo is performing better. Mercedes is more expensive in almost every aspect. For instance, the *Total Cost per Kilometer* of Mercedes is €1.428 whilst the *Total Cost per Kilometer* of Volvo is only €1.101. This is a significant difference considering these costs are incurred for every kilometer driven on average. Other aspects like the *Average Fuel consumption* also prove Volvo's winning side with 23.59 (l/km) against 26.09 (l/km) of Mercedes. Finally, the Monthly CO_2 emissions of Mercedes are much higher with 697.14 (g/km) against 582.53 (g/km). With these results, the choice can be made to replace the M4 with a Volvo truck supported by a data-driven basis.

In conclusion, the research question "*What examples of data-driven suggestions for decision-making and measurable results can be given?"* is answered with examples like being able to show a low *Capacity Utilization* and using the tool to test ideas, or evaluating a truck driver based on the driving performance KPIs from Figure 6-1, or supporting decisions like replacing M4 and picking Volvo as a truck supplier because of the better results. These insights have been discussed with the Supply Chain Manager, and the results mentioned to give a data-driven basis for decisions or see the consequences of decisions in the results is deemed useful by the Supply Chain Manager to improve the decision-making. With this the draft dashboard and the KPIs are a solution to the action problem *"The Supply Chain Manager struggles at making decisions."* and the core problem *"Available data is not being is not being utilized to support decisions"* since the available data is now utilized to support decisions.

7.2. Deployment

This Section answers the sub-research question "*What steps are required for the implementation of the KPIs and the draft dashboard at Company X?"*.

At the current stage, the dashboards are only draft dashboards and steps have to be taken to become of practical use to the Supply Chain Manager and Company X. To visualize an implementation plan, a roadmap can be used. It provides a clear, structured visual plan that aligns stakeholders, manages timelines, and ensures focused progress toward achieving the project's goals [39]. Figure 7-1 shows a roadmap with four phases, the Preparation, the Implementation, the Rollout and the Review. The deployment starts with the Preparation, the draft dashboards are made, the KPs are made and a data collection is made, the first step is to transfer these deliverables to the Supply Chain Manager. This is done at the start of the deployment. The next step is to transfer the knowledge to the Supply Chain Manager, most of the knowledge can be transferred through reading the research and additional explanations can be given personally if necessary.

For the Implementation phase, Company X requires week 1 to week 4 to automate data updates. Currently, maps are assigned to each data source, however, the exported data needs to be manually added each day, week or month to get updated values within the dashboard. A script or tool to automate the export of data is recommended to reduce manual intervention and errors. Moreover, the ERP data source has to be improved since it is prone to the signing-off of the truck drivers. Another step is to test the dashboard functionalities, many of the draft dashboard KPIs automatically update whenever new data is added to one of the maps, some testing has been done, however, testing by adding different data sets can help to identify whether the transformations of the Power Query Editor still work and the data visualization change correctly. The third and main step for Company X is to transfer the Excel to PowerBI. The Supply Chain Manager mentioned using PowerBI for other data analysis-related projects. If the Supply Chain Manager wishes to transfer the draft dashboards to PowerBI Excel can be used as a blueprint for the dashboard designs and the KPIs.

After the Implementation phase from weeks 1 to 4, the Rollout phase follows from weeks 5 to 6. During this phase, the resulting dashboard from the Implementation phase is to be deployed to the user base by having access to the PowerBI. In this case, the Supply Chain Manager will be the main user but other employees in the supply chain field can be asked to test the dashboard. Step two is about monitoring and supporting the initial deployment of the dashboard. Support has to be provided for issues and feedback can be gathered for immediate improvements.

Simultaneously with the Rollout phase, the Review phase starts. This phase is endless and requires continuous attention. One step of this phase is to continuously evaluate the dashboard based on the objectives, and questions like “Are all the KPIs still relevant for the transportation performances?” or “Is the data being presented effectively?” have to be asked. Based on this step, the next step of planning new enhancements can be made by adding new data sources and improving KPIs and visualizations. Ideas are adding order-picking related data sources and routing-related sources to introduce new performance KPIs for order-pickers like picking performance and to get more accurate results by including routing KPIs. Finally, an update schedule has to be planned based on the frequency of data updates to ensure the maps and data sources are regularly being refreshed.

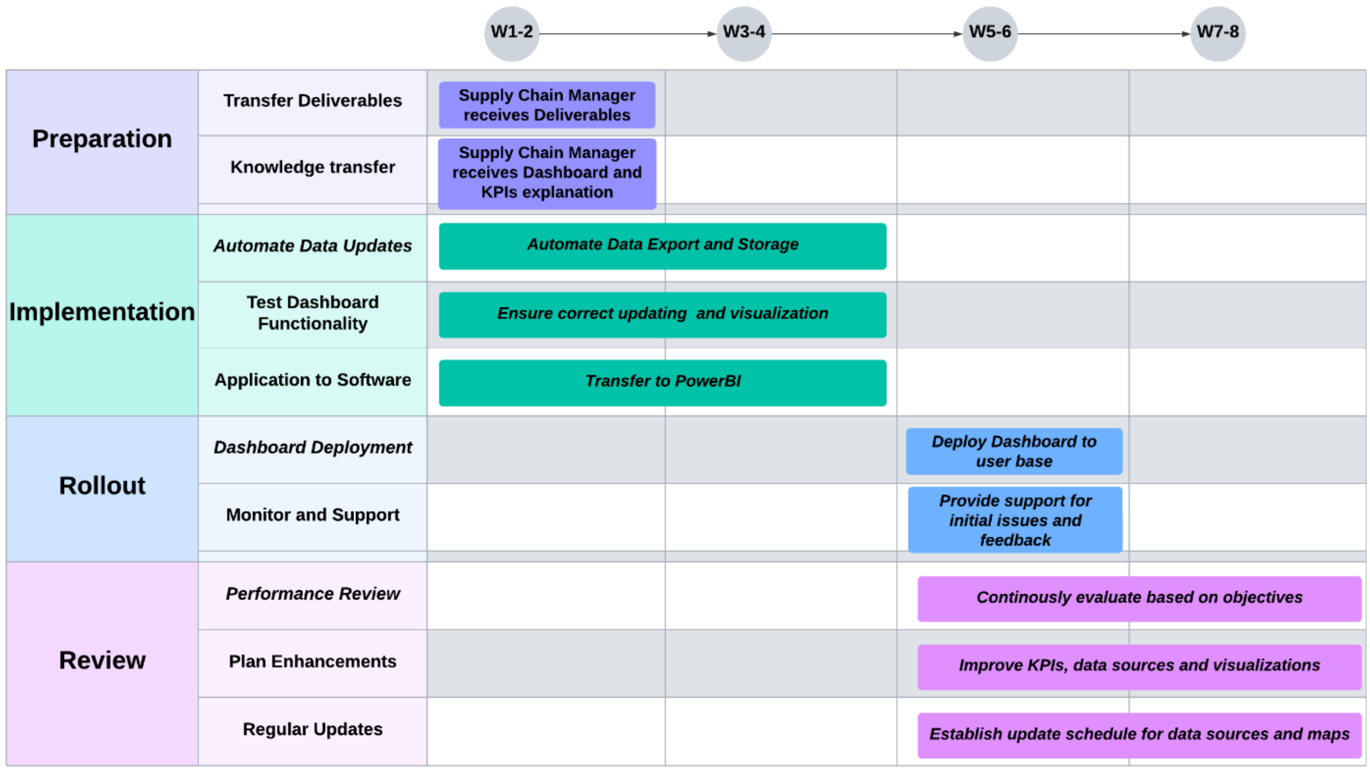

Figure 7-1: Deployment roadmap for the KPIs and draft dashboards

To review the Deployment Section, the research question "*What steps are required for the implementation of the KPIs and the draft dashboard at Company X?"* is answered with the given steps of the roadmap in Figure 7-1. The Evaluation Section showed that some results and decisions can be offered. Nevertheless, to make the draft dashboards practical for Company X, main steps like transferring to PowerBI, automating data exports and improving the data sources are important to get reliable data-driven KPIs that can be easily accessed and evaluated.

8. Conclusion, recommendations and further research

A conclusion of the findings is drawn based on the Chapters and the main research question

“How can Company X create insight into the transportation and order-picking to make data-driven decisions in the supply chain?”

is answered in Section 8.1. The final recommendations to Company X are given in Section 8.2 and further research is discussed in Section 8.3.

8.1. Conclusion

In this research, the aim was to answer the main research question *“How can Company X create insight into the transportation and order-picking to make data-driven decisions in the supply chain?”*. This Section will summarize the findings and reflect on the results of each Chapter.

Through the application of the Crisp-DM methodology in the Introduction Chapter, the research began with a thorough understanding of the business context, including the working methods of employees and the total costs associated with the trucks. The Business Understanding involved conducting interviews and analyzing financial data, which provided valuable insights into the varied practices and costs within the company.

The next step involved identifying available data for transportation and order-picking in the Data Understanding Chapter. However, due to insufficient data for order-picking, the research focused solely on transportation. A data set for transportation was identified.

In the KPIs Chapter, a theoretical framework was developed and used to create KPIs relevant to the transportation sector. The KPIs were filtered with a checklist and sorted based on the Three Hierarchical Levels and the four perspectives of the Balanced Scorecard. A sorted KPI list was developed.

The Data Preparation Chapter phase was used to prepare and transform the data sets with the Power Query Editor to fill the KPIs. For some KPIs, additional data variables had to be created to make the data applicable. A database applicable to the KPIs was created.

During the Modelling Chapter, these KPIs were used with the prepared data to design a draft dashboard that could serve as a decision-making tool for the supply chain manager. This draft dashboard, aimed to evaluate supplier performances, truck performances, driver performances and cost performance to offer support for decision-making and intel on the consequences of decisions. As a result, a Driver Performance Dashboard and a Fleet Performance Dashboard have been created.

The research concluded by demonstrating in the Evaluation and Deployment Chapter that the draft dashboards could give examples of possible evaluations and decisions based on data-driven arguments and the dashboards could be used to test decisions and adjust decisions based on the measured results. Finally, a deployment plan was given with a roadmap showing the steps needed to implement the draft dashboards and KPIs for practical use at Company X. Now with the use of the draft dashboards and the KPIs, Company X can improve the decision-making with a data-driven basis and the available data is utilized to support transportation decisions, addressing the company's core problem "*Available data is not being utilized to support decisions*". By following these steps Company X can create insight into transportation answering our main research question on how to create this insight.

8.2. Recommendations

This Section will offer direct recommendations drawn from the results of the research. The recommendations are listed with explanations:

1. **Export ERP data related to the picking performance of order-pickers**. In Section 2.1 different picking methods, such as using the reach truck at the end or dividing articles based on weight/volume were identified. Analyzing data related to picking performance allows for evaluations of the order-pickers and identifying best practices. Identification of best practices can help in improving the overall performance of order-pickers.
2. **A data collection has to be introduced where the delivery time starts when departing at Company X and ends when returning to Company X.** The current data collection through inconsistent signing-off by the truck drivers can include mistakes and decrease validity. This recommendation provides accurate data on delivery durations, improving the reliability of KPI delivery performance KPIs.
3. **Switch routes of truck drivers and see how it impacts KPIs in the Driver Performance Dashboard.** This recommendation of changing routes allows for the evaluation of driving performances on identical and different routes. Besides, the impact of how route changes affect KPIs can be identified.
4. **Test ideas to increase the *Capacity Utilization*.** In Section 7.1, the *Capacity Utilization* was determined to be around 0.55, whilst the Supply Chain Manager expected it to be at least 0.75. Low *Capacity Utilization* indicates inefficiencies in truck loading. By testing ideas, reasons and improvements for the *Capacity Utilization* can be found
5. **Replace the truck M4 with a new truck from the supplier Volvo based on the cost and environmental performances shown in the Fleet Performance Dashboard.** Based on Section 7.1, current data shows significant costs in Figure 6-2 by the truck M4 in terms of *Maintenance costs* and *TCO*. The recommendation is to replace the truck to reduce risking more high *Maintenance costs* with a new Volvo truck. Volvo has demonstrated better performance in terms of costs and the environment and is likely to perform better.
6. **Advise truck driver M4 on the driving weaknesses based on the driving performance KPIs.** In Section 7.1 truck driver M4 was identified as the worst-performing driver. By identifying and addressing driving weaknesses, the driver can improve their driving behaviour accordingly.

The general recommendation is to use the tool to test ideas, seek improvements and enhance the tool by improving the data quality and including more extensive KPIs.

8.3. Further Research

This Section will give limitations and explain suggestions for further research to improve and increase the solutions.

The result of the draft dashboards required some limitations to maintain the scope of the research and Company X had its limitations. Firstly, the main exclusion from the Data Understanding Chapter onwards is the order-picking because there was a lack of data from the supplier and Company X. To extend the research, KPI literature research can be done based on order-picking. Based on these KPIs suggestions of data that should be collected by Company X can be made.

One important limitation to be considered is the identical routes. Since data variables to identify distances and exact locations were limited and this would require a lot of work, the truck drivers are considered to drive identical routes within the Netherlands. Aspects like type of road, weather circumstances, highway usage and so on would complicate the research to an extreme extent. This does impact the validity of the results. If one truck driver or truck is only driving in residential areas and the other truck is only driving on highways, results related to fuel consumption and braking can be influenced. Even so, most of the truck drivers in the interviews answered to have a high variance in routes which should decrease the impact if all truck drivers drive all kinds of routes. Additional research can be done to include routing-related KPIs allowing for an even more detailed performance analysis.

Another limitation is not all vehicles are included. The van is missing the transportation fleet. This limitation is made because the van only delivers in small packages and is difficult to compare to the transport trucks. Besides, the van does not have a tachograph like the transport trucks to get measurable data from the suppliers. This limitation impacts performances related to the fleet as a whole, but the limitation is not that impactful since the van only contains a very small section of the fleet. If measurable data becomes available for the van, the fleet can be completed by adding the van to the scope of the research.

Two final suggestions for improvement can be recommended to Company X. Currently, the draft dashboard can be refreshed and many variables will be updated. However, a Business Intelligence tool like Power BI offers more extensive and automatic options for analytical performance reports. Therefore, converting the draft dashboard to Power BI is a suggestion for further research. The second suggestion is to search for additional KPIs that are considered important in the literature that are not specifically available to be converted with the existing data, however, these KPIs can be based on assumptions and encourage Company X to expand their data collection to gain more detailed intel on transportation.

Bibliography

[1] Patterson, L., & Patterson, L. (2023, 8 augustus). What are data, information, and knowledge? Internet of Water - Better Water Data for Better Water Management. https://internetofwater.org/valuing-data/what-are-data-information-and-knowledge/#:~:text=Information%20is%20created%20when%20data,Knowledge%20is%20what%20we%20know.

[2] Heerkens, H. (2019). *Micro lectures: mpsm research cycle.* https://vimeo.com/showcase/2938606/video/101271294

[3] Negash, S., & Gray, P. (2008). Business intelligence. In Springer eBooks (pp. 175–193). https://doi.org/10.1007/978-3-540-48716-6_9

[4] Jungheinrich AG. (z.d.). *Order-pick truck | Jungheinrich*. Jungheinrich. https://www.jungheinrich.nl/heftruck/order-pick truck

[5] Axestrack Software Solutions. (2023, 16 juni). *Truck Transport Cost per Kilometer in India: A Comprehensive Guide*. Axestrack. https://www.axestrack.com/truck-transport-cost-per-kilometer-in-india-a-comprehensive-guide/

[6] *MyEducator - CRISP-DM: Data Mining Process*. (z.d.). https://app.myeducator.com/reader/web/1421a/2/qk5s5/

[7] Palacios, H. J. G., Toledo, R. A. J., Hernández, G., & Navarro, Ã. A. M. (2017). A comparative between CRISP-DM and SEMMA through the construction of a MO DIS repository for studies of land use and cover change. *Advances in Science, Technology And Engineering Systems Journal*, *2*(3), 598–604. https://doi.org/10.25046/aj020376

[8] Schröer, C., Kruse, F., & Gómez, J. M. (2021). A Systematic Literature Review on Applying CRISP-DM Process Model. *Procedia Computer Science*, *181*, 526–534. https://doi.org/10.1016/j.procs.2021.01.199

[9] Palacios, H. J. G., Toledo, R. A. J., Pantoja, G. A. H., & Navarro, Á. A. M. (2017). A comparative between CRISP-DM and SEMMA through the construction of a MODIS repository for studies of land use and cover change. *Adv. Sci. Technol. Eng. Syst. J*, *2*(3), 598-604.

[10] Kenneth A. Jensen - *Project Methodology*. (2016). https://sites.google.com/view/kajensen/profile/project-methodology

[11] Nightingale, A. (2009). A guide to systematic literature reviews. *Surgery*, *27*(9), 381–384. https://doi.org/10.1016/j.mpsur.2009.07.005

[12] Faveto, A., Traini, E., Bruno, G., & Lombardi, F. (2021). Development of a key performance indicator framework for automated warehouse systems. *IFAC-PapersOnLine*, *54*(1), 116–121. https://doi.org/10.1016/j.ifacol.2021.08.013

[13] Bhagwat, R., & Sharma, M. K. (2007). Performance measurement of supply chain management: A balanced scorecard approach. *Computers & Industrial Engineering*, *53*(1), 43–62. https://doi.org/10.1016/j.cie.2007.04.001

[14] Leppäkoski, A., Sievi-Korte, O., & Hämäläinen, T. D. (2021). Framework for creating relevant, accessible, and adoptable KPI models in an industrial setting. In *Lecture notes in business information processing* (pp. 81–97). https://doi.org/10.1007/978-3-030-91983-2_7

[15] Küçükaltan, B., Irani, Z., & Aktaş, E. (2016). A decision support model for identification and prioritization of key performance indicators in the logistics industry. *Computers in Human Behavior*, *65*, 346–358. https://doi.org/10.1016/j.chb.2016.08.045

[16] Rodríguez-Padial, N., Marín, M. M., & Domingo, R. (2015). Strategic Framework to maintenance Decision Support Systems. *Procedia Engineering*, *132*, 903–910. https://doi.org/10.1016/j.proeng.2015.12.576

[17] Kaplan, R. S. (2009). Conceptual foundations of the balanced scorecard. In Handbooks of management accounting research (pp. 1253–1269). https://doi.org/10.1016/s1751-3243(07)03003-9

[18] Ridzuan, F., & Zainon, W. M. N. W. (2019). A review on data cleansing methods for big data. Procedia Computer Science, 161, 731–738. https://doi.org/10.1016/j.procs.2019.11.177

[19] Zhu, M., Bonk, C. J., & Doo, M. Y. (2020). Self-directed learning in MOOCs: exploring the relationships among motivation, self-monitoring, and self-management. Educational Technology Research and Development, 68(5), 2073–2093. https://doi.org/10.1007/s11423-020-09747-8

[20] Sharda, R., Delen, D., Turban, E., & King, D. (2017). *Business intelligence, analytics, and data science : a managerial perspective* (4th ed., global ed). Pearson Education Canada. https://public.ebookcentral.proquest.com/choice/publicfullrecord.aspx?p=5832070

[21] Alsaawi, A. (2014). A Critical Review of Qualitative Interviews. Social Science Research Network. https://doi.org/10.2139/ssrn.2819536

[22] Castleberry, A., & Nolen, A. (2018). Thematic analysis of qualitative research data: Is it as easy as it sounds? Currents in Pharmacy Teaching And Learning, 10(6), 807–815. https://doi.org/10.1016/j.cptl.2018.03.019

[23] Kijewska, K., Małecki, K., Iwan, S. (2016). Analysis of Data Needs and Having for the Integrated Urban Freight Transport Management System. In: Mikulski, J. (eds) Challenge of Transport Telematics. TST 2016. Communications in Computer and Information Science, vol 640. Springer, Cham. https://doi.org/10.1007/978-3-319-49646-7_12

[24] Pozueco, L., Gupta, N., Pañeda, X. G., Magaña, V. C., Melendi, D., GarcíA, R., & Rionda, A. (2023). Data Analytics to Support a Smart Fleet Management Strategy. *IEEE Intelligent Transportation Systems Magazine*, *15*(2), 115–127. https://doi.org/10.1109/mits.2022.3208316

[25] Yang, Z., Ercan, T., & Tatari, Ö. (2016a). Life cycle based multi-criteria optimization for optimal allocation of commercial delivery truck fleet in the United States. Sustainable Production And Consumption, 8, 18–31. https://doi.org/10.1016/j.spc.2016.04.003

[26] Vujanović, D., Momčilović, V., Bojović, N., & Papić, V. (2012b). Evaluation of vehicle fleet maintenance management indicators by application of DEMATEL and ANP. Expert Systems With Applications, 39(12), 10552–10563. https://doi.org/10.1016/j.eswa.2012.02.159

[27] Matusiak, M., De Koster, R., & Saarinen, J. (2017). Utilizing individual picker skills to improve order batching in a warehouse. European Journal Of Operational Research, 263(3), 888–899. https://doi.org/10.1016/j.ejor.2017.05.002

[28] Grosse, E. H., & Glock, C. H. (2015). The effect of worker learning on manual order picking processes. International Journal Of Production Economics, 170, 882–890. https://doi.org/10.1016/j.ijpe.2014.12.018

[29] Atanasković, P., Gajić, V., Dadić, I., & Nikoličić, S. (1970). Selection of Forklift Unit for Warehouse Operation by Applying Multi-Criteria Analysis. Promet, 25(4), 379–386. https://doi.org/10.7307/ptt.v25i4.1338

[30] Zajac, P., & Rozic, T. (2022). Energy consumption of forklift versus standards, effects of their use and expectations. Energy, 239, 122187. https://doi.org/10.1016/j.energy.2021.122187

[31] Austin, Z., & Sutton, J. (2014). Qualitative research: Getting started. Canadian Journal Of Hospital Pharmacy/˜The œCanadian Journal Of Hospital Pharmacy, 67(6). https://doi.org/10.4212/cjhp.v67i6.1406

[32] Şimşek, B., Pakdil, F., Dengiz, B., & Testik, M. C. (2013). Driver performance appraisal using GPS terminal measurements: A conceptual framework. Transportation Research. Part C, Emerging Technologies, 26, 49–60. https://doi.org/10.1016/j.trc.2012.07.006

[33] Zis, T. P., Psaraftis, H. N., & Reche-Vilanova, M. (2023). Design and application of a key performance indicator (KPI) framework for autonomous shipping in Europe. Maritime Transport Research, 5, 100095. https://doi.org/10.1016/j.martra.2023.100095

[34] Gonzalez-Pascual, E., Nosedal-Sanchez, J., & Garcia-Gutierrez, J. (2021). Performance evaluation of a road freight transportation company through SCOR metrics. Case Studies On Transport Policy, 9(4), 1431–1439. https://doi.org/10.1016/j.cstp.2021.07.001

[35] Schloter, L. (2022). Empirical analysis of the depreciation of electric vehicles compared to gasoline vehicles. Transport Policy, 126, 268–279. https://doi.org/10.1016/j.tranpol.2022.07.021

[36] Jackson, S. B., Liu, X., & Cecchini, M. (2009). Economic consequences of firms' depreciation method choice: Evidence from capital investments. Journal of Accounting & Economics/Journal of Accounting and Economics, 48(1), 54–68. https://doi.org/10.1016/j.jacceco.2009.06.001

[37] Roulston, K. (2010). Interview 'Problems' as topics for analysis†. Applied Linguistics, 32(1), 77–94. https://doi.org/10.1093/applin/amq036

[38] Hayes, A. (2024, 19 maart). Coefficient of Variation: Meaning and How to Use It. Investopedia. https://www.investopedia.com/terms/c/coefficientofvariation.asp

[39] Ryan, L. (2016). Data visualization as a core competency. In Elsevier eBooks (pp. 221–242). https://doi.org/10.1016/b978-0-12-803844-4.00011-x

[40] Olimpo, G. (2011). Knowledge flows and graphic knowledge representations. In Elsevier eBooks (pp. 91–131). https://doi.org/10.1016/b978-1-84334-646-3.50005-8

[41] Roughton, J., & Crutchfield, N. (2016). Effectively Managing a JHA Process using Six Sigma. In Elsevier eBooks (pp. 377–406). https://doi.org/10.1016/b978-0-12-803441-5.00015-5

Appendix

I. Systematic literature review – KPI

Systematic literature reviews aim to identify all research addressing a specific question to give a balanced and unbiased summary of the literature [11]. Through an SLR we can find an unbiased answer to an important research question. We will conduct the SLR protocol in this Section by going through the following steps:

1. Definition of knowledge problem
2. Criteria
3. Identification of academic databases
4. Search terms
5. Search log
6. Conceptual matrix
7. Integration theory (done in Section 4.1 Theoretical framework)

Definition of knowledge problem

The research goal is to create a draft dashboard with the use of KPIs to give insight into the maintenance costs of the supply chain and the relation to the usage of trucks by the employees. The main step to give insight will be to find a strategy to write KPIs that are applicable to the company. It is vital that the KPIs can represent and explain the problem to the manager to help in reducing costs. Currently, we lack the knowledge to solve this problem of defining useful KPIs. Hence, the research question to our knowledge problem for the SLR is:

"What frameworks can be used to develop KPIs that evaluate the supply chain within a company?"

Criteria

To start searching for articles we need to make it more specific to avoid many results that are not applicable to the research. Inclusion and exclusion criteria are introduced to include things the article should contain and exclude things the article should not contain. If the article does not abide by the criteria the article can be disregarded. The criteria are in Table 3.

Inclusion criteria	**Exclusion criteria**
Written in English	Not peer-reviewed
Articles should offer concepts, models or frameworks to develop KPIs	Published before the year 2000

Articles relating to the warehouse	Not cited by other articles
Articles relating to logistics	Articles about Inventory management
Articles relating to maintenance	Articles about Demand planning
Articles relating to order pick trucks or transport trucks	

Table 0-1: Inclusion and Exclusion criteria

Identification of relevant academic databases

To identify relevant academic databases we consider our wish in articles about different sectors. Therefore we pick multidisciplinary databases. Moreover, we want peer-reviewed articles to increase the quality of the articles. The two databases that we select are Scopus and Web of Science. These databases are broad databases and the articles are peer-reviewed. The databases are also included in the list of relevant databases in the UT library to confirm our selection. Through these two databases we can find many results in relation to our research question.

Search terms

The search terms have to include the key concepts of our research questions. Key concepts from the research questions are: KPI, Company, Develop, Framework and supply chain. The key concepts are ordered from 1 to 5 in the Table 4. Our main goal is to find a KPI framework, so those two are considered most important. Develop is used to indicate a framework with steps to make KPIs. The relation to the supply chain helps to find something fitting to our research and company is added to offer a company related framework. In relation to the key concepts we find related terms, narrower terms and broader terms to support our search. In Table 4, all related search terms linked with the key concepts are given. The search terms help in finding relevant articles faster and checking their usefulness.

	Key Concepts	**Related terms**	**Narrower terms**	**Broader terms**
1	KPI	Core indicator,	Balanced Scorecard	Indicator, performance indicator, performance measure, metrice
2	Framework	Model, methodology	Analytical framework, conceptual framework	Concept, system
3	Develop	Define, Create	Identify, Clarify	Evolve, progress

4	Supply chain	Warehouse, Logistics	Supply Chain Optimization, Transportation Management	Business Operations, Business Management
5	Company	Business	Corporation	Organization, Industry

Table 0-2: Search terms

Search log

The following Table 5 consists of a search log for the two databases Scopus and Web of Science.

Source	**Search string**	**Total hits**	**Remarks**
Scopus	(TITLE-ABS-KEY ("key performance indicator") OR TITLE-ABS-KEY ("performance measure") OR TITLE-ABS-KEY (kpi)) AND (TITLE-ABS-KEY (framework) OR TITLE-ABS-KEY (model))	29597	These are way too many hits. The search string needs to be more narrow.
Scopus	(TITLE ("key performance indicator") OR TITLE ("performance measure") OR TITLE (kpi)) AND (TITLE (framework) OR TITLE (model))	390	We reduce the string to the title. The hits decreased greatly. Still, these are too many hits, many do not seem helpful, the string needs to become more narrow.
	(TITLE ("key performance indicator") OR TITLE ("performance measure") OR TITLE (kpi)) AND (TITLE (framework) OR TITLE (model) OR TITLE (approach) AND TITLE-ABS-KEY ("supply chain") OR TITLE-ABS-KEY (warehouse) OR TITLE-ABS-KEY (maintenance) OR TITLE-ABS-KEY ("industrial setting"))	56	Adding relation to the supply chain and industry help to reduce articles. Some articles seem useful, but still a bit too many results and some do not seem useful.
	(TITLE ("key performance indicator") OR TITLE ("performance measure") OR TITLE (kpi)) AND (TITLE	30	Setting the title requirement for the supply chain related aspects helps to reduce articles. Many of the titles

	(framework) OR TITLE (model) OR TITLE (approach) AND TITLE ("supply chain") OR TITLE (warehouse) OR TITLE (maintenance) OR TITLE ("industrial setting"))		seems useful, the articles are further evaluated.
Web of Science	(TI=(kpi)OR AB=(kpi)OR AK=(kpi) AND TI=(framework) OR AB=(framework) OR AK=(framework))	1,665,089	Way too many results, we need to narrow our search.
Web of Science	(TI=(kpi) OR AK=(kpi) AND TI=(framework) OR AK=(framework))	93,077	We removed the relation to the abstract, but there are still way too many results.
Web of Science	(TI=(kpi)AND TI=(framework)	19	We removed the relation to the author keywords, this helped greatly in reducing the results. Some results do not seem useful based on the title, however, some do seem useful. These articles will be further evaluated.
Web of Science	(TI=(kpi) AND TI=(framework) AND TI=(develop))	0	Adding develop to get more useful hits, resulted in no articles.
Web of Science	(TI=(kpi) AND TI=(framework) AND TI=(supply chain))	0	We decide that the earlier results in Web of Science should suffice.

Table 0-3: Search log

The search log resulted into multiple results. First, the Table 5 shows 19 hits in the Web of Science database. We limited the search only to KPI and framework to get these results, a difficulty was to get more useful articles, the number of articles would quickly decrease to a small number of articles. After going through the articles we find one useful article for our research question, article [13] in the bibliography. Secondly, Table 5 shows 30 hits in the Scopus database. For the Scopus database, we had to add many aspects to find useful results, many of the hits did not fit to our research question, however, after restricting to the title and adding supply chain related aspects and other terms for the framework and KPI we managed to get interesting results. Scanning through the 30 hits, we ended up with 4 interesting articles, article [10], [11], [12] and [14] in the bibliography. The total of 5 articles are used for the conceptual matrix and integration theory.

Conceptual matrix

This step compares concepts within the articles relating to our research question. A box is checked in the Table 6 if the article offers information about the concept.

Concept	Explanation	[10]	[11]	[12]	[13]	[14]
Systematic literature review to sample KPIs	Through a SLR KPIs are found in other literatures related to the research.	x			x	
Survey to sample KPIs	Through a questionnaire to the stakeholders KPIs are found related to the research				x	
Balanced Scorecard to sort KPIs based on four perspectives	The four perspectives are financial, customer/stakeholder, internal business process, and learning and growth.	x	x	x	x	x
Three hierarchical levels (Strategical, tactical, and operational) to sort KPIs	Strategical is for long-term, tactical for middle-term, and operational detailed decision-making.	x	x			x
KPI evaluation based on criteria	Certain criteria's are given to exclude KPIs are include them			x	x	
Delhi method rate KPIs	Through repeated surveys experts can give feedback on the KPIs and give a rating	x			x	

Table 0-4: Conceptual matrix

II. Interview thematic analysis

1. What steps do you need to follow?
2. When do you find your work easy?
    a. Why?
3. When do you find your work difficult?
    a. Why?
    b. Do you have ideas on how this could be made easier?
4. Do you have personal tricks that you use to do things faster?
    a. What are they and how do you do it?
5. Do you ever have problems with the machines?
    a. With which machines?
    b. What are the problems? How do they arise?
6. Does your truck function well?
    a. Do you find driving the truck easy or difficult?
        - Why?
7. What training have you had?
    a. What do you think of these trainings?
8. What kind of orders do you usually handle? (many different items/heavy items)
9. Are there certain circumstances when you can do your work better or circumstances when you can do your work less well?
    a. Why?
10. Does it take you a lot of time to find the right items?
    a. Why not/why?
    b. What would help to improve this quickly?
11. What do you think of items that have multiple parts?
    a. How do you make this the most simple for yourself?
12. Is there enough space in the warehouse and are items well organized?
    a. Would you organize items differently or what would you change?
13. Do some items sometimes break quickly?
14. Do you ever make picking errors?
15. Additional comments:

Figure 0-1: Order-picker interview questions

Codes	Themes	Order-pickers						Frequency
		O1	O2	O3	O4	O5	O6	
General difficulty of work	Easy	x	x	x	x	x		5
	Hard						x	1
Challenges of work	Knowing the items before picking to decide on an order			x	x		x	3
	Determining the criteria to sort the order				x		x	3
	Busy period		x					1
Working methods to reduce order-picking time	Checking the order beforehand	x	x		x	x		4
	Use the reach truck at the very end if it is by required multiple times	x						1
	Larger boxes on the bottom and smaller ones on the top				x	x		2
	Heavy items on the bottom and lighter items on top	x	x		x	x		4
	Stackable items on the bottom	x	x			x		3
Truck problems	Little to no problems	x	x	x	x	x		5
	Major problems						x	1
Reason of truck problems	Pallets in the aisles	x		x	x			3
Truck satisfaction	High	x	x	x	x	x	x	6
Difficulty of truck usage	Easy	x	x	x	x	x		5
	Hard						x	1
Truck repairs	Not recently			x			x	2
	Recently, a fast technical department repair		x		x	x		3
	Recently, a supplier repair	x						1
Trainings	Blom training for the reach truck, EPT and stacker. Internal training for the order-picker.		x	x	x		x	4
	All trainings internal	x				x		2
Opinion of Trainings	Useful	x	x		x		x	4
	Theory different than practice			x				1
	Insufficient practice					x		1
Sort of orders	Large and difficult orders	x				x		2
	Middle orders		x	x	x			3
	Small orders						x	1
Problematic conditions	No replenishment	x			x			2
	Long waiting time for the reach truck	x	x		x	x		4
Ideas to decrease order-picking time	Having more items and faster-moving items at the order-pick trucks height.	x				x		2
	Phone additions (skip items, sort on weight, show city location)		x	x		x		3
Time to find items	Little, due to experience	x	x		x	x		4
	More, due to less experience			x			x	2
Multiple parts opinions	No problems.	x			x	x		3
	Description not clear enough		x		x			2
	Find the right parts can be difficult if location is messy			x			x	2
Multiple parts fixes	Reading the description carefully	x	x		x	x		4
	Bundling the parts			x		x		2
	Indication of number of parts in description						x	1
Warehouse space	Sufficient	x	x	x	x	x	x	6
Warehouse organisation	Good		x		x	x		3
	Can be better	x		x			x	3
Warehouse organisation fixes	Group small items by sector	x				x		2
	More workstations					x		1
Breaking of items	Sometimes	x	x	x	x	x	x	6
Pick errors	Rarely	x	x		x	x		4
	At first more, now less			x			x	2

Table 0-5: Order-picker thematic analysis

1. What steps do you need to go through?
2. When do you find your work easy?
    a. Why?
3. When do you find your work difficult?
    a. Why?
    b. Do you have ideas on how this could be made easier?
4. Do you have personal tricks you use to do things faster?
    a. What are these and how do you do it?
5. How would you describe your driving route?
    a. Do you often have to drive the same routes?
        i. How do you feel about this?
    b. Do you often have to brake?
    c. Can you often use the highway?
6. How would you describe your driving style?
    a. Do you brake hard and accelerate quickly?
    b. Do you coast and accelerate slowly?
    c. Have you ever received fines?
        i. Why?
7. What is the reason for your driving style?
8. What problems do you encounter with customers?
    a. How does the registration process at the customer go?
    b. Do you have to wait long at the customer's location?
    c. Do you encounter other types of problems with customers?
9. How long does a stop take on average?
    a. Does this vary per customer?
    b. Could this have other causes?
10. How long does loading take?
11. How long does unloading take?
12. When is the delivery note signed?
    a. Does this vary per customer?
13. What trainings have you received?
    a. What do you think of these trainings?
14. Any recent repairs?
15. Are there differences between Volvo and Mercedes?

Additional comments:

Figure 0-2: Truck driver interview questions

Codes	Themes	Truck drivers				Frequency
		V1	V2	M3	M4	
General difficulty of work	Easy	x	x	x	x	4
Challenges of work	Special attention customers	x	x			2
	Busy				x	1
	Signing off			x		1
	Backwards driving		x			1
	New customers		x	x		2
Working methods to decrease delivery time	Knowing the instructions		x			1
	Knowing the customers	x	x	x	x	4
	Signing off myself			x		1
	Bring a hand truck				x	1
Route description	Long distances	x	x			2
	Long distances and residential areas			x		1
	Short distances and residential areas				x	1
Route variety	Fairly varied	x	x	x		3
	Little varity				x	1
Opinion on high variation	Positive	x	x	x	x	4
Brake usage	Not as much	x	x			2
	Sometimes			x		1
	A lot				x	1
Highway usage	Long distances	x	x			2
	Some short and long distances			x		1
	Only short distances				x	1
Driving style	Economical and automatic	x	x			2
	Calm and controlled			x	x	2
Reason for driving style	Truck limitations	x	x			2
	Speeding limit and relaxed			x	x	2
Fines	More than 10 years ago	x	x			2
	4 years ago				x	1
	In the last three quartes of a year			x		1
Frequency of customer problems	Sometimes			x		1
	Rarely	x	x		x	3
Sort of customer problems	Long waiting time	x	x	x	x	4
	Customer does not accept goods	x	x			2
Waiting time at customer	Waiting queue	x	x	x	x	4
	No customer present	x	x	x	x	4
	Delivery to a specific location	x	x	x		3
	New customers		x	x		2
	No allowance to unload	x	x	x		3
Stop time	Average of 10 minutes	x			x	2
	7.5 minutes			x		1
	12.5 minutes		x			1
Variation stop time per customer	High	x	x	x	x	4
Loading time	20 minutes	x				1
	30 minutes		x		x	2
	45 minutes			x		1
Point of sign off	After unloading				x	1
	After unloading, occasionaly later myself in consultation with the customer	x	x			2
	After unloading, occasionaly later myself without consultation			x		1
Trainings	Economical driving	x	x			2
	Volvo training			x	x	2
Opinion on trainings	Useful	x	x	x		3
	Tiring				x	1
Repairs	Adblue system	x	x			2
	Tail lift				x	1
	Maintenance		x		x	2
	Trailer			x		1

Table 0-6: Truck driver thematic analysis

KPI Name (green:literature, yellow:experts)	I. and II. Cause-and Effect Relationship of KPI	III. Data	IV. Measurement Criteria	V. Useful Results	VI. Research Objective
Capacity utilization	✓ Driver KPI affects Efficiency and Costs (TCO)	✓	✓ Percentage of total capacity	✓ Intel on efficiency	✓ Supports decisions
Maintenance costs	✓ Driver KPI affects TCO	✓	✓ Total maintenance costs	✓ Intel on costs	✓ Supports decisions
Time between failures	✓ Outcome KPI affected by Maintenance frequency	✗	✓ Time between repairs	✓ Intel on efficiency	✓ Gives information
Fuel consumption	✓ Driver KPI affects Fuel costs	✓	✓ Liters per kilometer	✓ Intel on drivers	✓ Supports evaluations
CAPEX	✓ Driver KPI affects TCO	✓	✓ Capital cost of truck	✓ Intel on costs	✓ Supports decisions
Lifetime kilometers	✓ Driver KPI affects Cost Per Kilometer	✓	✓ Total kilometers driven	✓ Intel on trucks	✓ Gives information
CO_2 emission	✓ Outcome KPI affected by Braking	✓	✓ Grams per kilometer	✓ Intel on trucks	✓ Gives information
Total life cycle costs	✓ Outcome KPI affected by Age of truck	✓	✓ Sum all costs over truck's life	✗ Lacks residual value	✗ Not complete
Age of truck	✓ Driver KPI affects TCO	✓	✓ Purchase date to current date	✓ Intel on trucks	✓ Gives information
Idle duration	✓ Driver KPI affects Driver Performance	✓	✓ Time with engine stationary	✓ Intel on drivers	✓ Supports evaluations
Fuel costs	✓ Outcome KPI affected by Fuel consumption	✓	✓ Fuel price * kilometers	✓ Intel on drivers	✓ Supports evaluations
Average speed	✓ Driver KPI affects Fuel costs	✓	✓ Distance / time	✗ Speed is limited	✗ Not applicable
Average loss cost of fuel	✓ Outcome KPI affected by Idle duration	✓	✓ Idle distance * Fuel price	✓ Intel on costs	✓ Gives information
Net difference CO_2 emissions	✓ Outcome KPI affected by Average speed	✓	✓ Net difference between trucks	✗ Already covered	✗ No new intel
Weight per delivery	✓ Driver KPI affects Fuel costs	✓	✓ Kilograms per delivery	✓ Intel on efficiency	✓ Gives information
Average distance travelled	✓ Driver KPI affects Fuel costs	✓	✓ Kilometers per month	✗ More a data variable	✗ Not as KPI
Delivery time per driver	✓ Driver KPI affects Efficiency and Costs	✓	✓ Time per complete delivery	✓ Intel on driver	✓ Supports evaluations
Complete deliveries per supplier	✗ No impact, deliveries are not done by suppliers	✗	✗ Not done by suppliers	✗ Not by suppliers	✗ Not applicable
Complete deliveries per driver	✓ Driver KPI affects Efficiency and Costs	✓	✓ Complete deliveries per month	✓ Intel on driver	✓ Supports evaluations
Roll out (%)	✓ Driver KPI affects Driver Performance	✓	✓ Percentage of total kilometers	✓ Intel on driver	✓ Supports evaluations
Cruise-control (%)	✓ Driver KPI affects Driver Performance	✓	✓ Percentage of total kilometers	✓ Intel on driver	✓ Supports evaluations
Braking (%)	✓ Driver KPI affects Driver Performance	✓	✓ Percentage of total kilometers	✓ Intel on driver	✓ Supports evaluations
TCO	✓ Outcome KPI affected by Maintenance costs	✓	✓ All costs minus residual value	✓ Intel on costs	✓ Supports decisions
TCO (fuel incl.)	✓ Outcome KPI affected by Maintenance costs	✓	✓ TCO with fuel included	✓ Intel on costs	✓ Supports decisions
Cost per Kilometer	✓ Outcome KPI affected by Lifetime kilometers	✓	✓ TCO / lifetime kilometers	✓ Intel on costs	✓ Supports decisions
Fleet fuel Cost per Kilometer	✓ Outcome KPI affected by Lifetime kilometers	✓	✓ TCO with fuel included	✓ Intel on costs	✓ Supports decisions
Customers per driver	✓ Driver KPI affects Efficiency and Costs	✓	✓ (TCO + fuel) / lifetime kilometers	✓ Intel on driver	✓ Supports evaluations
Residual value	✓ Driver KPI affects TCO	✓	✓ Capital cost minus depreciation	✓ Intel on costs	✓ Supports decisions
Average fleet age	✓ Outcome KPI affected by Age of truck	✓	✓ Total fleet age / 4	✓ Intel on fleet	✓ Gives information
Average lifetime kilometers	✓ Outcome KPI affected by Lifetime kilometers	✓	✓ Total fleet kilometres / 4	✓ Intel on fleet	✓ Gives information
Maintenance frequency	✓ Outcome KPI affected by Braking	✓	✓ All maintenance records	✓ Intel on trucks	✓ Gives information
Driver Performance	✓ Outcome KPI affected by Roll out	✓	✓ Points based on driving KPIs	✓ Intel on driver	✓ Supports evaluations

Table 0-7: Full KPI checklist evaluation

III. Tactical and Operational KPI definitions

Tactical KPIs:

- Total Maintenance costs = All maintenance costs from maintenance records summed either per truck or per supplier of trucks.
- Total fleet costs = Total maintenance costs and total capital costs of all trucks summed.
- Residual value = The truck's current value, based on 15% straight-line depreciation which means that from the initial price, 15% is depreciated every year. If a truck is 4 years old and 15% of the initial price (€100000) is €15000, the residual value would be €100000 – (4*€15000)=€40000.
- Average Monthly fuel consumption per supplier = The monthly fuel consumption per truck is found in the suppliers data, the trucks of the same supplier are summed and divided by the number of trucks per supplier (2).
- Roll out (%) = The roll out kilometers per month divided by the total kilometers per month taken from the suppliers data.
- Cruise-control (%) = The cruise-control kilometers per month divided by the total kilometers per month taken from the suppliers data.
- Idle (%) = The stationary time with the engine on, per month divided by the total time per month taken from the suppliers data.
- Braking (%) = The braking kilometers per month divided by the total kilometers per month taken from the suppliers data.
- Average fleet age = The age of all trucks summed, divided by the number of trucks in the fleet (4).
- Average lifetime kilometers = The lifetime kilometers of all trucks summed, divided by the number of trucks in the fleet (4).

Operational KPIs:

- Maintenance frequency = All the maintenance records are counted per truck or supplier.
- Average monthly weight per driver = The total weight per complete delivery on average per month per driver. This can be done with pivot tables of the ERP data.
- Average monthly customers per driver = The total customers per complete delivery on average per month per driver. This can be done with pivot tables of the ERP data.
- Average monthly complete deliveries per driver = The average number of complete deliveries done in a month per driver. This can be done with pivot tables of the ERP data.
- Average monthly delivery time per driver = The delivery time between the first customer sign-off and the final customer sign-off per complete delivery on average per month per driver. This can be done with pivot tables of the ERP data.
- Age of each truck = The current date – the purchase date of a truck. Information is given by Company X.
- Lifetime kilometers of each truck = Total number of kilometers driven by the truck at the current date. Information can be found on the tachometer in the car.

IV. PDF formatting to Excel

- Create a map and add the relevant files. Two maps are made one for each truck with multiple files for each month of the truck's performance.
- In the data tab on the ribbon, click get data, from file, click map and find the map you want to use.
- It will open a collection of files in the map, click combine and transform data
- The Power query editor opens and we go on the data table and unfold the content
- Now we apply steps to transform the data, we have a big table with 5 columns and many rows that can increase based on the number of files in the map. In Table 0-8, column 1 and column3 are filled attributes and column2 and column4 are filled with the corresponding values of the attributes. The goal is to have all the attributes in one column and the values in another column per source.

Source.Name	**Column1**	**Column2**	**Column3**	**Column4**
Source 1	Attribute 1	Value 1	Attribute 2	Value 2
Source 1	Attribute 3	Value 3	Attribute 4	Value 4
Source 2	Attribute 1	Value 1	Attribute 2	Value 2
Source 2	Attribute 3	Value 3	Attribute 4	Value 4

Table 0-8: First query table

- We start by filtering empty cells in column2 two remove headers of the pdf with no data and to remove unusable attributes and values, so we only remove the 'empty' cells not cells with a 0.
- We change the headers of the columns, Column1 = Attributes 1, Column2 = Data 1, Column 3 = Attributes 2, Column4 = Data 2
- We duplicate this table twice and name the first duplication Attributes 1 (Truck 1) and the second duplication Data 1 (Truck 1)
- In Attributes 1, we remove both data columns, we select the Attributes 1 column and the Attributes 2 column and unpivot the columns which creates two new columns, one column 'Attribute' filled with Attributes 1 and Attributes 2 so the previous column names and one column with the Attribute value filled with the actual different attributes. Finally we add an index column to create a unique identifier for every source and its attribute and attribute value. The result table can be seen in Table 0-9.

Index	**Source.Name**	**Attribute**	**Attribute Value**
1	Source 1	Attributes 1	Attribute 1

2	Source 1	Attributes 2	Attribute 2
3	Source 2	Attributes 1	Attribute 1
4	Source 2	Attributes 2	Attribute 2

Table 0-9: Second query table

- In Data 1, remove both attribute columns. Then select the Data 1 column and the Data 2 column and unpivot the columns, which creates two new columns, one column 'Attribute' filled with Data 1 and Data 2, so the previous columns names and one column with the Data Value filled with the actual different values. Again we add an index column and change the 'Data' name in the 'Attribute' column to 'Attributes' so this column becomes the same as in the Attributes 1 table which is necessary for the next step. The structure is shown in Table 0-10.

Index	**Source.Name**	**Attribute**	**Data Value**
1	Source 1	Attributes 1	Value 1
2	Source 1	Attributes 2	Value 2
3	Source 2	Attributes 1	Value 1
4	Source 2	Attributes 2	Value 2

Table 0-10: Third query table

- Now both queries Attributes 1 and Data 1 are merged as new, we select the 'Index', 'Source.Name' and 'Attribute' columns as equal columns and create a new query Result 1 and the 'Attribute' and 'Index' columns are deleted. The Result 1 structure can be seen in Table 0-11, now the attributes are all in one column and all the data values are in one column.

Source.Name	**Attributes**	**Data**
Source 1	Attribute 1	Value 1
Source 1	Attribute 2	Value 2
Source 2	Attribute 1	Value 1
Source 2	Attribute 2	Value 2

Table 0-11: Fourth query table

- In Result 1, we pivot the Source.Name column and do not aggregate the values. This gives our the final structure shown in Table 0-12. With this structure, whenever a file is added, an additional column with the corresponding values of the month for each attributes are added.

Attributes	**Source 1**	**Source 2**	**Source 3**

Attribute 1	Value 1	Value 1	Value 1
Attribute 2	Value 2	Value 2	Value 2
Attribute 3	Value 3	Value 3	Value 3
Attribute 4	Value 4	Value 4	Value 4

Table 0-12: Fifth query table

- Now we want to pivot the table again to get the Sources as Months in the first column and the attributes divided over the columns. Pivot without aggregating values and selecting the Sources creates the final composition of the table. Now whenever, report is added to the map and row is added to the Table 0-13.

Months	**Attribute 1**	**Attribute 1**	**Attribute 1**
Month 1 (Source 1)	Value 1	Value 2	Value 3
Month 2 (Source 2)	Value 1	Value 2	Value 3
Month 3 (Source 3)	Value 1	Value 2	Value 3
Month 4 (Source 4)	Value 1	Value 2	Value 3

Table 0-13: Sixth query table

- We repeat this process and create the same queries for Truck 2 and close & load each query to its own sheet in the Excel