

Impact analysis of a modal shift for EMONS 2WIN cargo business unit

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Preface

Dear Reader,

In front of you lays my bachelor thesis, marking the end of my three-year journey here at the University of Twente. This research was conducted during the period of March till July 2022 at Emons during a global pandemic. To say it has been quite a journey would be an understatement. Due to the COVID pandemic, acquiring a company was tremendously difficult. After several long months of reaching out to multiple companies and not receiving a positive answer, I was finally introduced to Emons – a family-owned logistics company with a history of providing innovative solutions. From the moment I arrived at their headquarters, I had the opportunity to meet people from every department, all eager to learn and all passionate about what they do on a day-to-day basis. I was always welcome to join any meeting and felt like a part of the company in every way.

I am very grateful for all the assistance and help that I received from the moment I acquired this thesis up until the moment of its completion. It has definitely been a rewarding journey for me, as I was introduced to the field of logistics, whilst having the opportunity to work with a small team of hard-working and like-minded individuals. I would like to thank my first supervisor Sebastian Piest for introducing me to Emons and for always providing excellent guidance and support, especially at times, when there have been obstacles along the way. With frequent communication and words of encouragement I was able to make significant progress every day. I am grateful for the discussions and insightful feedback that I had from my second supervisor Derya Demirtas, as it enabled me to think from a different perspective and improve on my work. From the company I would like to thank my supervisor Roland Tonk for giving me the necessary company information and having the time to discuss any thoughts/ideas/obstacles on my end, thereby helping me structure and deliver a working and correct tool. I am also grateful for the additional information and suggestions I received from Saumyajit Parida from a transport planning and data perspective, as I was able to expand the tool further. To my family and friends, thank you all for your continuous support and encouragement throughout my journey!

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Management summary

In recent years, multimodal transport has been largely used around the world for transportation of goods. The term multimodal has the meaning of transportation, involving multiple modalities, such as road, sea, rail and air (Jenny,2021) . With road transportation being the most widely used (<https://www.freightera.com/>), it is also often combined with road or rail for (intercontinental) shipments.

This research is carried out at EMONS, a logistics company, specialising in providing innovative services across Europe. The goal of this research is to provide an insight into the effects a modal shift will have on the network. The impacts have been made on several levels and the results obtained suggest that the container unit, along with the proposed ports have the potential for reducing equipment costs in the near future.

The case study concerns the journey from Germany to Ireland, where more than one modality must be used. The transportation unit used is a trailer and currently, a combination of road, rail and sea modalities is used, where the trucks transit through the UK by road. Due to Brexit, there has been a change in the customs regulations, costs and waiting times, associated with entering and exiting the United Kingdom. This and other factors, such as external pressure and insufficient capacity poses a threat to the daily operations of the company and increases coordination complexity. Therefore, the aim of this research is to do an impact assessment of a modal shift, where different alternative routings are identified and subsequently assessed that have a direct connection by ferry between continental Europe and Ireland. Following along is the introduction of containers as transportation units to ease the transition between the sea and road modality.

A literature review has been done in order to view existing methods of evaluating a potential modal shift and identify any possible gaps, not thoroughly discussed, which can be explored . Most studies, investigating the potential for modal shift share the use of logit models and utility functions, however when in discussion with the company, these models tend to not provide a sufficient basis for comparison and the results are difficult to interpret. On the other hand, stochastic and simulation models, were not possible to implement, due to the limited data in terms of waiting times. On another note, we have identified cost and transit time as main variables for our research, as mentioned in other research paper. Moreover, a limited, but present number of studies explore uncertainties in the network either on a tactical, operational or strategic level and no found source explores all three. From a discussion with the Operations department, the biggest uncertainty is related to delays in transit time, therefore it was decided to explore this aspect further. Several sources also make use of sensitivity analysis as a post-tool to see how much the chosen variables change when increasing or decreasing the inputs. We have decided to include sensitivity as well, seeing it as a valuable addition to our work. Therefore, it was jointly decided to explore the topics of uncertainty, sensitivity and variable computation in one impact tool.

The impact tool incorporates three aspects: measurement of the proposed alternatives and current situation, a demand forecasting to identify potential savings and a sensitivity and uncertainty analysis of the solution alternatives. Overall, two versions of the tool were

developed, with an additional design proposal of a third one. In the first version, the focus was mainly on measuring the chosen key performance indicators, in order to obtain the cost analysis of the alternatives. The design was chosen in discussion with the company and during the course of multiple meetings, the cost per pallet was measured with the tool by calculating all cost elements together. It was crucial to be able to validate the correctness of the calculations, thus cross-validation and comparison with pre-existing cost analysis tools from Emons was made. In the second version the focus was about deciding what kind of uncertainty and sensitivity analysis to do. It was of value to the company to obtain information, regarding possible increases in fuel and a possible traffic jam delay, thus they were both programmed as scenarios in the tool.

Results suggest that the alternative routings with the container unit have a similar gross cost per pallet of around €100 when the current equipment and route. The travel time for the container is 6-8 days, which is double that of the 2WIN double deck trailer, however with less distance travelled by road, the container solution reduces the driving hours and thus saves cost, as seen in the figures below. From the sensitivity analysis there is an increase of 1 percent for each 5 percent change in fuel price.

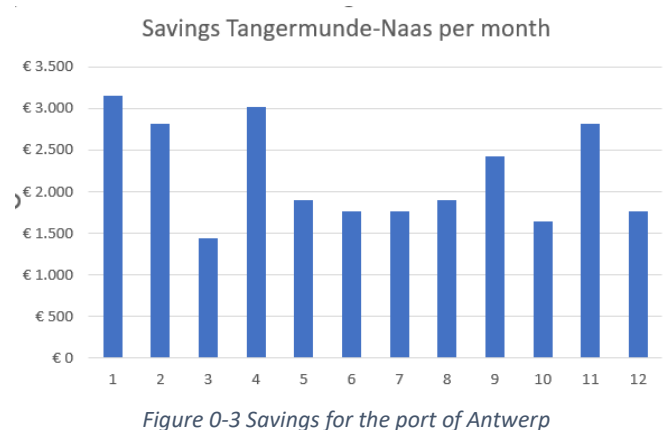
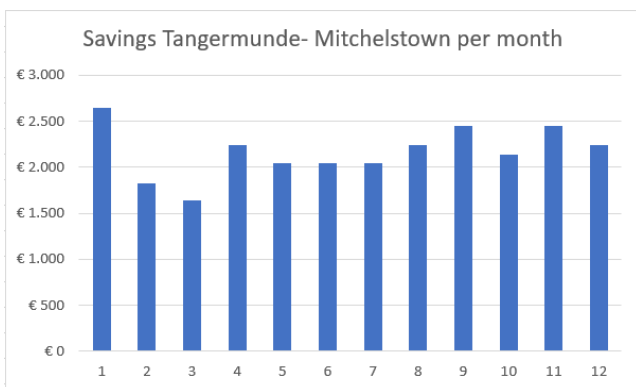
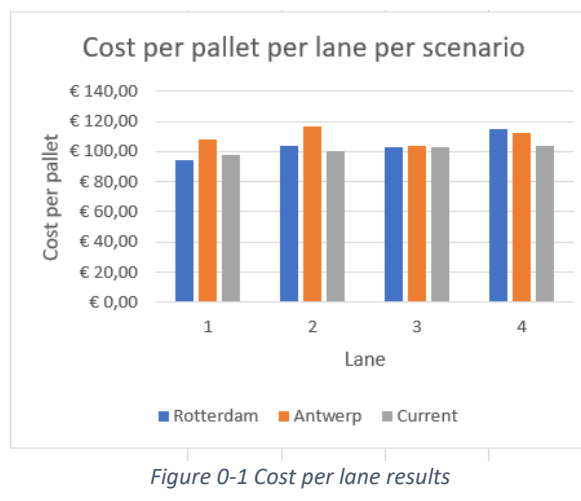


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1. Introduction

In this chapter, an introduction to the company and case is given. **Section 1.1** starts with the background of Emons and what services they offer. Additionally, an overview of the issues that they are currently facing is presented, all divided into three categories. This gives rise to the core problem, the solution of which will be investigated further in this thesis. Once the core problem is known, the gap between the desired and current situation is emphasized by the action problem and the main goals of Emons are identified in **Section 1.2**. After the root cause has been established, what follows is a methodology, that is used for solving our problem. It consists of five steps and a brief overview of all of them is given in **Section 1.3**. **Section 1.4** is a collection of all research and knowledge questions, the answers to which help us solve our problem. Lastly, **Section 1.5** concludes this chapter by outlining the structure of the thesis.

1.1 Problem context

Emons Group is a logistics company consisting of three brands: Van Huët Glass Logistics, Emons Cargo 2WIN, Hofmans. It is a family-owned business from 1943 to this day. With more than 700 employees in 10 offices across Europe, they specialize in providing *innovative and sustainable transport* as well as supply chain data analysis (www.emons.eu). One of its branches has created a double-deck solution for transporting a large multitude of pallets to the end consumer. In their website the 2WIN truck is said to decrease emissions by up to 40 % and can transport 64% more pallets in one-go, compared to the regular truck.

The 2WIN equipment is used throughout continental Europe, however it is also used for reaching customers in Ireland, by passing through the UK. The focus of this study is on reaching Ireland (with Germany as a starting point), where in order to do so there are three modalities involved – travel by road, sea and rail (Jenny, Z., 2021). While the new trailer design is advantageous in terms of travel through continental Europe, a few issues arise when multimodality is considered. They are divided into several groups, an overview of which can be seen below.

Insufficient capacity

To start with, all ports have various requirements and restrictions about cargo size. Containers are widely accepted and can be placed at any level of the ferry, making it easier to stack multiple orders in one-go. However, with the 2WIN equipment being loaded it is only possible for it to be placed in the lower levels of the deck, thereby putting a restriction on how many orders can travel simultaneously, which can reduce reliability of the orders being shipped. Furthermore, a big share of the 2WIN trucks is being used for travel by sea, which poses a limit to the capacity that can be used elsewhere in continental Europe.

High costs and travel time

During the current route the driver is required to be in the vehicle for the whole duration of the journey. This implies being present during travel by both rail and ferry, which incurs additional costs. Travelling to the UK brings some costs as well, due to Brexit (about 100€ both ways) and the driver spends about 2 to 3 hours in preparation of documents to be able to

enter, further increasing the lead time. Due to the larger size of the truck, cost of the ferry trip can be also seen as high in comparison with the cost of a container by 50 percent. Last, but not least, with such a large portion of the route being by road, there is a significant amount of empty lineage observed, which brings upon unnecessary costs.

External pressure

Customers of the company value shorter lead times and lower price. With the current price and a lead time of 4 days, the customer in Ireland has put pressure on this matter by requesting shorter delivery times. With such variety in multimodality, indeed several alternative lanes could be considered for the optimization of such variables. Nowadays, there is a large array of competitors (Suardiaz Group, a3 Logistic, Vervaeke to name a few) that have developed multimodality with truck/rail/ferry as the main transport. They are using a multitude of containers, making it easier to travel by sea. Competitiveness and pressure from the customer side indicate the need for such multimodal study, as there could be substantial losses in revenue (less orders) and/or loss of potential customers if this issue is not investigated further.

All in all, while the 2WIN is well-suited for travel by road with its high payload and minimized costs, its design makes it difficult to combine with sea transport to reach other countries, such as Ireland. Further cost and delays, observed in one specific country poses yet another issue. With all mentioned, there are difficulties with meeting market demand. The core problem in this case is the *UK part of the journey, which makes coordination efforts rather difficult.*

With the core problem in mind, our solution would be to identify possible alternative routes that do not pass through the UK. In other words, a ferry connection which can be made between continental Europe and Ireland is worth considering, as it has the potential of increasing the quality of service, that the customer needs. Options include ports in either Germany, the Netherlands or Belgium. As this connection will take up a large portion of the overall travel, an additional cargo type can be defined to ease the transition from road to sea (as seen in Fig.1-2).

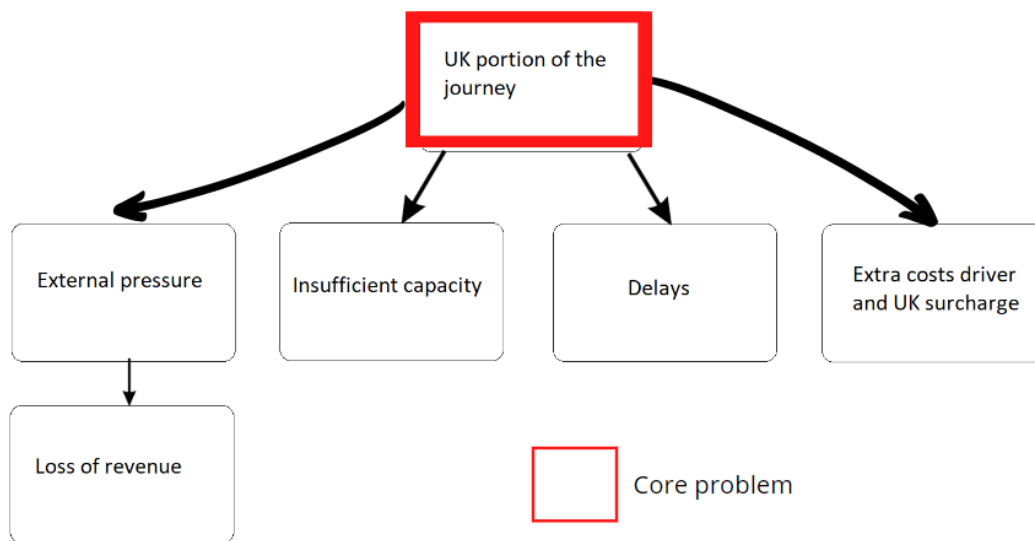


Figure 1-1 Problem cluster



Figure 1-2 Proposal for the introduction of a container transportation unit

1.2 Action problem

As mentioned in Section 1.1, the core problem defined is that of the UK portion of the journey for the case Germany- Ireland. The action problem (the focus of this section) corresponds to the discrepancy between the norm and reality observed. We can define our action problem as the following:

Emons wishes to meet a lead time of 4 days for goods travelling to Ireland from Germany, however there are delays and higher costs than expected during their current route when travelling through the UK.

Solving the action problem will have the benefits of providing a way to ensure the fit between the 2WIN truck and the ship containers at the port. Additionally, a new route being defined as a result can contribute to reducing the cost per pallet and total journey time.

For the aim of the study we have presented Emons with a list of objectives, normally found when discussing an alternative route. Out of these objectives, we have asked the company to rank them from most to least important. The results are the following:

1. **Reduce cost – measured by the cost per pallet (in euros)**
2. **Reduce travel time – measured by total travel time (in hours)**

3. Reduce driver demand – measured by number of drivers
4. Reduce emissions – measured by CO_2 emissions (in kiloton)

The outcomes of this research will be ultimately measured based on these factors and as can be seen each is properly measured with its specific unit. For the beginner stage of this project the first two factors in bold will be used for initial assessment. They are chosen, as they are both rapidly increasing and bringing about losses to the company. Afterwards, the last two factors will be used for a final comparison.

1.3 Problem solving approach

In order to tackle this problem, careful consideration about the end product is needed. This research consists of two steps: defining the modalities and identifying an optimal route in terms of cost from A to B by making a list of the suitable ports. In reality, these two steps can be thought of as two artefacts, intertwined with each other. They would be the main focus of this research. Therefore, we have defined the design science research methodology (Design Science Research general steps (Vaishnavi & Kuechler, 2004), consisting of five steps:

1. Awareness

The first stage would be assessing the current situation. From data files information is obtained about the frequency and volume of orders to Ireland, such that trends (for instance a peak in orders) can be detected. Information about the exact current route and associated costs/ number of trucks/ driving time/ port requirements will be used to compare with other alternatives. All sources of information are collected from the company via files or interviews with employees.

2. Suggestion (Artefacts)

Based on the information gathered an idea about the volume of goods/limitations of ports can be obtained, thus a proposal for a new type of configuration for the supply chain can be made. This will be made in accordance with the container restrictions that the ports impose. Along with that, a new network is proposed, such that overall travel time by road is minimized, as well as the total costs associated. This will be done as a second step in phase 2. Both will be determined via means of a literature search.

3. Development

From the proposed lanes, a model will be developed in order to compare them, along with a further comparison based on whether the 2WIN equipment or a container is used. For the network alone multiple alternative lanes will be generated and assessed, in order to obtain the most suitable one.

4. Evaluation

Once all Key Performance indicators (KPIs) have been selected and once step 3 has been implemented, results can be obtained and all proposed ideas can be compared with the current situation via comparing the KPIs. Examples of relevant KPIs include total cost per unit, percentage of journey by road and total travel time. A table will be used to represent the results.

5. Conclusion

From step 4 conclusions can be made about the suitability of the proposed ideas. From these conclusions, and keeping in mind the aim of this research, a list of recommendations for further improvement can be made.

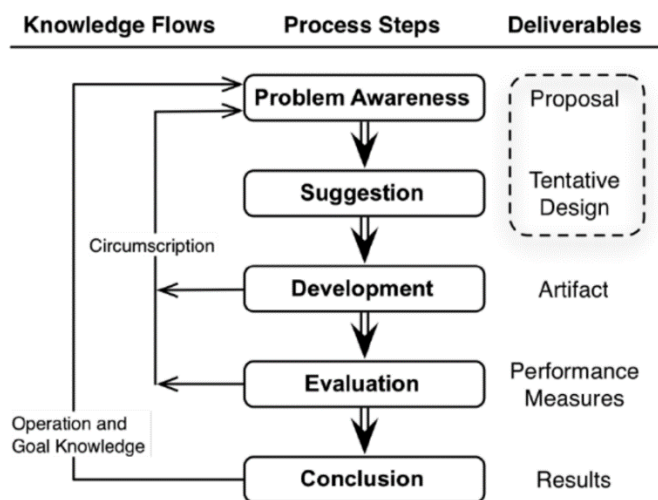


Figure 1-3 Design Science research methodology (Vaishnavi & Kuechler, 2004)

1.4 Knowledge problems/research questions

In order to solve the action problem, the need for a modal shift arises, consisting on defining modalities and alternative lanes. This is all part of the main research questions to be answered. Afterwards, a model needs to be defined for the impact assessment. This can then be considered a knowledge problem, since we are seeking a methodology to create a model.

The main research question to be answered is:

What is the impact from introducing alternative routings with a container transportation unit?

In order to answer the main research question, at each step of the DSRM, several sub questions have been defined.

Research questions

1. What is the current situation? (**Phase 1**)

For this part a good understanding of the current equipment is needed. Information, such as size of the truck, cost of manufacturing and total cost per kilometer can be easily obtained from the company, as well as the number of orders during the course of one year or more years, in order to track the volume of goods and detect any patterns. Once this step is done, the following step would be to obtain the exact route from both locations in Germany to both locations in Ireland to be used as a benchmark tool.

Sub-questions:

- What is the current demand pattern?
- What are the current expenses and travel time?
- What are the equipment characteristics?
- What is the route followed?
- Which departments are involved?
- How is planning made?

2. What alternative routings exist? **(Phase 2)**

In order to answer this question, one major limitation to our choice would be the requirements of the ports in terms of cargo size. Then a logical choice would be investigating all eligible ports, that have destinations in Ireland. From this list, the container requirements for each port can be determined from their website and the final list can be broken down to two or three alternatives.

Sub-questions:

- Which ports are located in Germany/Belgium/Rotterdam?
- What are the container requirements for each port?

3. What are the key needs/requirements/constraints for an impact tool? **(Phase 3)**

Knowledge questions

4. Which variables do companies consider in the decision-making process of introducing a modal shift? **(Phase 3)**

Sub-question:

- What is the weight of each variable?

5. How to model a modal shift? **(Phase 3)**

Sub-question:

- How is uncertainty modelled?

6. How to evaluate different options when presented with multiple factors? **(Phase 4)**

7. What are the long-and short-term impacts of a modal shift? (Phase 5)

1.5 Structure of the thesis

In this chapter, we have introduced the company and problem context. The core problem of travelling through the UK has been identified and the purpose and research direction have been given, both mainly connected to the identification of alternative routes and the introduction of a new cargo type as a way to ease the transition from road to sea transport. The remainder of this thesis is as follows:

<i>Research/Knowledge question</i>	<i>Answered in</i>
What is the current situation?	Current situation (Chapter 3)
What alternative routings exist?	Solution design and validation (Chapter 5)
What are the key needs/requirements/constraints for an impact tool?	Solution design and validation (Chapter 5)
Which variables do companies consider in the decision-making process of introducing a modal shift?	Conceptual framework (Chapter 2)
How to model a modal shift?	Conceptual framework (Chapter 2)
How to evaluate different options when presented with multiple factors?	Conceptual framework (Chapter 2)
What are the long-and short-term impacts of a modal shift?	Discussion and recommendation (Chapter 6)

Table 1-1 Structure of the research questions

2. Conceptual framework

In this chapter, the literature review is concerned. **Section 2.1** serves as an introduction to multimodal transportation and includes a classification, based on three levels of decision-making. **Section 2.2** describes mathematical models used in transportation, whereas **Section 2.3** is an introduction to forecasting as a resource to estimate future savings. **Section 2.4** focuses on common uncertainties when travelling from A to B and **Section 2.5** discusses some evaluation methods. Lastly, **Section 2.6** concludes this chapter.

2.1 Multimodal transport and classification

The transportation chain is generally divided into three segments (SteadieSeifi, Dellaert, Nuijten, Van Woensel, & Raoufi, 2014). The pre-haul refers to the first part of the trip, where typically travel is done by truck from the loading location to the port. The long-haul portion includes travel by ferry between the departure and destination port by the use of containers and the end-haul refers to the last-mile delivery, also normally done by a truck.

In terms of planning, the authors identify strategic, tactical and operational planning problems (Archetti, Peirano, & Speranza, 2022) (Elbert, R., Müller, J., & Rentschler, J., 2020). The first term is related to the decision of where to locate the hub in the network as a connection point for all incoming goods from all origin locations. In the context of a multimodal network with a sea connection, the hub in this case is the port. Once an infrastructure is decided upon, the next step is to identify the services used and their capacity, as well as all the modalities involved, so that proper scheduling may begin. This is the essence of tactical planning. Operational planning is on a day-to-day level, where it deals with all uncertainties and disturbances, that are otherwise not detected in tactical and strategic planning, including sudden maintenance, weather changes and much more. Other factors, such as traffic jams, hub failures and demand uncertainty apply to all three levels of planning and are discussed in more detail in Section 2.4.

2.2 Modelling

Based on the literature review conducted, the use of logit models is common for decision-making. For instance, with a lack of transport information, a route enumeration module can be followed, in which choice sets can be generated (de Bok, de Jong, & Tavasszy, 2017). The authors have defined a generalized cost function and several combinations of modalities to choose from, out of which those with the lowest cost are selected. By also analyzing the flow of goods they are able to use a multinomial logit model. Other models being used stochastic/dynamic models (Ormevik, Fagerholt, & Erikstad, 2020), (Hao & Yue, 2016).

2.3 Linear regression

In a supply chain, one of the crucial aspects for supporting planning and design decisions is the creation of a forecast for demand (Chopra & Meindel, 2019). A future value of demand is of help for resource management and capacity planning in both long-and short term

operations. One type of forecast commonly used is the time series forecast, which is based on historical data for several years. This is the focus of this section. When looking through years of data, often we observe seasonal trends and patterns, where we need to take this variability into account, in order to create a basis for estimating demand. The solution in this case is to deseasonalize (level) the data, as is discussed in the book of Chopra and Meindel (2019). The formula seen below is taken from the book.

$$\text{Systematic component} = (\text{level} + \text{trend}) \times \text{seasonal factor}$$

Demand has a systematic component and a random component. The systematic components consists of the level, trend and seasonal factor. The level refers to the demand, in which there is a lack of any seasonal variability, the trend for the next period is either upward (increasing) or downward (decreasing). The seasonal factor is the one that takes the exact seasonal changes into account in the end. All three combined create a measure for determining the demand for the next period. Now we dig deeper into how to compute the systematic component.

For a given year there is possibility of estimating the demand on a quarterly or a monthly basis and this determined the number of seasonal factors present. The first step is to deseasonalize the data.

$$\bar{D}_t = \begin{cases} \left[D_{t-(p/2)} + D_{t+(p/2)} + \sum_{i=t+1-(p/2)}^{t-1+(p/2)} 2D_i \right] / (2p) & \text{for } p \text{ even} \\ \sum_{i=t-[(p-1)/2]}^{t+[(p-1)/2]} D_i / p & \text{for } p \text{ odd} \end{cases}$$

Figure 2.1. Deseasonalizing the demand (equation by Chopra & Meindel, 2019)

Here, if the periods are 12 for example and we are looking for the deseasonalised value of $t=7$, then we take two averages: from $t=1$ to $t=12$ and from $t=2$ to $t=13$ and afterwards we take a new average of both. Now the next step is to define the level and trend.

$$\bar{D}_t = L + Tt$$

Figure 2-2 Components (equation by Chopra & Meindel, 2019)

Linear regression seeks the relationship between two variables. D_t is the dependent variable and time is set to be the independent variable, as we are looking into how demand changes with time. Such calculations can be made in Excel by using Regression as part of the Data analysis toolpack option. From the descriptive statistics the level and trend are given and can be subsequently used to determine the demand for future periods of $t=37$ and up.

2.4 Uncertainty analysis

With regards to uncertainty analysis there the most common fluctuations found in literature are connected to hub failures, demand and transit time variability (Delbart, Molenbuch,

Braekers, & Caris, 2021). The authors have gathered academic papers on uncertainty on three levels – tactical, strategic and operational. Strategic decisions refer to the hub location problems. For uncertainty mitigation generally the scenario generation is used and heuristic tools are frequently used as a solution method. With tactical decisions the author distinguishes between a service network design, which is connected to the offering of services on a given route and network flow planning, which is connected to the planning of orders within the network. The SND's aim is to minimize the total cost. Demand variability is typically associated with SND, while changes in transit time and capacity are related to NFP. In the case of increased transit time a penalty for a late delivery is used and the most common solution method is a metaheuristic (Tabu-search, ant colony, simulated annealing). Last, but not least, operational decisions are linked to (re)planning and resource management. In terms of rerouting several options exist, such as a genetic algorithm (Padamkar), which is an evolutionary algorithm. The essence lays in combining two well-performing options to create one with good traits from both “parents”. Another type of a solution method is linear programming as part of Operations research (Winston, 2004) , where most modal shift potentials are evaluated by means of a mixed integer or an integer programming method.

2.5 Multi-criteria decision making

With multiple (sometimes conflicting criteria) it is often difficult to make an informed final decision. For the successful evaluation of multiple factors there is a wide variety of multi-criteria decision-making tools, or MCDM. A detailed systematic literature review, answering this research question can be found in the Appendix. Here we present the findings. Dhulipala (2021) uses fuzzy logic to determine the exact routing, where multiple options are present. Sasidharam (2021) uses it in a similar way. In short, fuzzy logic can be applied universally, as long as there is a logical system. There is a set between 0 and 1, however it is not binary, as you can have numbers in between. Zhang (2022) has opted for a combination between the Analytic network process and another MCDM tool, whereas Inan (2022) has used the Analytical hierarchy process for determining a railway route. The fundamental difference between ANP and AHP is that ANP takes into account any possible relationship between two decision elements, whereas with AHP each element is accepted to be independent.

Source	Analytic network process	Fuzzy logic	AHP
Zhang,CL.(2022).			
Sasidharam, M (2021).			
Inan,A. (2022).			
Dhulipala, S. (2021).			

Table 2-1 Concept matrix

2.6 Conclusion

In this chapter, we have examined which variables companies consider in the decision-making process of introducing a modal shift, with cost, transit time and frequency being the most common. We have examined multiple MDCM, including fuzzy logic and AHP and we have seen ways, in which modal shifts are modelled, including the use of stochastic models, heuristics and genetic algorithms. Next to this, we have newfound knowledge about the field of multimodality and how to model the alternative scenarios, such that we can delve deeper into the next chapters.

3. Current situation

In this chapter, an overview of the current situation is presented. **Section 3.1** begins with a detailed description of the route, followed by the 2WIN by dividing it into five parts with the inclusion of three modalities. The transfer cities and procedures at the ports are briefly mentioned. **Section 3.2** introduces the 2WIN equipment and its capacity and size. **Section 3.3** deals with the identification and description of all cost elements, included in the current cost calculation of all four lanes, whereas **Section 3.4** focuses on the travel time computation by taking into account the work schedule and waiting times at the sea and rail connection. As this is a multimodal study, there are several factors that can affect the journey, such as traffic jams, German laws and schedules, as is to be seen in **Section 3.5**. With large amounts of data available, we focus on the observation of demand and investigating any seasonal changes or patterns to be discovered, along with creating a forecast of future demand – the focus of **Section 3.6**. Finally, conclusions regarding this chapter are made in **Section 3.7**.

3.1 Departments

For this case study there are three departments involved at Emons – the finance, sales and operations department. The order administration management (operations) department consists of order administration managers and dispatchers and the finance department is divided into invoicing and bookkeeping departments. An overview of the connection between all three departments is given below.

In the beginning stage the number of orders are being negotiated between the customer and the order administration managers. During this process, the OAM are in another consultation with the dispatchers in order to establish how many available trucks and drivers the company has that can be used for a given day/week/month. In the case that the actual capacity is lower than the one required by the customer, the OAM negotiate a lower amount of orders and vice versa. The operations department is responsible for the day-to-day processes, such as determining the schedule and monitoring the activity of drivers to ensure that goods are delivered on time. The sales department on the other hand does negotiations with the customer about the price of transportation and the invoicing and bookkeeping departments keep track of the payments, made by the customer.

3.2 Route

Currently, a container begins its journey from one of the two loading location in Germany – either the town of Luneburg or Tangermunde. In order to arrive in Ireland, there are three types of modalities involved – travel by road, sea and rail. Each part is discussed more in detail below, with all the information given by the company.

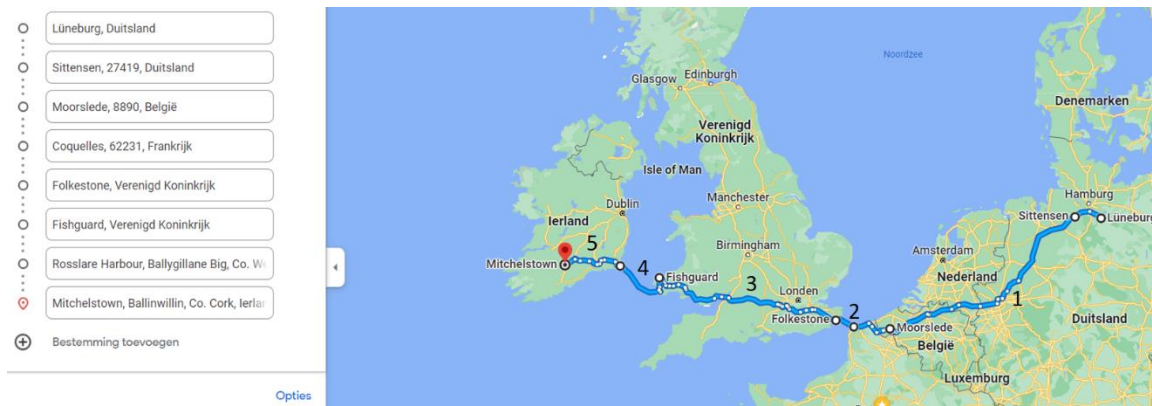


Figure 3-1. Visualization of lane Luneburg – Mitchelstown + overview of modalities

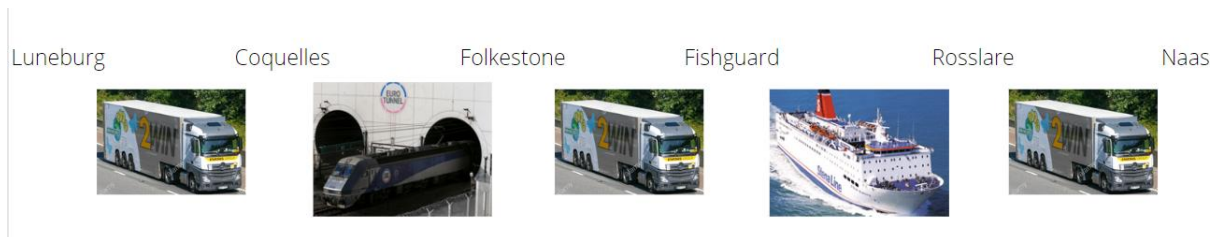


Figure 3-2 Overview of modalities used for the current route

1. Road (Continental Europe)

During the road portion of the journey, the order is firstly being loaded into the truck by the driver in a process, taking approximately 2 hours for a load of 52 pallets. On the next day, the truck leaves the loading location and continues its way to Coquelles, France, by passing through the Netherlands and Belgium and incurring additional costs, such as toll charges (which are discussed in the next section). The 2WIN follows a predefined optimal routing, that goes through the depots, located in NL and BE and if needed, a switch of drivers and/or truck can be made quickly. The speed of the truck is about 65 km/h and after a day, the truck arrives at the port in France, ready to enter its next phase.

2. Rail (France – UK)

In this part the truck arrives at the port in France and the driver prepares all necessary paperwork to enter the UK. Afterwards, the truck is driven on the platform on the lower levels and the driver remains there for the whole duration of the travel. The rail via Eurotunnel is every 30 minutes, thus there is no significant delay in loading the cargo. After an estimated travel time of about 45 minutes, the truck arrives at the port in Folkestone.

3. Road (UK)

Once in England, the truck driver continues his/her way by road until it reaches the port in Fishguard, Wales.

4. Sea (UK- IE)

During this part of the journey, the order is being transported via ferry by the company of Stena Line. Similar to the rail portion mentioned above, the driver has to prepare the necessary documents in order to transit from a non-EU state to an EU state. After a travel time of around 2 hours, the 2WIN and driver arrive in Ireland.

5. Road (IE)

Upon arrival, the order is again being transported by road to one of the unloading locations in Ireland – Naas or Mitchelstown.

3.3 Equipment



Figure 3-3.2WIN equipment

For the journey Germany – Ireland, the 2WIN equipment is used (represented by the figure above). They are a double-deck configuration, designed for carrying up to 52 pallets with a maximum height of 1.6 metres. In the figure on the right, the moving platform can be seen, which is used for loading pallets on the first and second level

For the whole duration of the travel the equipment travels in one piece. An overview of the dimensions can be seen below.

	Truck + trailer	Trailer
Height (in cm)	1700	1360
Width (in cm)	250	250
Length (in cm)	400	400

Table 3-1. Dimensions of the 2WIN equipment

3.4 Cost elements

The associated costs for the whole duration of the journey can be taken as fuel cost, driver salary, costs for maintenance, cost for Eurotunnel/ship and toll charges. A summarised version of all the expenses encountered can be seen below in Tables 3-2, 3-3 and 3-4.

3.4.1 Road

<i>Element</i>	<i>Background information</i>
Lease of truck and trailer	<p>The lease of both parts is for a period of 6 years and an interest of 2 percent. From this the value for one year can be obtained. Afterwards, there are two options:</p> <ul style="list-style-type: none"> ▪ Obtain cost of lease per km – dividing by the total kilometers that a truck can travel in a year ▪ Obtain cost of lease per day – dividing by the total number of working days in a year <p>For this research, it is more preferred to use the cost of lease per km, as they are dependent on the road distances.</p>
Maintenance of truck and trailer	The maintenance of both parts is a single value, obtained per km.
Driver wage	The driver wage is on an hourly basis and includes the working hours, as well as the small breaks that the driver undertakes. With the driver being present during all points of the journey, he/she is also being paid during travel via Eurotunnel and ferry.
Fuel	The fuel price taken for this research is its pre-pandemic value, however it can be changed as this research progresses.
Toll charges	As the truck is going through Germany, the Netherlands and Belgium, toll charges are in place based on the category and emission state of the vehicle.

Table 3-2. Overview of cost elements, applying to the road portion of the journey

3.4.2 Rail

<i>Element</i>	<i>Background information</i>
UK surcharge	Due to Brexit, the UK is no longer part of the European union. As a result, for transporting goods from an EU state to a non-EU state, additional paperwork and a surcharge for a two-way journey are introduced. The value of the surcharge as of May 2022 is taken into account.
Eurotunnel price	Includes the full price for a one-way travel for one truck
Driver wage	Applied as the driver is present during travel via Eurotunnel

Table 3-3. Overview of cost elements, applying to the rail portion of the journey

3.4.3 Sea

<i>Element</i>	<i>Background information</i>
Ferry price	For the 2WIN equipment, the price for a one-way trip is €325, whereas for the container configuration in both ports chosen the price is €750 for a single trip and €450 for the return trip, where there is an empty container.
Additional surcharges	In this category, the fuel surcharge is a mandatory one to be added. It is calculated every year to be of specific value and can be found in the Surcharge category in the port's website. For this research the fuel surcharge for the month of May 2022 is taken into account. Furthermore, there are surcharges (for loading and unloading), dependent on the whether the driver requires additional help to load the truck onto the ferry. In the current situation the driver is solely responsible for driving the truck onto the lower levels of the deck, therefore no such surcharge is taken into account.
Driver wage	Applied as the driver is present during travel via ferry (for 2WIN)

Table 3-4. Overview of cost elements, applying to the sea portion of the journey

3.5 Travel time

The total driving time from Germany to Netherlands can be split into three parts:

Travel by road

This part covers the journey from the loading locations up until the port in Coquelles, as well as the route from Folkestone to Fishguard. In order to estimate the driving time, an average truck speed of 65 km/h is taken into account. Additionally, the driver's work schedule has to be taken into account. It can be represented as follows:

<i>Duration</i>	<i>Type</i>
4.5 h	Driving time
0.75 h	Rest
4.5 h	Driving time
10 h	Rest

Table 3-5. Driver working schedule

For the first 4.5 hours of driving the driver is entitled to a short break of 45 minutes, after which another set of 4.5 hours begin. At the end nearly 10 hours will have passed, thus the driver can now rest for 10 hours. Afterwards, the cycle begins again. Only the short breaks are paid.

Travel by rail

For this part the cost for using Eurotunnel is taken into account. From Eurotunnel's website (<https://www.eurotunnel.com/uk/>) it can be observed that the average duration is 35 minutes, however there is additional paperwork and documents that need to be arranged before loading the truck, due to the UK not being part of the EU. From previous experience, Emons has estimated a total of 3 hours in total needed: from the moment the truck arrives to Coquelles until the moment it arrives at Folkestone. Currently, some nationalities are not allowed to enter the UK, due to additional requirements, imposed by the government. Thus, only around 80-90 percent of all drivers can follow this route.

Travel by ferry

This includes the final journey from Fishguard, England to Rosslare, Ireland. Similar to the previous point, from the carrier website (<https://www.stenalinefreight.com/>) it is said that the travel time is 3 hours and 15 minutes, however with additional documents the total travel time becomes 4 hours.

3.6 Conclusions

In this chapter, we have answered the research question: "What is the current situation?", as part of Step 1: Awareness in the DSRM. We have visualized the route from Germany to Ireland and have described all parts of the journey. The size and capacity of the 2WIN trailer and truck are now known and serve as a guiding tool towards the identification of capacity, as well as alternative ports to be determined in the following chapters. Subsequently, we have a basis for calculating the cost and travel time, as all elements are already identified.

4. Data analysis and forecasting

In this chapter, the demand per lane is analysed for the years of 2019 up until 2021. This is discussed in **Section 4.1**. Subsequently, forecast is made by the use of a statistical method, called linear regression (discussed also in Chapter 2), which will be the focus of Section 4.2. Finally, **Section 4.3** provides an overview of this chapter.

4.1 Shipments data

For the four lanes present on the route Germany to Ireland, an overview of the orders per month are given for the years 2019, 2020 and 2021. Given this information, trends and seasonal patterns can be seen below.

For all three years, there has been a consistent increase in the number of orders in the month of March and November. The largest decrease is set around January. An average of 50 orders are observed every month (related to each order having a capacity of 52 pallets). Demand is relatively constant with seasonal patterns and there is no trend of increased demand for years 2 and 3 to be observed.

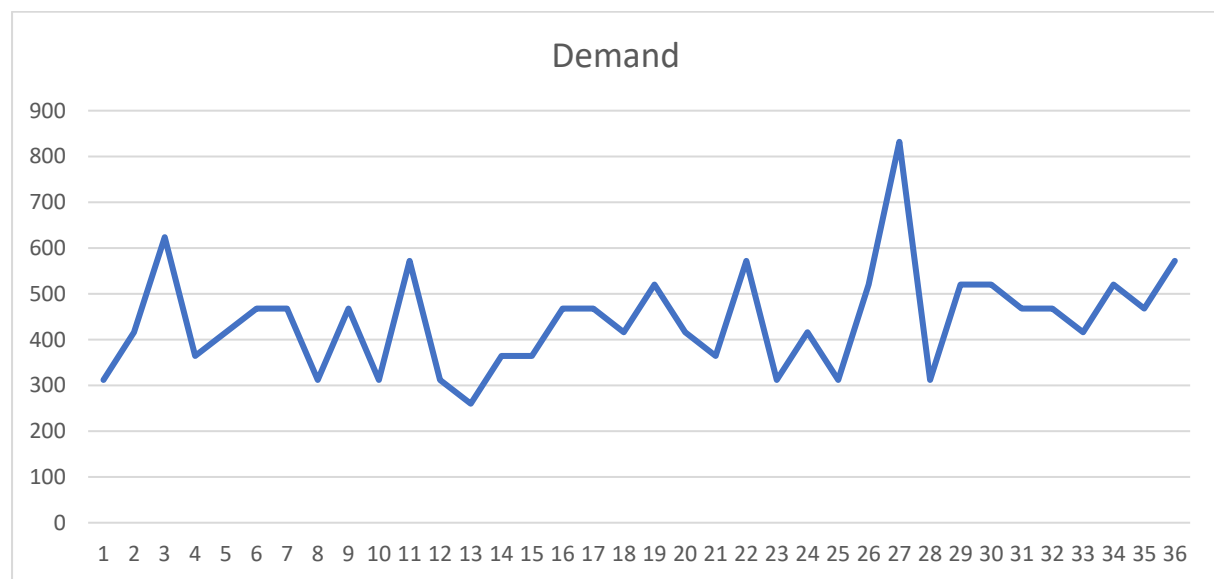


Figure 4-1. Number of orders for 2019-2021 for the lane Tangermunde – Mitchelstown

4.2 Forecasting future demand

The next step in analyzing the demand includes a forecast to be made for the year 2022 and for the near future. Based on data for three years and four lanes, future demand can be predicted by means of linear regression. In short, linear regression analyses the linear relationship between two variables, after which it predicts the future demand. For our case, we are investigating the connection between the period and the demand and whether it can

be defined as positive or negative. However, we have the patterns and seasonal changes to take into account. For this reason the first step is deseasonalizing the data, that is obtained by averaging the data.

For instance, we are evaluating the data based on periods of 12 months. By looking into Fig.1.4, in order to deseasonalize the demand for July 2019, an average is made of demand for the previous 6 months and the next 5 months. Afterwards, the same is done, but by starting one month later, i.e. the previous 5 months. Both values are then averaged, thereby giving the deseasonalized value, shown in the final column.

=AVERAGE(K2:K13)						
I	J	K	L	M	N	O
Year	Month	Demand	Period	Moving average 1	Moving average 2	Deseasonalized demand
1	January	312	1			
1	February	416	2			
1	March	624	3			
1	April	364	4			
1	May	416	5			
1	June	468	6			
1	July	468	7	420,3333333	416	418,1666667
1	August	312	8	416	411,6666667	413,8333333

Figure 4-2. Deseasonalizing the demand

A linear regression is done by using the Analysis Toolpack option that Excel provides. The dependent (Y) variable is set to be the deseasonalized demand and the independent (X) variable is month i. In order to account for the seasonal changes in demand, the seasonal factor is defined and included in the estimation of future demand. The results obtained apply to the year 2022 (as observed in Fig. 1.5) and can be further validated by comparison with the exact values observed from January to June 2022.

Year	Month	Demand	Period	Moving average 1	Moving average 2	Deseasonalized demand	Regression	Seasonal factor	Forecast
4	January		37						710,8003
4	February		38						495,3392
4	March		39						395,8831
4	April		40						596,9734
4	May		41						478,1386
4	June		42						489,3695
4	July		43						479,5575
4	August		44						600,3228
4	September		45						586,8666
4	October		46						549,053
4	November		47						592,3594
4	December		48						607,5201

Figure 4-3. Forecast of demand for 2022 made using linear regression

4.3 Conclusion

In this chapter we have understood the seasonal demand and patterns, scattered across three years of historical data. Furthermore, we have been able to create a toolkit in Excel, where we have found a relationship between the demand with each upcoming period. By using this relationship, have determined the future demand for the year of 2022 and subsequent years.

5. Solution design

In this part, the development of the Impact tool is discussed. This chapter begins with a brief introduction of the needs, constraints and requirements of the tool as stated in **Section 5.1**. **Section 5.2** introduces a list of all simplifications made to model the current situation, divided into several categories. What follows is a detailed description of the way the tool operates, including a formulation of the cost function and the way travel time is calculated. This can be found in **Section 5.3**. In **Section 5.4** assessment of the validity of the tool is made by comparison with existing software that the company uses for calculation of the cost per lane and in **Section 5.5** an overview of all scenarios executed is provided.

5.1 Introduction and aim of the tool

As stated in Section 1.1, the aim of this research is to perform an impact analysis of a modal shift. In this case, the transition from road-rail-sea to road-sea modalities is implied. This is achieved by looking for direct links between continental Europe and Ireland. From the conceptual framework in Chapter 2 a list of categories, dealing with modelling network designs can be found. The most important objectives are to minimize the cost per lane, as well as the travel time. With the task of modelling, there is a multitude of criteria that the designed tool needs to satisfy, a goal that needs to be reached and several constraints that need to be taken into consideration. An overview of each category mentioned can be seen below.

Functional requirements

With the task of modelling the current situation, a very broad array of cost elements needs to be included and each of these elements may vary overtime. It is therefore crucial to be able to easily change the input in case its value undergoes any change. This can apply for the fuel price, but also regarding ferry prices, costs of maintenance, etc. The model needs to be easily accessible and clear, all users must be well-aware as to how this tool operates. Having in mind the fact that there are several lanes present in one scenario, multiple scenarios require the comparison of a large multitude of lanes to be calculated, thus the ability to simultaneously compute multiple alternatives is desired.

Technical requirements

During the process of identifying the variables to be included in this tool, it was also seen that there exist a number of restrictions and simplifications that need to be made. This includes the existing schedule of the drivers, as well as the ferry schedule and possible traffic. All these components need to be accurately incorporated within the tool, so that the current situation can be properly replicated.

Constraints

Existing constraints of this tool can be capacity-wise, such as the maximum number of pallets that both container and 2WIN trucks have or the maximum cargo that can be loaded in one ferry. Other restrictions, such as the driver schedule and the maximum speed can be seen as relatively constant, but the price of existing cargo services and the traffic delays encountered can be increasingly varying. Nevertheless, they need to be taken into account.

Needs

Ultimately, what is needed is the creation of a tool, where the user can easily input the data of all cost elements, schedule and restrictions and the scenarios desired for a comparison with the current situation. The tool in turn provides a detailed overview of the cost-based and travel-based impact and uses the outcomes for comparison with the current 2WIN configuration. Afterwards, a summary of all KPIs is presented and the outcome with regards to the driver demand is investigated for all scenarios mentioned.

As a result from the conceptual framework, there are a number of directions, in which one can model a network, consisting of multiple modalities. The major objective is the minimization of the cost per pallet, which implies the creation of a cost function for calculation. With rich literature in the field of multimodality, there exist a multitude of sources, where modelling of a service network is done by integer programming. This was also discussed in the literature review of Chapter 2. Furthermore, there is the distinction between asset and non-asset management included in the model. For this research the focus is on creating an integer programming model without the use of asset management, as primarily the creation of a route structure is investigated.

With all kept in mind, the next step is the choice of a programming language. In the end, VBA was chosen and the reason is twofold: firstly, the company is very reliant on Excel in their day-to-day operations and secondly, Excel macros are easy to use and can be understood by every user.

5.2 Mathematical model

For both the container and the 2WIN there are different cost structures in place. Below an overview of the similarities and differences in both cost structures can be seen.

Same cost elements	Different cost elements
$u = \text{fuel cost (fuel consumption)}$	$m, m_T = \text{maintenance cost}$
$b = \text{belgian toll fee}$	$l, l_T = \text{lease cost}$
$g = \text{german toll fee}$	$nd = \text{number of days of journey}$
$n = \text{dutch toll fee}$	$p = \text{number of pallets}$
$s = \text{speed of the truck}$	$f, f_T = \text{cost of the ferry}$
$dw = \text{driver wage}$	$d = \text{number of drivers needed}$

Table 5-1 Overview of cost elements

Moreover, there are cost elements specific to either the 2WIN or the container configuration. This can be seen in Table 5-2.

<u>Container-specific cost elements</u>	<u>2WIN-specific cost elements</u>
cc = Cost for renting a container per day	e = Cost of Eurotunnel
fe = Cost of transporting an empty container	UK surcharge

Table 5-2. Specific cost elements for the 2WIN and container

Calculation of the cost elements

The first stage in defining all cost elements is to compute the distances between the city pairs throughout the lanes. For Rotterdam and Antwerp there is the continental part and the Irish part and for the 2WIN the division is in 3 parts – the continental, UK and IE parts. An overview of all parts is given below.

lr = distance from Luneburg to Rotterdam

tr = distance from Tangermunde to Rotterdam

la = distance from Luneburg to Antwerp

ta = distance from Tangermunde to Antwerp

dm = distance from Dublin to Mitchelstown

dn = distance from Dublin to Naas

lc = distance from Luneburg to Coquelles

tc = distance from Tangermunde to Coquelles

rn = distance from Rosslare to Naas

rm = distance from Rosslare to Mitchelstown

UK = UK distance in km

The next step is to connect the distances to the right lanes. The first point to consider is the definition of the distance from loading to unloading location. Here port k represents either Rotterdam (2), Antwerp (1) or the current ports (3). For all 12 lanes the outcomes are the following:

x_{ijk} = distance from loading location i to unloading location j with port k

$$x_{111} = lr + dn$$

$$x_{121} = lr + dm$$

$$x_{221} = tr + dm$$

$$x_{211} = tr + dn$$

$$x_{112} = la + dn$$

$$x_{122} = la + dm$$

$$x_{222} = ta + dn$$

$$x_{212} = ta + dn$$

$$x_{113} = lc + rn$$

$$x_{123} = lc + rm$$

$$x_{223} = tc + rm$$

$$x_{213} = tc + rn$$

In the next stage of the tool, all cost elements are calculated, starting with the equipment cost, which is the combination of the fuel, maintenance and lease costs. The maintenance costs consist of two parts. The first part is the maintenance of the truck, which is the same for both configurations, however for a container there is also the maintenance of the chassis – an equipment placed to connect it to the truck. For the 2WIN the second maintenance cost is that of the trailer. As there are two loading locations, two ports and two unloading locations for the container solution, there is a total of 8 different possible combinations and values for the equipment cost, as seen formulated below. In comparison, with the 2WIN there are only 4 different lanes/combinations.

c_{ijk} = equipment cost from loading location i to unloading location j with port k

$$c_{ijk} = (m + l + u) * x_{ijk}$$

$$c_{ij3} = (m_T + l_T + u) * x_{ij3} \text{ (for 2WIN)}$$

The next step is to determine the driver expenses encountered during the whole one-way trip. As mentioned in Chapter 2 , the driver experiences long (10h) and short (0.75h) breaks. Short breaks are after the first 4.5 hours of driving and the long breaks occur after 9 full hours of driving. The short breaks are paid, whereas the long ones are unpaid. For the actual transit time the inclusion of both short and long breaks are needed, however for this part specifically only the small paid breaks will be included. As can be seen below, the driver expenses for the same 8 lanes is defined and the cost is calculated as follows. The total distance from the loading to the unloading location (road portion) is divided by the speed to obtain the driving time in hours. Afterwards, for every 9 hours, an additional time of 0.75 hours is added to the initial value of the driving time, so that the full working hours are obtained. Afterwards, the new value is multiplied by the driver salary. This approach applies to both container and 2WIN.

d_{ijk} = driver expenses from loading location i to unloading location j through port k

d_{ij} = driver expenses from loading location i to unloading location j

$sr = \text{short break of the driver}$

$$d_{ijk} = \left(\frac{x_{ijk}}{s} + \left(\frac{x_{ijk}}{9s} \right) * sr \right) * dw \text{ (for container)}$$

$$d_{ij} = \left(\frac{x_{ij}}{s} + \left(\frac{x_{ij}}{9s} \right) * sr \right) * dw \text{ (for 2WIN)}$$

Toll charges apply for travel in Germany, Netherlands and Belgium. Due to lack of toll fees in the UK or Ireland, the focus in this part is now on continental Europe only. The user is not required to put all distances as input, the values are stored in the code itself. For Antwerp and Rotterdam the Belgian and German distances are the same, thus in the formulation below differentiating by port is not added. However, for the 2WIN the truck follows a different route, thus separation by configuration is needed.

$bx_{ij} = \text{belgian distance for loading location } i \text{ (} i = 1,2 \text{) for configuration } j \text{ (} j = 1,2 \text{)}$

$gx_i = \text{german distance for loading location } i \text{ (} i = 1,2 \text{) for configuration } j \text{ (} j = 1,2 \text{)}$

$G_{ij} = \text{total toll charge for Germany from loading location } i \text{ for configuration } j \text{ (} j = 1,2 \text{)}$

$B_{ij} = \text{total toll charge for Belgium from loading location } i \text{ for configuration } j \text{ (} j = 1,2 \text{)}$

$$G_{ij} = gx_{ij} * g$$

$$B_{ij} = bx_{ij} * b$$

The structure of the total toll charge varies, dependent on which countries the truck passes through. Belgian fees are excluded for reaching the port of Rotterdam and the fee in the Netherlands is per day, independent of the distance travelled.

$T_{ik} = \text{total toll charge from loading location } i \text{ to port } k \text{ (} i = 1,2 \text{), (} j = 1,2,3 \text{)}$

$$T_{11} = G_{11} + B_{11} + n$$

$$T_{12} = G_{11} + n$$

$$T_{21} = G_{21} + B_{21} + n$$

$$T_{22} = G_{21} + n$$

$$T_{13} = G_{13} + B_{13} + n$$

$$T_{23} = G_{23} + B_{23} + n$$

For the ferry price the base price is added as input, along with all surcharges applicable, such as fuel, loading and unloading surcharge. For the 2WIN the base price is the same in both

directions, however as it is our perception that the container is travelling back empty, the fee for the return trip is slightly reduced. Another point to consider is the Eurotunnel cost for the 2WIN, as well as the surcharge of 100 euros for entering the UK, that applies for a two-way trip.

With a given container price per day, the total length of the ferry journey is added as well by the user. Afterwards, the total rent cost of the container can be obtained. On the way back the container returns to the loading location empty and the rental cost has is doubled, when comparing with the one-way 2WIN trip (as will be discussed shortly).

nd = number of days of journey

C = total rent cost of container

$$C = cc * nd$$

Cost per lane and Cost per pallet

In order to accurately compare the existing 2WIN equipment to the container configuration, several adjustments need to be undertaken with regards to the cost per pallet. While the cost per pallet can be proven effective in comparing both configurations, there is a difference between a two-way trip with the container vs the 2WIN.

At the time when the 2WIN reaches the unloading location in Ireland and delivers all 52 pallets, another set of pallets from the same or other customers is being loaded in order to transport it to Europe. Therefore, in a two-way trip there is a total of 104 pallets being transported. This implies obtaining the cost per pallet by having the total two-way cost per lane and dividing it by the 104 pallets.

As a comparison, due to the container configuration being an option not currently used, with the maximum capacity of 33 pallets it is assumed that on the return trip there is no opportunity for any other goods to be loaded and the container travels back empty. Therefore the cost per lane for a two-way trip is divided by 33 pallets and not 66 pallets.

cp_{ijk} = cost per pallet from loading location i to unloading location j through port k

cl_{ijk} = cost per lane (loading location i , unloading location j through port k)

$$cl_{ijk} = d_{ijk} + T_{ik} + c_{ijk} + f + C$$

$$cp_{ijk} = cl_{ijk}/p$$

Transit time

Calculation of the transit time is similar to the way the driver expenses are calculated. The only difference that now short and long breaks are considered for every 9 hours that the driver is working. Therefore, the new variable travel time has been defined, along with the variable, taking into account both breaks of the driver.

h_{ijk} = travel time from loading location i to unloading location j through port k

r = driver rest for every 9 hours driving (short + long break)

$$h_{ijk} = \frac{x_{ijk}}{s} + \left(\frac{x_{ijk}}{9s} \right) * r$$

5.3 Impact tool

Impact tool – step by step



Figure 5-1 Contents of the Impact tool

Based on the requirements and needs of all stakeholders, an impact tool is proposed, that provides the following. The first step is to determine all options and modalities, that can be used with a container configuration. This includes all direct connections possible. All relevant information for the ports can be found online. After this has been achieved, several variables of critical importance must be selected. Based on the literature review and interviews with experts, we have defined cost per pallet, transit time and driver demand as our main ones. The next step is to input all parameters, mentioned in Section 5.2 and an overview of all cost and transit time elements is given. Because we are dealing with static data, sensitivity analysis is included as a next step in order to see how cost changes once one or more input parameters are adjusted. Based on interviews, conducted with managers from Emons, the parameter that has the highest fluctuation in price is the fuel and fuel surcharge cost, thus we increase their value by 5,10,15 and 20 percent in order to see how much the cost per pallet changes. From Chapter 2 it is also evident that there exist a number of uncertainties with regards to transit

times, hub failures and demand that makes day-to-day planning especially complex, thus we introduce an uncertainty analysis part in our impact tool, where at a certain point throughout the journey to the port we encounter a traffic jam. Two options are defined – either the truck stays on the route to wait out the delay, posing some extra costs, or the truck is rerouted to the nearest port. Both options are compared to each other, taking departure times of the port into account as well. The final step is to evaluate all options by applying an Analytical Hierarchy Process method as a Multiple criteria decision- making support tool, where the preference can be obtained in percentages for each option.

During the process of creating the tool, two versions have been developed. The first version's aim was to compute all predefined variables, while the second version expanded the tool by adding the sensitivity analysis and uncertainty analysis steps. Below a visual and practical introduction of the impact tool is provided, with both versions are explained in more detail. Additionally, we reflect on the use of the mathematical tool (Section 5.2) in Sections 5.3.1 and 5.3.2. With the latest version of the tool being version 2 and with the everchanging values of the fuel and ferry, it is advised to update the update the impact assessment on a quarterly basis, in order to improve accuracy.

The first step in the impact tool is to identify all alternatives. In Germany, Netherlands and Belgium the main ports are located in Rotterdam, Antwerp and Hamburg. It appears that Hamburg only has connections to the United Kingdom (<https://www.hafen-hamburg.de/en/homepage/>), therefore it is excluded from the list. Therefore, the two eligible ports with direct connections and no container restrictions are Rotterdam and Antwerp. A visualized comparison of routes with the port of Rotterdam as an alternative is provided in Fig. 5.2.

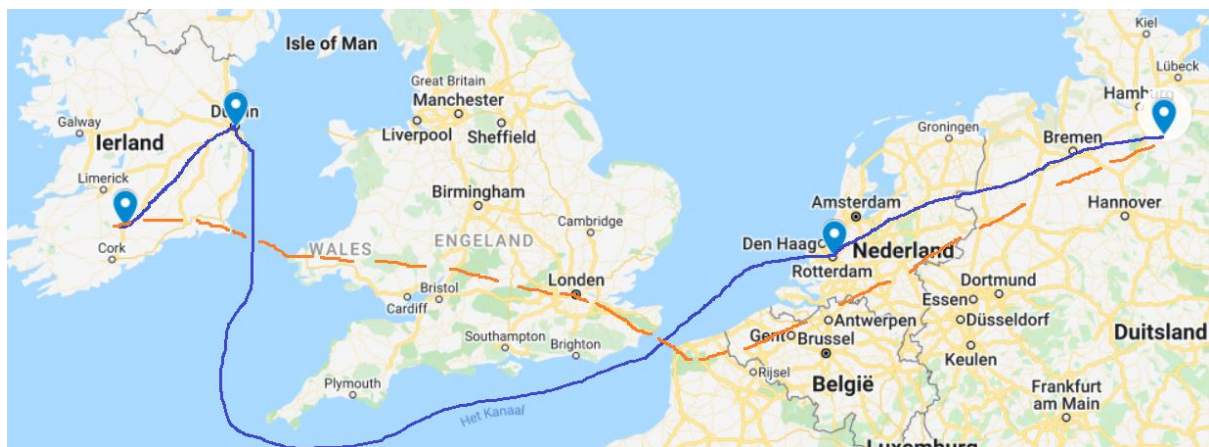


Figure 5-2 Current route (in orange) vs proposed alternative (in blue)

5.3.1 Version 1.0



The first version in Excel consists of several sheets, with the primary one being the Fill in sheet. Its main goal is for the user to select all lanes to be compared. The first step is to identify all

scenarios that are to be investigated. Next to “Choose first scenario” the first port of interest can be written down. Next to that, the Loading location, Destination port and Unloading location are needed for all four lanes. After Scenario 1 has been done, the user is free to add another scenario in the next table. It is important to note that this part concerns the road-sea-road configuration specifically. For this base, under Scenario 1 Rotterdam port was added and under Scenario 2 – port of Antwerp.

Step 1: Define all scenarios			
Choose first scenario:		Rotterdam	
Loading location	Departure port	Destination Port	Unloading location
Luneburg	Rotterdam	Dublin	Naas
Loading location	Departure port	Destination Port	Unloading location
Luneburg	Rotterdam	Dublin	Mitchelstown
Loading location	Departure port	Destination Port	Unloading location
Tangermunde	Rotterdam	Dublin	Naas
Loading location	Departure port	Destination Port	Unloading location
Tangermunde	Rotterdam	Dublin	Mitchelstown

Figure 5-1. Input scenarios in Impact tool



Once all scenarios have been added, the next step is to fill in all cost elements for both the current and the container transportation unit. The cost elements are the same as those treated in Chapter 3 and used in the mathematical model in Section 5.2. They are divided into three parts: equipment specific, which deals with lease, maintenance, fuel and more, but also including the driver wage, toll charges per country and all costs, associated with the ferry connection. In comparison, the current equipment and routing have an additional surcharge for passing through the UK, as well as one more connection done by rail. On the sides the 2WIN button initiates the macros that calculate the variables.

Step 2: Define the costs for container			Step 3: Define the costs for 2WIN equipment		
Part 1			Part 1		
Equipment specific	Fill in:		Equipment specific	Fill in:	
Driver wage		euros per hour	Driver wage		euros per hour
Fuel base		euros per liter	Fuel base		euros per liter
Lease of chassis		euros per hour	Lease of trailer		euros per hour
Maintenance of chassis		euros per km	Maintenance of trailer		euros per km
Lease of truck		euros per hour	Lease of truck		euros per hour
Maintenance of truck		euros per km	Maintenance of truck		euros per km
Fuel consumption		liters/100 km	Fuel consumption		liters/100 km
Speed		km/h	Speed		km/h
cost of container per day		euros			
total travel time		days			
Part 2			Part 2		
Toll charges			Toll charges		
Toll charge Germany		euros per km	Toll charge Germany		euros per km
Toll charge Belgium		euros per km	Toll charge Belgium		euros per km
Toll charge Netherlands		euros per day	Toll charge Netherlands		euros per day
Part 3			Part 3		
Ferry			Surcharge UK		in euros
Ferry 1 - base price		in euros			
Surcharge		in euros			
Length of journey		in days			
Return trip price		in euros			
			Part 4		
			Ferry		
			Ferry 1 - base price		in euros
			Surcharge		in euros
			Length of journey		in days
			Return trip price		in euros
			Eurotunnel cost		in euros
			Duration of Eutotunnel trip		in hours (from arrival to arrival)
			Duration of Ferry trip		in hours (from arrival to arrival)

Figure 5-2. Input parameters

A breakdown of all expenses, as well as the travel time can be seen in Figure 5.3. The equipment cost includes the fuel, maintenance and lease and is calculated based on the total distance from the loading location to the departure port together with the distance from the destination port to the unloading location. In other words, the long-haul part of the journey is not included. The working hours are computed, excluding the long-haul leg, primarily as the driver is not in the vehicle during the ferry trip. The paid working hours include the driving hours and small breaks. The next part is the toll charges, where the expense is dependent on how many kilometers the truck travels through each specific country. Only for the Netherlands a one-day ticket of 8 euros can be bought, thus the distance is not taken into account for the toll charge. The price of the ferry and the price of renting a container are also shown. All aforementioned cost elements combined give the total cost per lane. Both transportation units have a different number of pallets and need to be compared, thus the cost per pallet is introduced as a unified measure.

Next to this, the travel time is computed by taking into account the distance, speed of the vehicle and driver hours. By adding the ferry duration, we obtain the total transit time, as marked in green.


		Luneburg	Rotterdam	Dublin	Naas
Part 1 Cost					
Equipment cost		Road length	Cost per km	Total equipment cost	
<input data-bbox="197 277 300 315" type="text" value="?"/>					
Driver salary		Working hours (paid)	Wage per hour	Driver expenses	
Toll charges		German km	Toll charge per km	Total German toll	
		Belgian km	Toll charge per km	Total Belgian toll	
		NL	Toll charge (one-time fee)	Total Dutch toll	
Ferry		Base price	Surcharges	Total ferry price (2-way)	
Container					
		Total travel time(one-way)	Cost of container per day	Total cost container(1-way)	
			Cost per lane		
			Cost per pallet		
Part 2 Travel time					
Road portion		Distance	Speed	Travel time (in days)	
Ferry				Travel time (in days)	
Total				Transit time (in days)	

Figure 5-3. Overview of cost and travel time

5.3.2 Version 2.0

In this version, the uncertainty analysis relates to the scenario generation of a traffic jam. This is the latest version of the tool; a proposal for a third version is made, which will be discussed in the subsequent sections. Once the lane is defined, the user sets the point of the journey, in which the delay occurs. For example, a passing point of 225 kilometers implies that the truck is currently in Germany. The delay is expressed in hours and its value can be freely chosen. The time of departure is that of the truck from the loading location. On the right two options, either stay on route or proceed to another port can be chosen. For both options the cost per pallet, travel time and emissions is given from the moment the truck departs from the loading location.

For the distance between the loading location and the moment until the traffic jam, all variables are calculated in the same manner as in Section 5.3.1. Afterwards, as it diverges, for the stay on route option additional travel time is added, which also increases the equipment cost. In case of proceeding to another port, the additional time that it takes to reach the other port and cost are added.

Origin	Departure port	Destination port	Destination		Option 1	Stay on route
Luneburg	Rotterdam	Dublin	Naas		Cost per pallet	
					Travel time	
					Emissions	
Km passed	225					
Delay	0,5					
Time of departure	11,50				Option 2	Proceed to port i
Country					Cost per pallet	
					Travel time	
					Emissions	

Figure 5-3 Uncertainty analysis

In the process of having a discussion with the Operations department, it was mentioned that the fuel price is the main parameter of changing value and often increasing in a short period of time. As the rest of the parameters remain nearly the same and based on the idea of the literature review, the sensitivity analysis is made by adjusting the price of the fuel.

5.3.3 Version 3.0

Version 3.0 is the newest proposed design, where a heuristic, such as machine scheduling can be added in order to minimize the maximum lateness and it does provide near-optimal solutions. For instance, given that three trucks can be loaded at the same time and we send nine trucks, each with a setup time, deadline (which is the departure time of the port), duration of 15 hours (which is the travel time) and release date, the number of different trucks can be minimized and a schedule can be made. It is merely a suggestion that can be used still in the further development stage of the tool.

	r	duration	deadline	setup time
O11	-2	15	13	1
O12	29	15	44	1
O13	60	15	70	1
O21	-3	15	13	1
O22	28	15	44	1
O23	59	15	70	1
O31	-4	15	13	1
O32	27	15	44	1
O33	58	15	70	1

Figure 5-3 Machine scheduling

5.4 Assumptions and simplifications

Waiting time at the port

The waiting times at the ports are deterministic.

With the 2WIN configuration going through the UK and due to Brexit, delays occur due to the preparation of documentation at the port site. This is experienced two times in throughout the journey – once in Coquelles, France before entering Eurotunnel and once in Fishguard, UK, before going to Ireland. From historical data it can be seen that the actual length of the trip via Eurotunnel is 3 hours and via the StenaLine ferry it accounts to 4 hours. Both values include the waiting time and travel time and both are important for calculating the transit time and the driver expense (the driver is being paid during both parts). Therefore, they are both included in the tool.

However, with the container configuration no waiting time is assumed – the travel is between two EU member states and the container is being immediately stacked on the ferry – which is not possible with the 2WIN equipment.

Distances

All distances used in this research are measured via the use of Google maps. In order to increase accuracy, historical data of a single journey was used in order to identify the cities throughout the truck travels and include them in the final route. The correctness of the values are validated afterwards by comparison with existing software that is used by the company.

During the journey from both loading locations, it was also seen on the map that both routings coincide around the border between Germany and the Netherlands. Therefore, it is assumed that the travel distance in the Netherlands and in Belgium is the same regardless of which loading location the truck starts its journey from.

Additionally, by viewing the lanes leading to Rotterdam and Antwerp it was further established that both routings for the German portion of the road are of close value, thus they are taken to be equal.

5.6 Analytical hierarchy process

In this moment we have already defined all alternatives and all variables have been calculated. The next step is to find a way to evaluate all existing proposals and compare them with the current scenario. There are several factors present and a need for an evaluation method is present. Instead of ranking alternatives based on only one criteria of the highest importance, we have opted for a multi-criteria decision making method, as it involves the careful consideration of all factors and it will be more insightful for the company. The MCDM

chosen is the Analytical Hierarchy Process (AHP) that combines rankings from criteria and alternatives and determines the option with the highest value. During the literature review phase of this research it was found as one of the methods for evaluating several criteria (the main process can be found in the systematic literature review in the Appendix).

For all criteria, a comparison matrix is made, in which the user compares two options. Moreover, there is an additional table, where the user compares the different alternatives to each other. Based on this comparisons (which are on a scale from 1 to 9, from less to more preferred – also found in the Appendix), different scores are assigned to each alternative, the higher the score, the stronger the preference.

Cost	<i>Current</i>	<i>Alternative A</i>	<i>Alternative B</i>
<i>Current</i>	1	0,142857143	0,2
<i>Alternative 1</i>	7	1	0,333333333
<i>Alternative B</i>	5	3	1
<i>sum</i>	13	4,142857143	1,533333333

Figure 5-4 Comparison matrix of cost criteria

5.7 Conclusion

The results show that the container introduction has nearly the same costs as the current equipment, but the transit time is longer, due to the ferry trip. While the container may require more trucks to depart nearly simultaneously, the new routing also requires 50 percent less driving time and the driver is not in the vehicle during the ferry trip, which brings costs down. In the figure below, based on the number of orders, the expenses saved for both Rotterdam and Antwerp can be seen below.

6. Validation

In this chapter, the focus is on validating the impact tool in all its versions. **Section 6.1** begins with verifying the tool and checking the correctness of the outputs given the inputs. **Section 6.2** explores the validation of the first version of the tool, including its comparison with another cost analysis tool the company is using. **Section 6.3** begins a new iteration in the Design Science Research Methodology for the introduction of version 2.0. Finally, **Section 6.4** provides the closing remarks for this chapter.

6.1 Design verification

Design verification is related to ensuring that the chosen inputs match the outputs and whether there is a clear working link between them. In this context, in the beginning stages, multiple conversations were carried out, connected to the identification of all the cost elements and how they are used. Subsequently, after careful consideration a proposal for an initial design was made, which was agreed upon. The identification was a rather quick process, however the next challenge encountered was how each cost element is connected to each other and at what point of the journey. After making a list of all elements (that can be found in Chapter 3: Current situation), the total route was divided into five different parts (similar to the way the current routing was introduced in Fig.3.1 in Chapter 3) and for each stage the involved elements were discussed. The main points of attention were connected to the driver schedule, where part of the breaks were paid, and the toll charges and equipment cost. After each meeting, an outline would be identified, and by the process of trial and error a method was made for modelling the cost. Afterwards began the process of programming in Visual basic for application, which take a considerable amount of time, due to all the aforementioned. During each step of programming, the macros were run and intermediate results were assessed for accuracy. In the end, the final macro was run and manual addition in Excel was made, so as to compare the outputs obtained, by combining all the inputs. By following a step-by-step approach whilst having intermediate checks, the impact tool was verified by the Operations and Data department at Emons.

6.2 Version 1.0 evaluation

In order to validate our findings in the first version, we have compared our findings with the pre-calculation tool which the company uses to compute the costs per lane by manually adding the toll charges, distance and other direct costs such as the ferry trip. All other parameters are embedded within the tool. By adding scenarios to the pre-calculation tool our results show that the price for the current equipment is the same as that of the impact tool. In terms of possible transit time variability experts from Emons suggest to decrease the speed of the vehicle in order to take this into account, thus instead of 65 kilometers per hour we now have a speed of 60 per hour. Additionally, we have added 1 hour of loading time and 2 hours of waiting time at the port for the model for the current equipment, based on expert opinion in order to best reflect on this aspect. At a certain point during the validation process there was a difference of €100 between what was measured by the impact tool and by the

pre-calculation tool, which prompted the use of cross-validation in order to determine the cause. The first point to consider was to evaluate each element specifically in the impact tool and compare. In that way, the root problem was determined to be the calculation of the two-way trip and more specifically the toll charges being added once. After this issue was fixed, the results obtained by the impact tool coincided with these of the company program and thus our first version was valid.

6.3 Design iteration

After version 1 had been determined, our focus shifted on expansion and inclusion of more aspects for investigation. Therefore, our task was now connected to the identification of how to introduce a version 2.0 of the tool, which would give even more insight on the impact that a modal shift would have on the network. From the DSRM, another iteration was then made, starting with performing another literature review. From the literature review a certain amount of sources, regarding uncertainty and sensitivity analysis had been found and from the Operations department it was found that the major dynamic occurrence in a current trip is related to variability in transit time. Additionally, fuel prices are known to be of everchanging value. Therefore, the contents of version 2.0 were decided.

6.4 Conclusion

In this chapter, we have learned about the verification and validation methods, used for the both versions of the impact tool. With regards to design verification, consultation with two of the departments of Emons – Data and Operations were made frequently and intermediate checks were done, so as to ensure that what is being set as input in the system matches the results found. Afterwards, the next point to consider is validating both versions of the tool, thus comparison with existing software was made, in order to compare the outputs. Once a significant difference was found, cross-validation was employed.

7. Discussion and recommendations

7.1 Results and findings

From Chapter 4 we have identified the purpose and inner workings of the impact tool. Three scenarios were chosen: the current situation, Alternative A (Rotterdam) and Alternative B (Antwerp). The lanes are defined as follows:

Lane 1: Luneburg – Naas

Lane 2: Luneburg – Mitchelstown

Lane 3: Tangermunde – Naas

Lane 4: Tangermunde – Mitchelstown

Regarding the cost per pallet, we have defined two separate ways of comparison. The first one is related to comparing a one-way 2WIN and a two-way container, due to reasons, mentioned in the chapter Solution design. Taking this case, it is seen that the 2WIN solution has a cost per pallet of around €50, which is 50 percent cheaper than the other two alternatives with the container configuration (which are closer to €100). The results are visualized in Fig.7-1.

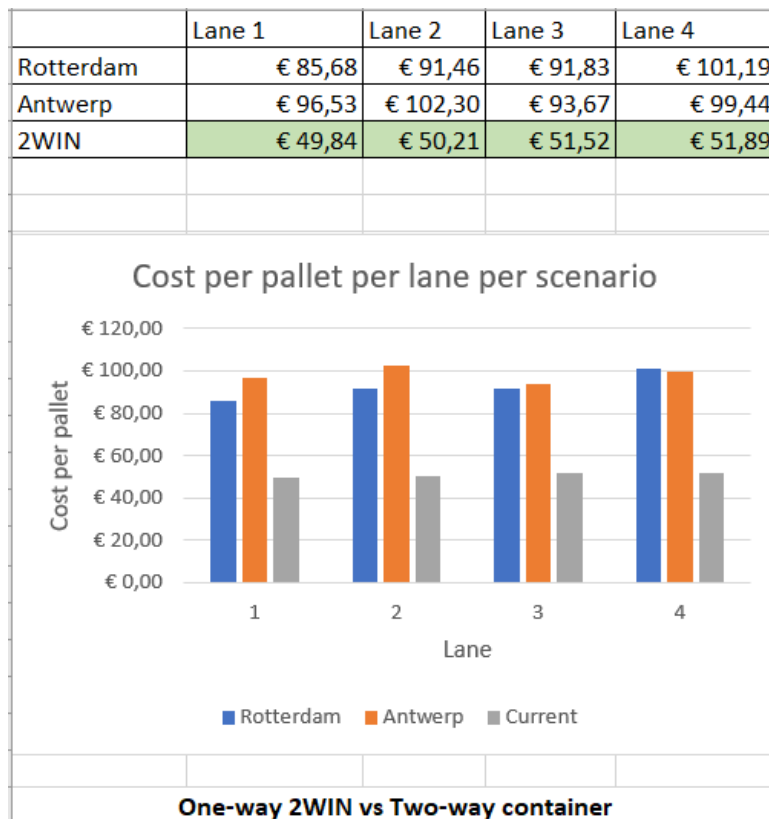


Figure 7-1 Cost per pallet results for a One-way 2WIN and a Two-way container

The other method to consider is by using both equipment for a two-way trip, where we can see overall results differ. Now Rotterdam port is the cheapest alternative for 2 lanes out of 4 and the same applies for the current routing with the 2WIN. The cost per pallet for all scenarios now range about €100.

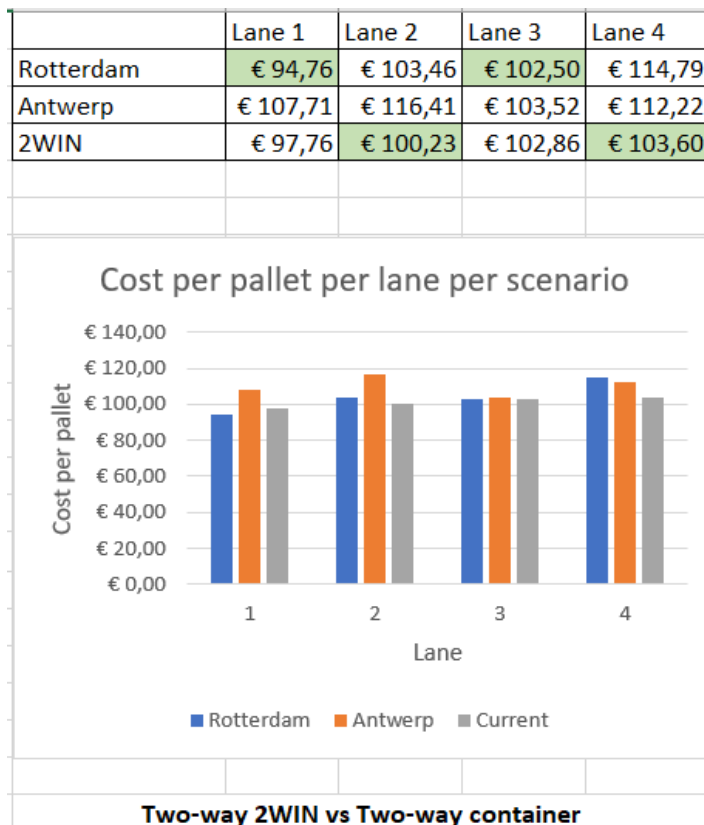


Figure 7-2 Cost per pallet results for a Two-way 2WIN and container

Regarding the uncertainty analysis, we have decided to generate several scenarios, where the fuel price and fuel surcharge is continually increased by 5 percent, in order to see the effect that it has on the cost per pallet. Our main conclusion can be seen in Fig. 7-3. We conclude that by increasing the fuel by 5 percent each time, there is a 1 percent change in the cost per pallet, which is regardless of the equipment or routing used.

	Lane 1	Lane 2	Lane 3	Lane 4	Fuel price increased by:
Rotterdam	€ 85,68	€ 91,46	€ 91,83	€ 101,19	0%
Antwerp	€ 96,53	€ 102,30	€ 93,67	€ 99,44	
2WIN	€ 49,84	€ 50,21	€ 51,52	€ 51,89	
	Lane 1	Lane 2	Lane 3	Lane 4	
Rotterdam	€ 86,74	€ 92,67	€ 92,97	€ 102,49	5%
Antwerp	€ 97,70	€ 103,62	€ 94,77	€ 100,70	
2WIN	€ 50,43	€ 50,81	€ 52,14	€ 52,51	
	Lane 1	Lane 2	Lane 3	Lane 4	
Rotterdam	€ 87,80	€ 93,88	€ 94,11	€ 103,79	10%
Antwerp	€ 98,87	€ 104,95	€ 95,87	€ 101,95	
2WIN	€ 51,02	€ 51,40	€ 52,75	€ 53,13	

Figure 7-3 Impact of a fuel increase on the cost per pallet

In terms of savings, because of the reduced distance needed to be travelled by road, driving hours can be spared, which can save on costs. Below, an overview for 2 lanes is given, and as input the number of orders via container is put (from the forecast, made in Chapter 4: Data analysis).

Outcome: Savings in euros		
	TM-Naas	TM-MT
January	€ 3.148	€ 3.017
February	€ 2.819	€ 2.099
March	€ 1.441	€ 1.838
April	€ 3.017	€ 2.558
May	€ 1.900	€ 2.297
June	€ 1.770	€ 2.297
July	€ 1.770	€ 2.297
August	€ 1.900	€ 2.558
September	€ 2.428	€ 2.757
October	€ 1.639	€ 2.428
November	€ 2.819	€ 2.757
December	€ 1.770	€ 2.558

Figure 7-5 Savings by choosing Rotterdam port

Outcome: Savings in euros		
	TM-Naas	TM-MT
January	€ 2.741	€ 2.645
February	€ 2.429	€ 1.828
March	€ 1.204	€ 1.634
April	€ 2.645	€ 2.236
May	€ 1.612	€ 2.043
June	€ 1.516	€ 2.043
July	€ 1.516	€ 2.043
August	€ 1.612	€ 2.236
September	€ 2.140	€ 2.452
October	€ 1.419	€ 2.140
November	€ 2.429	€ 2.452
December	€ 1.516	€ 2.236

Figure 7-4 Savings by choosing Antwerp port

2WIN	Container			Saved expenses R	Saved expenses A
10	16			€ 2.098,58	€ 1.827,61
11	18			€ 2.229,02	€ 1.924,18
12	19			€ 2.558,01	€ 2.236,23
13	21			€ 2.688,45	€ 2.332,80
14	23			€ 2.818,89	€ 2.429,37
15	24			€ 3.147,87	€ 2.741,42
16	26			€ 3.278,31	€ 2.837,99
17	27			€ 3.607,30	€ 3.150,03
18	29			€ 3.737,74	€ 3.246,60
19	30			€ 4.066,72	€ 3.558,65

Figure 7-6 Savings

7.2 Research questions revisited

From Section 1.4, seven research and knowledge questions have been defined, with each question being discussed throughout this research. Starting with the current situation, we have learned in Chapter 3: Current situation that there are seasonal patterns throughout the years of historical data, with peaks in March and decreased demand in the winter. We know the current route combines the sea, road and rail modalities and goes through Germany, the Netherlands, Belgium, France and the United Kingdom before finally arriving in Ireland. From the size of the trailer it is concluded that a 40 inch container can be introduced with a maximum capacity of 33 pallets, which contrasts the 52 pallet capacity of the current equipment. By having frequent conversations with the operations and sales department the basic cost elements have been obtained, which are then used as input for the impact tool. We have identified Rotterdam and Antwerp as two ports, having no container restrictions, that also provide direct connections from continental Europe to Ireland. The need for an easy to use practical tool is addressed, where constraints, such as capacity and scheduling has to be taken into account, whilst being able to simultaneously evaluate several lanes and scenarios. We have identified cost and travel time as our main variables and from Chapter 2 we now understand how a multimodal network is modelled. We have been presented with multiple criteria decision making methods and have chosen AHP as a method for evaluation. Last, but not least, we are aware of the impact that a modal shift has on several levels.

7.3 Discussion

The aim of this research is to examine the effect that a modal shift would have on the company's processes. We have defined a methodology of 5 steps, called the DSRM and we have examined the current situation as a benchmark for comparison with the alternative scenarios. From the literature review we have learned how to model a modal shift, as well as the different components and aspects of (re)planning on all three levels. We have created a forecast to be able to predict future demand and we have introduced the concept of an impact tool, also consisting of 5 steps and defining the modalities, variables, uncertainty, sensitivity and evaluation aspect. The tool has been designed as one of the final steps in the methodology and all variables have already been measures and results have been obtained.

From the beginning, during the literature review phase a limited amount of sources were found, with respect to sensitivity analysis. In the few sources encountered a sensitivity analysis of increasing fuel and/or demand was included briefly as a post-calculation aspect. Similarly, with uncertainty analysis sources are focusing solely on problems, arising on either an operational, tactical or strategic level. The combination of uncertainty, sensitivity analysis and variable computation when taking into account two transportation units was not found as often in literature and was thus a deciding factor in the creation of this thesis, as our aim was to explore the modal shift from a unified perspective. While we have successfully created a support tool for an impact assessment, there is still a lot to be done. The impact tool has its own limitation, due to either lack of information or lack of time. Both aspects are mentioned in the next section.

Ultimately, what we are presented with is an answer to the question of whether the new route in combination with the new unit of transportation have enough benefits in order to be introduced at the company. Certainly, based on our findings the new route does provide a similar cost per pallet when taking into account a two-way trip for both the container and trailer. In reality however, once the trailer arrives in the UK, it picks up orders from England and therefore travels back to Germany full, which saves on expenses, connected with fuel, driver wage, etc. In the case that the container is introduced, it will travel back empty in its initial stage, because we no longer have the any incoming orders from the UK to Europe. This increases the empty miles in comparison with the trailer and the trailer has a 50% lower price per pallet in that situation. Unless customers are found for picking up orders from the Netherlands to any point in Europe, the trailer will remain the cheapest option. On the other hand, with the container solution the driver is no longer present during the ferry trip and can continue to work with other orders, thereby saving resources. It is estimated that savings with regards to fuel and driving hours are ranging from 1400 to 3000 euros per month. Due to the fact that a higher number of trucks will be needed for the containers (as they fit 33 and not 52 pallets), it is again a tradeoff between the number of trucks and working hours, as working hours are being cut off by half (the truck is no longer a part of the ferry trip). The implications that this alternative route has for the customer is that they need to place their orders several days earlier than before to ensure their products being delivered on time. This implies a need for an earlier forecast, which, from a consultation with the Sales department at Emons, poses a difficulty for their clients. From the company side, one of their largest expenses is connected to fuel consumption. From the sensitivity part of the impact tool when increased by 5% the cost per pallet increases with 0.6 euros. While it may seem little, when taking for instance a forecast of 760 pallets for the month of January, it corresponds to an increase of about 450 euros just for one lane per month. If we assume the same demand for the other lanes, the increase sums up to be around 1800 euros per month.

Some relevant direction for future research can be connected to expanding the current view of a modal shift. Uncertainties, arising on all three levels can be incorporated in one common tool, thereby connecting the work of several departments, so as to improve integration and communication. The side-by-side comparison of different transportation units, coupled with the measurement of all relevant variables can be expanded by the introduction of more

modalities. The inclusion of more modalities for comparison was a step originally planned, but difficult to fulfill due to lack of time. However, it could be included in a future version 3 of this tool. The creation of a schedule for the trucks, going to the port can also provide insight into planning and potentially reduce the number of trucks needed, if heuristics are added as a solution method.

7.4 Limitations

Even though the impact tool takes a number of valuable factors into account, it does not come without its limitations.

Due to lack of information

Stochasticity is an integral part of all journeys, irrespective of the modalities used. There will always be waiting time at the port or traffic jams on the highway. In order to best estimate the time needed to reach point B from point A, stochastic models can be used, which take into account the varying nature of waiting times. In order to do so, historical data is used, however there was no available data to be used from the company, thus the task of finding a proper distribution was made especially difficult.

Due to lack of time

In this research, our plan included adding rail as an option, worth considering , however, due to lack of time this was not possible to explore.

7.5 Recommendations and closing remarks

Container route in the long run

We have found that the new route has around the same cost as the 2WIN equipment. Furthermore, from the forecast made in Chapter 4, estimated savings come to about €20000 per lane. With increasing the number of orders, the container unit, along with the new route increases savings and is therefore suitable for the long run for most products. Our suggestion is to consider renting multiple containers, such that the capacity of the double-deck trailers is used elsewhere throughout Europe. We suggest having Rotterdam as an alternative port, as Antwerp poses a higher cost per pallet. Once the containers are rented and shipped to both loading locations, the pallets can be loaded in three trucks at the same time and subsequently sent to arrive at the final destination. We are making a tradeoff between cost and travel time, where the customer can receive a lower price for their orders, however with a longer delivery window. This is usually discussed during the negotiation phase between the order managers and the customer.

Current route for perishable items

An important note to consider is that there are multiple types of products being delivered and one type in particular are all perishable foods, that have a low shelf life. With an average delivery window of about 6 to 8 days when using a container, it is the customer's preference of a shorter lead time that we can provide the following recommendation – for all perishable items Emons can consider following their current routing and equipment. This is a tradeoff between cost and travel time, where time is of essence. In this way, customers have the security of receiving their orders within a shorter period of time. The disadvantage found is the lack of a lower price that can be offered for the customer.

All in all, the transportation industry has been rapidly developing and constant improvements and new introductions are being made. In the field of combining several modalities, there is certainly added complexity in terms of planning and coordination, however at the same time that leaves us with multiple opportunities for growth in every aspect.

This research is based on computation of specific cost elements that Emons has provided, however the coding can be always adjusted. The idea behind the impact tool can be applied to any other company and/or company case, dealing with the introduction of a alternative route in the road-sea-road modalities and having options for either a trailer with 52 or a container with a certain amount of pallets. Most of the elements that Emons has are also expenses that other companies share, thus little adjustment may be needed.

At this point in time, it is our hope that this thesis adds value to existing theory in this field, while simultaneously opening a new door for new research in the near future. We look forward to any new developments that may arise.

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Appendix

Systematic literature review

In this research, a number of research questions have been defined, so as to assist in gaining knowledge in solving the main action problem. One of the research questions concerns the evaluation stage. Once all alternatives have been defined and calculated in terms of time, cost, emissions, etc., how will they be evaluated and compared? As each stakeholder has different goals/interests and as multimodal networks possess a great deal of factors to be taken into account, the defined research question is thus:

How to evaluate different options when presented with multiple factors?

Answering this question provides an insight into how the decision-making process can be simplified as much as possible by providing a common framework. This is also part of the seven research and knowledge questions previously defined in Chapter 1: Introduction.

In order to answer this question, a systematic literature review is carried out. The methodology used is one by Denier and Tranfield (2009). It consists of 5 five steps, as can be seen below.

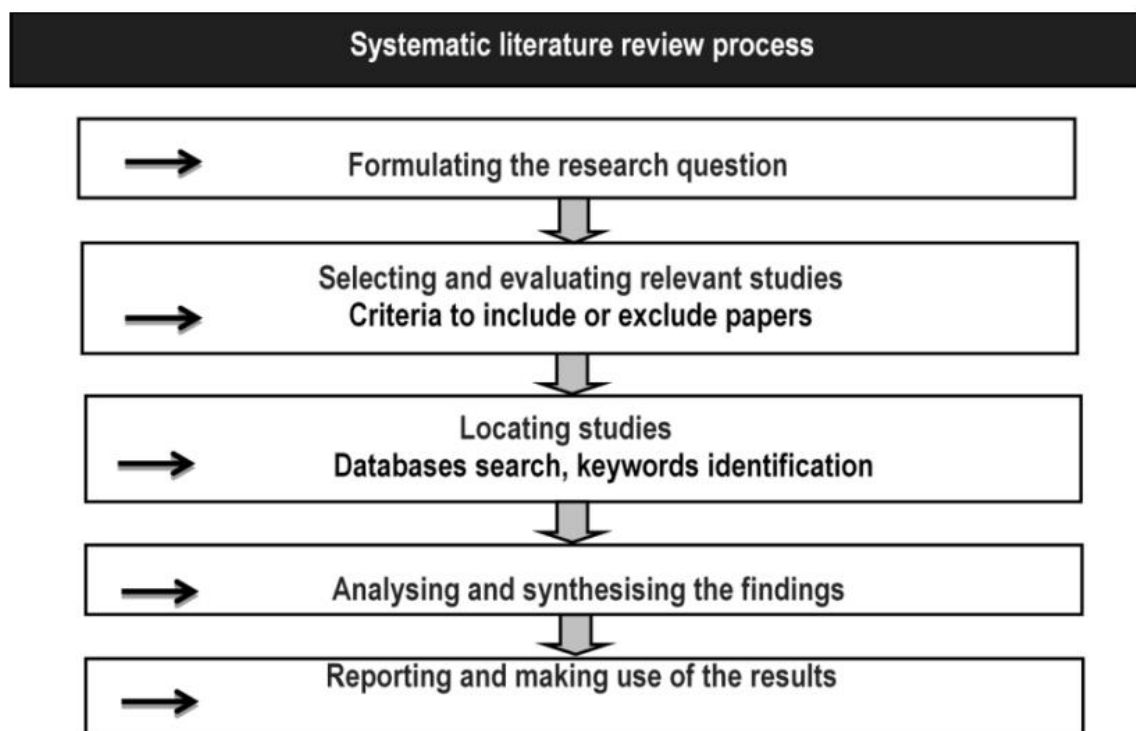


Fig.1 Literature review methodology (2009, Denier and Tranfield)

As the research question has already been formulated, the next step is evaluating the inclusion/exclusion criteria. Below a table with an overview of both can be seen.

Inclusion criteria	Reasoning
Keywords: “multimodal”, “transport” , “evaluation”, “alternative”, “method”, “choice”, “decision-making”, “routes”	This research concerns multimodal transport, thus it is crucial to have at least multimodal as a keyword. “Alternative” and “routes” correspond to the multiple option presented and “evaluation”, “method”, “choice”, “decision-making” are all used interchangeably for evaluation.
Exclusion criteria	Reasoning
Articles before 2019	Only recent articles are considered, so as to reflect more on current trends in multimodal transport
Field of Computer science, Material science, astronomy, Biochemistry etc. In other words, any field different than Transportation and Transportation Science Technology	They are not relevant to the field of transportation
Languages other than English	Difficulties in understanding
Paid articles	Cannot be accessed

Regarding the use of databases, Scopus and Web of Science were chosen, as they are one of the main largest databases, consisting of a large variety of academically trustworthy sources. The following search strings, as well as results can be seen below.

Search strings	Web of Science	Scopus
“multimodal” AND “alternative” AND (“method” OR “evaluat*”	1015 4	2128 42
“multimodal” AND “transport” AND “choice”	425 9	8823 12
(“multimodal” OR “transport”) AND “decision-making” AND “routes”	388 39	17748 144
<i>Total per database</i>	<i>1828</i>	<i>28699</i>
	<i>Total for both databases</i>	<i>30527</i>
	<i>After inclusion/exclusion criteria</i>	<i>250</i>
	<i>After scan of title, keywords and abstract</i>	<i>14</i>
	<i>After removing duplicates</i>	<i>8</i>
	<i>Final selection</i>	<i>4</i>

As can be seen, the inclusion and exclusion criteria caused a large decrease in the number of articles available, and out of 250 articles, only 15 were chosen as suitable based on looking through the title and the abstract. An overview of how many articles were selected by database is given below.

Search strings	Selected articles - Web of science	Selected articles - Scopus
<i>"multimodal" AND "alternative" AND ("method" OR "evaluat*"</i>	1	0
<i>"multimodal" AND "transport" AND "choice"</i>	0	1
<i>("multimodal" OR "transport") AND "decision-making" AND "routes"</i>	1	1

Analytical hierarchy process ranking criteria

Preference Level	Numeric Value
Equally preferred	1
Equally to moderately preferred	2
Moderately preferred	3
Moderately to strongly preferred	4
Strongly preferred	5
Strongly to very strongly preferred	6
Very strongly preferred	7
Very strongly to extremely preferred	8
Extremely preferred	9