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Transforming Internal Transport Choices – From Functional Practice to Structured Decision

Master's thesis in Supply Chain Management

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Summary

This study develops a structured decision-support model for evaluating and comparing transport alternatives for replenishment orders in a global supply chain. A case study was conducted at Company X which evaluates their currently used practice in comparison to a set of transport alternatives. Through which a calculated and theoretical reasoning behind their currently used transport alternative Parcel is provided.

A hybrid multi-criteria decision-making (MCDM) framework was constructed, using the Analytical Hierarchy Process (AHP) for creating weights for the criteria and Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) II to compare the alternatives. The alternatives, criteria and weights were decided in conjunction with the stakeholders of Company X. Five transport alternatives were evaluated: Parcel, Pallet Express, Pallet Standard, Pallet Consolidated and Sea Freight. The alternatives were evaluated across four criteria: Freight Cost, Lead Time, Delivery Reliability and Environmental Impact. The weight of the criteria was gathered through queries and validated by both aggregated individual judgements (AIJ) and aggregated individual priorities (AIP), resulting in a consistency ratio of 0,04.

Two datasets were used, dataset 1 and dataset 2, to evaluate the model and its results. The different datasets consist of products with different characteristics and costs. The results show that their currently used transport solution ranks first in the PROMETHEE II model with dataset 1 with a Net Flow of 0,3605 and achieves the lowest Total Cost of €60 664. Pallet Consolidated emerges as the preferred transport solution for dataset 2, which validates the supply chain strategy theory of there's no unified optimal solution that can be applied to all products.

Parcel performs the best in the two highest weighted criterion: Delivery Reliability and Lead Time, bringing attention to the subjectivity of MCDM models.

The research validates Company X current transport solution for replenishment orders and provides a scalable, data-driven framework to evaluate future datasets.

Keywords: MCDM, PROMETHEE, AHP, Transport Solutions, Supply Chain

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Glossary

D2P = Door to port.
P2P = Port to port; airport to airport.
P2D = Port/airport to door.
D2D = Door to door (D2P + P2P + P2D).
MCDM = Multi Criteria Decision Making
AHP = Analytical Hierarchy Process
PROMETHEE = PReference Ranking Organization METHod for Enrichment Evaluations
SC = Supply chain
SCM = Supply chain management
FCL = Full Container Load
LCL = Less than Container Load

1. Introduction

Global supply chains refers to globally integrated systems of operations and participants that manages the flow of materials, from raw materials to the end consumers. In this interconnected system exists multiple different parties such as transportation providers or distributors that operate internationally (Wang, Dong & Liu 2026, pp. 1-16). For globally operating manufacturing companies their products will be distributed globally to reach their desired destination. There are mainly five different ways the products can be transported by: railway, road, water transportation, pipeline or air. Choosing the correct supply chain operating strategy to efficiently handle the flow of material involves a complex decision making process where multiple factors need to be considered simultaneously (Haial, Berrado & Benabbou 2016, pp. 1-3).

For global companies to handle their operations in the best way possible, investments in IT systems such as enterprise systems are often made for their business advantage (Sanjay, Anoop & Balasubramanian 2006, p. 7). Through organizational restructurings, globalization, real-time enterprise information and other dynamics this often leads to enterprise system consolidation between multiple regional entities within the enterprise. By consolidating ERP systems, previous best-practices of business processes in local entities may be abandoned by standardization initiatives (Sanjay, Anoop & Balasubramanian 2006, p. 11).

This creates a challenge when companies need to justify whether a standardized global process should replace existing local practices, such as transport solutions. Deciding on a transportation solution is difficult because the impact cannot be evaluated through a single criterion (Liu, D., Zhao, S. & Liu, J. 2012, pp. 179-183). Instead, several factors, such as cost, lead time, environmental impact, operational feasibility, and stakeholder priorities, need to be considered together. Furthermore, these factors can be prioritized differently following the needs of the local practice. Hence, the local entities efficiency may be negatively impacted by standardizing processes (Sanjay, Anoop & Balasubramanian 2006, p. 11). This leads to a problem of comparing different transport solutions, as many underlying factors unique to each situation are present and considered. This challenge is reflected in the case studied in this thesis.

1.1 Background

Company X and other entities within the Company group will integrate into a shared ERP system. At the moment the different entities have their own preferred way of transporting goods between warehouses. The shift to a shared ERP will encourage a unified solution where Company X transporting methods may be affected. The current solutions have been developed through trial-and-error methods, enabling company X to avoid issues other entities in the group are facing. In case of a unified solution, these effects may disappear and Company X will be operating under worse conditions. Their current transport solution has insufficient data-driven justification necessary to validate its performance compared to other transport solutions. Company X therefore requires a structured framework that evaluates their current solution according to their priorities. To accommodate the evaluation of any future solutions, a tool usable by stakeholders at Company X is desired over a single evaluation of the current situation.

2. Research Purpose

When current transport solutions are challenged or questioned as a result of organizational changes, such as an ERP consolidation, there is a need for a framework to justify the currently used practice. Otherwise the currently used practice may be abandoned because of lack of supporting data. This research is developed in the context of a company facing this scenario, where the currently used transport solution lacks calculated and theoretical reasoning behind the currently used transport solution. Hence, the purpose of the study is to develop, through a case study, a structured decision-support model to evaluate and compare transport alternatives for replenishment orders, and to assess a currently used transport solution compared to a theoretically optimized one based on the decision-support model's output.

2.1 Research questions

It's necessary to identify and define the criteria that are prioritized when choosing a transport solution for replenishment orders before any comparison can be made between transport alternatives. The criteria are needed to establish the foundation for what the transport alternatives will be measured against and their relative importance is needed to know what drives the decision.

Once the transport alternatives and criteria are used as input to the decision-support model, the current practice can be compared to the model's result. If the currently used transport solution for replenishment orders is aligned with the model's suggestion, it provides calculated and theoretical justification to continue with the current practice.

These considerations are condensed into the following research questions:

RQ1 *What aspects are considered when choosing a transportation solution for replenishment orders and how do they compare to each other?*

RQ2 *How does the currently used transportation solution compare to a theoretically optimized one based on the identified decision factors?*

2.2 Scope & Limitations

In order to keep the project feasible the following limitations are established:

- Different products may have different optimal solutions, but due to the large assortment of products this work will be limited to product groups as the smallest unit of differentiation.

- Due to global presence and variety of conditions at local warehouses, this work will only regard the intra-warehousing transports, i.e. not to customers but between the companies own warehouses.

- The set of feasible transportation modes for replenishment orders may vary depending on the geographical location of a local warehouse. Since maritime transport and air freight can reach all relevant destinations globally, these transport modes will be primarily in scope of the investigation.

3. Research Design

The research design was based on the Systematic Combining described by Dubois and Gadde (2002, pp. 553-560). It enabled an iterative process where theory tried to formulate reality, and reality in turn adjusted theory. It also opened for additional theory to be introduced along the project, and redirecting towards theory more aligned with the observed reality.

The project was roughly divided into distinct sections: the initial research, data collection, model creation, model refining and model testing and validation. These phases were inspired by the Systematic Combining framework and its concept of matching. The shift between two phases acted as a point where the model was thoroughly tested against reality, and potential gaps and discrepancies were noted in order to further adjust the model, or if the discrepancy was significant enough redirect towards a more suitable alternative (Dubois & Gadde 2002, pp. 553-560).

3.1 Case introduction

This report involved a case study where the supply chain operations of a globally operating Med-Tech company was investigated and analyzed. The case study was conducted at Company X Mölndal (hereafter Company X). Company X was facing a problem where there is no calculated reasoning behind the current transport solutions for replenishment orders. In addition, Company X was in need of a model to evaluate future potential solutions and compare to current execution. Hence, a model was made where input variables of different scenarios and transport alternatives could be analyzed, making it possible to evaluate current performance and future ones.

3.2 Literature review

A literature review was conducted for frame of reference, and continued throughout the project in order to both grant an initial understanding of the project and how it connects to theory, as well as to deepen insight into potentially significantly useful frameworks. The literature review primarily consisted of peer reviewed articles and reports from Chalmers Library and Google Scholar. In order for the investigated frameworks to be relevant, recent articles were prioritised during the initial segment of the literature review, and from them significant contributors to the frameworks have been identified and reviewed for a more fundamental understanding. Keywords during the initial literature review were: Multi-Criteria Decision Making, PROMETHEE, AHP, rank reversal, deciding factors on transport mode, impact of transport mode. The literature review provided a foundation for selecting an appropriate MCDM model and identifying relevant criteria for its application.

3.2.1 Sustainable Criteria

MCDM has the strength of including criteria otherwise disregarded, such as sustainable criteria in the model. Guarnieria and Trojan (2019, pp. 347-355) mention sustainable criteria such as environmental impact, labor and human rights, certifications and reverse logistics.

While these criteria are related to the transport industry as a whole, it is not certain that all of these are prioritised by every potential user of the model. Potential sustainable criteria were considered and selected based on the availability of usable data and impact. For the model to be trustworthy, externally gathered information should be from trusted sources.

3.3 Data collection

Throughout this project, data was gathered by various methods to allow for a wide range of data types to be collected and analysed. Qualitative data were collected through interviews (Korzeniowska, Artienwicz & Jaworska 2023, p. 126). Semi-structured interviews were conducted to leverage flexibility and versatility during the session. This method allowed for follow-up questions while still having a framework of interview questions to have alignment throughout the dialogue (Kallio, Maija, Johnson & Kangasniemi 2016, p. 2955). This was complemented by questionnaires where stakeholders answered standardized questions (Korzeniowska, Artienwicz & Jaworska 2023, p. 121).

Secondary data was collected to help the study of the report. The secondary data has the advantage of being collected usually quicker than primary data, and in some cases the information may only be attainable in the form of secondary data (P. Schuster, Anderson & Brodowsky 2024, p. 99), which in the case of this study, was true. The secondary data in this report was data provided by Company X and Y, as the model has been based on the needs of the company. Company Y is another company within the same group, and shares warehouses and certain operations with Company X. Parcel and the Pallet solutions had enough information to make trustworthy calculations. Information regarding Sea Freight was greatly limited, both in accurate costs, lead times, the division of different legs and delivery accuracy. While Company X didn't completely lack data regarding Sea Freight, the data available is mostly based on promises from the Sea Freight Provider, or from a sparse use of sea freight.

Depending on how much data was available in-house for an alternative, additional data was gathered from different channels in order to not lack the performance of some criteria. The additional data was gathered using online resources recommended by stakeholders at Company X, making sure all data was accepted as usable by Company X. During the creation of the model the primary route investigated was from Venlo, NL, to Lancaster, Pennsylvania, U.S. A period of about three calendar months where operations were considered usual was used as a base to determine what products to investigate.

Since MCDM models require data for different alternatives this data in most cases have different origins. A significant part of model creation is accessing relevant data (Schuster, C.P., Anderson, B. & Brodowsky, G. 2014, p. 116). As such it's important to consider the veracity of the gathered data (De Tré, G., De Mol, R., & Bronselaer, A 2018, p. 542). The easiest way to determine if data is usable is by having the decision maker agree to use a certain datapoint or -set. However, the quality of the data can still impact the outcome of MCDM models.

A transport solution not thoroughly investigated is LCL Sea Freight. Since Company X hadn’t investigated LCL Sea Freight no data was available. Finding publicly available data instead provided vague ranges at best, and for far from all required data. These situations exemplified an inherent issue of MCDM models, the variations in data quality (De Tré, G., De Mol, R., & Bronselaer, A. 2018, p. 542

3.3.1 Primary Data

Several interviews were held with stakeholders. Each interview had a designated time of one hour, and had main topics the discussion focused on. When several stakeholders were present, the interview took the form of a meeting where a question was followed by discussion, until the stakeholders were in agreement of an answer. Outside of these semi-structured meetings frequent unstructured conversations were held with stakeholders 1 through 4, providing further insight and information. Stakeholder 5 was based in Venlo, and was only conversed with during planned meetings such as the semi-structured interviews. These insights were validated in the semi-structured meetings to ensure a structured workflow and have several stakeholders agree information was correctly interpreted.

Stakeholder 1 (Company X)	Primary Contact at Company X. Project Lead and Logistics Developer, S&OP.
Stakeholder 2 (Company X)	Supply Chain Manager, Materials and Purchasing, S&OP
Stakeholder 3 (Company X)	Project Leader External Logistics, Supply Chain Development
Stakeholder 4 (Company X)	Director Supply Chain
Stakeholder 5 (Company Y)	Transportation Manager at Venlo Warehouse

Table 1: Stakeholder Descriptions

As seen in table 1 stakeholders 1 through 4 were heavily involved in the departments’ Supply Chain Management and each had a different area of expertise. They all have significant experience in Company X’s situation, priorities, issues and solutions. By having meetings with multiple stakeholders present instead of interviews with a single stakeholder, the discussions led to comprehensive answers, solutions or insights with regard to multiple points of view. The fifth stakeholder mentioned in table 1 was critical in providing insight and data for transport solutions other than the one used at the Mölndal site.

The data used to calculate weights was gathered through queries. This made sure every respondent answered the exact same questions, and made it more flexible as each stakeholder could respond when it suited them.

Meeting #	Topic	Week	Participants	Duration
1	Introduction and Problem Description & Scope	Week 0	Stakeholders 1-4	1 hour
2	Workflows, Lead times, and Operations Overview	Week 2	Stakeholder 3	45 minuted
3	Model Concept Validation & Criteria	Week 3	Stakeholders 1-4	1 hour
4	Weights, Assumptions Validation, Cost of Capital	Week 7	Stakeholders 1-4	1 hour
5	Transport Alternatives Data	Week 8	Stakeholders 3 & 5	30 minutes
6	Clarification & Validation Transport Alternatives Data	Week 8	Stakeholders 3 & 5	1 hour
7	Model Finalization & Initial Results	Week 11	Stakeholders 1-4	1 hour
8	Results	Week 16	Stakeholders 1-4 + Audience	45 minutes

Table 2: Meeting Descriptions

Meeting #1 formalized the description and scope of the project. It was decided to focus on a D2D flow from a main warehouse in Venlo, NL to a local warehouse in Pennsylvania, US. This was based on two reasons: the flow of goods was considered stable, and since different departments in Company X sent goods with the same origin and destination shipping costs were available for five considered transport alternatives:

- *Parcel*
- *Pallet Express*
- *Pallet Standard*
- *Pallet Consolidated*
- *Sea Freight*

3.3.2 Secondary Data

Secondary data was provided by Company X and consists of product related datasets, operational and logistical data. The data was provided by Company X during meeting #2, as shown in table 2. It was used for the calculation of each transport alternatives' performance on the decided criteria and to calculate the total cost. The collection process was iterative, where initial data was requested and analysed, followed by requesting additional data when required. To ensure clarity and accessibility to the data sets, it was organized into separate categories based on its type and intended use. This enabled a structured approach to the data management and additional requested data could hence be more easily integrated.

The compiled datasets consist of the following categories: **Transport-related data, Product-related data and Miscellaneous data.**

Transport-related data includes information of the transport alternatives and its associated cost structure, delivery performance, lead times, environmental impact.

The cost structure for the transport alternatives have different set-ups in structure. Parcel shipments are express carriers that handle the D2D shipment with no fixed cost. Company X provided the average cost of parcel shipments between Venlo, NL. to Lancaster, Pennsylvania, U.S for the past year. Invoices of Parcel shipments were further requested. The invoice consists of the cost of shipments, parcel box dimensions and amount of parcels for a shipment.

For shipments regarding Pallets, the cost structure is different. The shipment is divided into three legs, the pre carriage (D2P), main carriage (P2P) and post carriage (P2D). The cost is based on the weight of the shipment or the volumetric weight if volume is more dominating than the weight. Each leg has different thresholds, cost per/kg and minimum shipping cost, and these thresholds are different again for the different Pallet alternatives .

Sea Freight follows a similar cost structure as shipments with Pallet shipments but the main carriage is a fixed cost of a container which was provided by Company X. The main carriage is not billed by chargeable weight, instead priced per the amount of containers needed.

The dataset of the cost structure also provided the route of the shipments.

Company X further provided performance data of past shipments for each transport alternative. The data included the service level, date of pickup for D2P, P2P, P2D and D2D and each leg's lead times, agreed lead time, actual lead time shipper and receiver.

Product-related data includes 2 sets of master data regarding the products. Data set 1 is compiled of Company X's items that were shipped during a 3-month period under normal conditions. Data set 2 is compiled of items from 3 hand-picked deliveries of Company Y, containing products with different characteristics and lower costs. Furthermore, the daily demand, cost, size, and weight of each item was requested.

The miscellaneous data consists of the capital binding cost, planning time and P2D lead time and annual working days.

Based on the routes used by the different transport alternatives, the emissions for one tonne of goods were calculated using EcoTransIT World's emission calculator, following the recommendation of Stakeholder 5 in meeting #5 (EcoTransIT World, n.d.).

3.4 Data Processing

The data needed to be processed before it was usable in the model. The annual total cost of a transport alternative was described as the sum of three different costs, the annual freight cost, pipeline capital cost, and cycle stock capital cost.

$$(1)\ TC = PC_{total} + CSC_{total} + FC_{total}$$

Where the pipeline cost of capital is defined as

$$(2)\ PC_{total} = C_{daily} * Lead\ Time$$

and

$$(3)\ C_{daily} = \sum_i (d_i * v_i * r)$$

where

$v_i = value\ of\ product\ i,$

$r = cost\ of\ capital,$

$d_i = daily\ demand\ of\ product\ i.$

The cycle stock cost of capital is defined as

$$(4)\ CSC_{total} = \frac{C_{daily} * f}{2}$$

where

$f = order\ frequency.$

The freight cost calculation is more complex, as it needs to account for multiple factors to accurately calculate what each shipment would cost. The formulas have been designed to accommodate different transport alternatives.

$$(5)\ FC_{total} = FC_{order} * Annual\ Orders$$

and

$$(6)\ FC_{order} = max(Q_{kg} * p_{pre}\ , m_{pre}) + max(Q_{kg} * p_{main}\ , m_{main}) + max(Q_{kg} * p_{post}\ , m_{post}) + C_{fixed} * n$$

$$(7)\ Q_{kg} = D_{kg} * f$$

$$(8)\ Q_{vol} = D_{vol} * f$$

$$(9)\ D_{kg} = \sum_i (d_i * max(w_i\ , \frac{V_i}{\alpha}))$$

$$(10) \qquad n_{sea} = \lceil \frac{Q_{vol}}{\beta} \rceil$$

$$(11) \qquad n_{other} = 1$$

where

$$p = price/kg,$$
$$m = minimum\ price,$$
$$C_{fixed,sea} = fixed\ cost/container,$$
$$C_{fixed,other} = fixed\ cost/order,$$
$$\alpha = volumetric - weight\ conversion\ factor,$$
$$\beta = effective\ usable\ volume\ of\ container,$$
$$w_i = weight\ per\ product\ i,$$
$$V_i = volume\ per\ product\ i.$$

It's worth noting that α is often very similar regardless of LSP, often around 6000 if the unit is cubic centimeters.

To find the order frequency the annual total cost was calculated with order frequencies iteratively increasing by 0.25 days. The lowest found value was then used as an optimized order frequency. The testing was limited to an order frequency of 20 days at most for both calculation- and operational feasibility.

$$(12) \qquad f^* = min\ (TC\ (f)\ )$$

where

$$f \in \{0.25, 0.50, 0.75, \dots, 20.00\}$$

Since Parcel didn't have the same cost structure, the cost/parcel was converted into a cost/kg based on the size of the predominantly used one. This cost could then be put as p_{main} for the alternative.

$$(13) \qquad p_{main,parcel} = \frac{Price\ per\ Parcel}{V_{parcel}\ /\ \alpha}$$

To make the environmental emissions comparable between alternatives, it was first converted from a per tonne basis to a per order basis, and then to a per annum basis.

$$(14) \qquad G_{annual} = G_{order} * \ Annual\ Orders$$

where

$$(15) \qquad G_{order} = G_{tonne} * \textstyle\sum_i \ (d_i * w_i) \ * f$$

To make the delivery performance easily comparable between transport alternatives the agreed lead time was compared to the actual lead time. The amount of shipments with actual lead times below or at the agreed lead times were considered on time. This was then converted to a percentage of total shipments using that transport alternative.

$$(16) \qquad OTD = \frac{\sum_i \quad x_i}{N_{on-time}} * 100$$

where

$$x_i = \ 1\ if\ LT_{actual,i} \leq LT_{agreed,i}$$
$$x_i = \ 0\ if\ LT_{actual,i} > LT_{agreed,i}$$

3.5 Model Evaluation

To evaluate the model, artificial scenarios and synthetic data were used to imagine different settings, scenarios and limitations of the model. Real data was primarily added from a master data file, providing most of the data needed for the scenarios. Synthetic data was made in collaboration with stakeholders to ensure a degree of realism where no data was available or reliable. The final model was validated through a series of complimentary and independent approaches. The robustness of the model was assessed through sensitivity testing where rank reversal was investigated. Moreover, the strength of the highest ranked transport alternative was evaluated by a set of unfavorable conditions, order frequency was evaluated, comparisons of the result produced from dataset 1 and 2, and a SWOT analysis to evaluate the model itself.

3.5.1 Sensitivity Testing

The rank reversal investigation was carried out by removing one alternative at a time from the set of five alternatives A = {A1, A2, A3, A4, A5} = {Parcel, Pallet Express, Pallet Standard, Pallet Consolidated, Sea Freight} and recalculating the rank for the remaining alternatives. The preference functions, parameters of q and p as well as weights remained unchanged. The operation was carried out in the following order:

- Run PROMETHEE II framework with alternatives A = {A1, A2, A3, A4, A5}.
- Remove alternative A1 → run PROMETHEE II → compare ranking of {A2, A3, A4, A5}.
- Restore A1, remove A2 → run PROMETHEE II → compare ranking of {A1, A3, A4, A5}.
- Restore A2, remove A3 → run PROMETHEE II → compare ranking of {A1, A2, A4, A5}.
- Restore A3, remove A4 → run PROMETHEE II → compare ranking of {A1, A2, A3, A5}.
- Restore A4, remove A5 → run PROMETHEE II → compare ranking of {A1, A2, A3, A4}.

3.5.2 Less Competitive Scenarios

Two less competitive scenarios were assessed to evaluate the competitiveness of the alternative and the impact on the model's result during unfavourable conditions. The first scenario simulated a situation where a major part of the transport cost discount was lost. The second scenario had the other criteria adjusted to perform 8-12% worse than the status quo to simulate reduced transport performance, while the full discount was still present. The third scenario combines scenario one and two, removing a majority of the discount and having the other criteria perform worse.

3.5.3 Sub-optimal order frequencies

A scenario was tested where order frequencies would stay the same as they are in the currently used practice compared to optimized calculated order frequencies. Consequently, their current practice could be evaluated further against a theoretically optimized one.

3.5.4 Secondary Dataset

A secondary dataset was provided by Company Y. The secondary dataset was added to assess the scalability of the model and if the model's result changed when products with different characteristics were added as input to the model. The results produced by the model using dataset 2 were compared to the result generated by dataset 1.

3.5.5 SWOT Analysis

A SWOT analysis was conducted to evaluate the model's characteristics. The outcome of the analysis visualizes the usability and limitations of the model in order for Company X to maximize the usability of the model, by making informed decisions (Gürel & Tat 2017, pp. 994-995).

4. Literature Review

Findings from the literature review are presented below. The literature review is divided into two sections, 4.1 and 4.2. Section 4.1 is regarding literature relevant to the method to compare transport alternatives. Section 4.2 is regarding subject covered literature.

4.1.1 Multi-Criteria Decision Making

Multi-criteria-decision-making (MCDM) has become a proven methodological approach to handle complex decisions that involve multiple and often conflicting criteria (Sun, X., Yu, B & Li, R 2025, p.2). MCDM methods have been applied in various industries such as environmental policy, engineering, health care and supply chain management. MCDM methods offer a structured and repeatable approach to assess alternatives and make decisions based on predefined criteria.

Among global studies there is a consensus to consider social, ethical, societal and environmental issues within the logistics strategy (Guarnieria & Trojan 2019, pp. 347-355). The traditional criteria used when making decisions, such as cost, quality, on-time delivery etc. doesn't cover socio-environmental criteria such as diversity, human rights, or reverse logistics etc. By incorporating both kinds of criteria in a MCDM-model results can be generated that are relevant to the situation at hand, providing a more comprehensive solution and encouraging sustainable choices.

In situations where multiple decisions need to be accounted for one of the most used methods is the Analytical Hierarchy Process (AHP) due to its ease of understanding and implementation (Gwarda, K. 2022, pp. 2-4). Since different criteria are weighed against each other it’s possible for the AHP to accommodate both measurable and abstract criteria, depending on what decision-makers choose to prioritise. Possible alternatives can then be judged based on how much they impact the chosen criterias and then weighed according to the chosen prioritisation. The method can however be time consuming when the alternatives are many and lacks the ability to evaluate one element in isolation (Daimi, S & Rebai, S 2023, p. 2-3).

AHP was introduced in 1980 by Thomas L. Saaty, who later (1996) introduced a similar model called Analytical Network Process (ANP) (Gencer, C & Gürpinar, D 2007, p. 2476). ANP is useful for problems where decisions can’t be built in a hierarchical structure because of dependencies and influences both between and within the alternatives and the criterias. ANP solves this problem by quantifying the interdependencies of criteria, hence providing a more realistic view of problems where interconnections exist within and between criteria and the alternatives ((Daimi, S & Rebai, S 2023, p. 3). This creates a network of elements instead of a hierarchical level as in AHP.

Another widely spotted MCDM technique is the Simple Additive Weighting (SAW) method (Hiremani, V et al. 2024, p.1). The SAW method is regarded as an effective method to solve

MCDM problems because it produces an overall score by accounting for the weight of each criteria (Hakim, B et al. 2025, p. 533). This is done by normalizing the data and adding up the weighted values for each criteria. An advantage to the SAW method is its simplicity in computation and transparent result. But compared to other MCDM methods it lacks the ability to measure the distance to the ideal solution.

TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) is another established method for MCDM known for being easy to program and compute, while still accommodating many possible variables and presenting solutions with a score based on how close they are to an ideal solution (Madanchian & Taherdoost 2023, pp. 1-3). TOPSIS is also beneficial when considering many attributes at the same time, since the actual calculations don't affect the number of process steps. One of the weaknesses of TOPSIS is the weighing of different attributes. TOPSIS itself does not have a method for weighing different attributes, only a method for accommodating potential weights in the calculations.

4.1.2 Analytical Hierarchy Process (AHP)

AHP is one of the most frequently applied multi-criteria-decision-models (Gwarda, K. 2022, p. 432). The popularity of using the model stems not only from its wide recognition and versatility in real world applications, but also from its simplicity by making complex evaluations more simple. AHP enables comparison of criteria and sub-criteria side-by-side in a structured basis, resulting in complex decisions making more manageable. Moreover, computing the process of AHP is relatively undemanding, in terms of both input data needed and time consuming. The process of AHP can be divided into five main stages, shown in Figure 1.

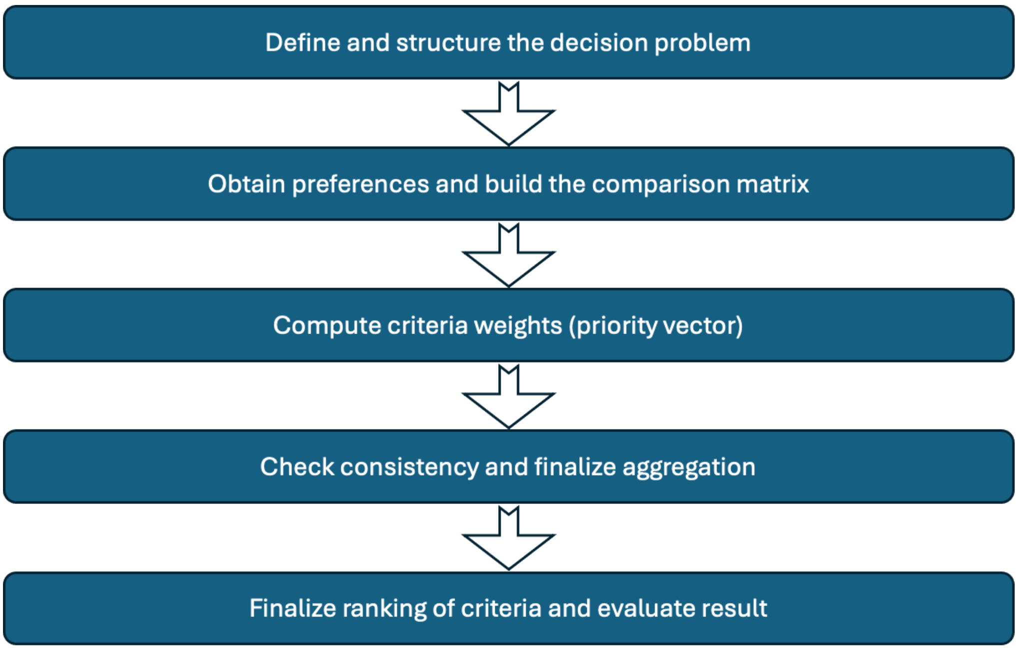

Figure 1: Five main stages of AHP

The first step includes defining the decision problem and decomposing the design problem into its fundamental components of criteria. The criteria are then structured in the format of a hierarchical decision making structure. A decision tree can be used in this stage, where the decision alternatives are positioned at the lowest level.

In the second step the decision maker provides preferential input to the decision criteria for each level of the hierarchy to indicate which one is more important and by how much. The criteria is compared by rating on a 1:9 scale where a score of 1 indicates equal importance and a score of 9 indicates the highest possible preference of one criteria over another. The even-numbered values (2, 4, 6, 8) represent intermediate levels of preference, indicating a slightly higher preference. Since the coefficients are compensatory, the value assigned to the less important criteria is the inverse of the preference given to the preferred one. For instance, if a criteria is rated 5 more important compared to another criteria, the less preferred criteria receives the inverse value of ⅕. At this stage, the preference matrix is also constructed.

If there is more than one respondent, there are two established ways to aggregate their results. Aggregated individual judgements (AIJ) is done by using the geometrical mean of the respondents preferences in the preference matrix (Foreman, E & Peniwait, K. 1998, pp 165-169). AIJ provides the benefit of an easier computation, since only one AHP calculation is done using an aggregated preference. The geometric mean makes AIJ useful when the group needs to make decisions and act as a single entity, since the geometric mean more effectively handles outliers than an arithmetic mean would.

The preference matrix is used in the third step to calculate the weights of each individual criteria, i.e., calculating the eigenvector. This is obtained by the numerical method of calculating the vector. This is done by normalizing the vector by squaring the preference matrix. The process is repeated until a stable normalized vector is found, representing the weight of the criteria. Meaning that for each iteration the newly obtained vector diverge to the previous vector no greater than by the constant $|\varepsilon|$.

Step four of the process includes summing the rows of the preference matrix. If the sum is equal to 1 (with consideration to the $|\varepsilon|$ error limit)., the iteration has been successfully computed. The consistency is also validated by calculating the consistency ratio (CR) (Saaty, W.R. 1987, p. 165). A consistency ratio below 0.10 is considered a good CR.

If aggregation is needed and AIJ wasn't used, the second established method called Aggregated Individual Priorities (AIP) would be used here. AIP takes the sums of the preference matrix, and arithmetically averages it between all respondents. This process takes more consideration for outlying priorities than AIJ does, and is therefore more suited for when a decision needs to consider different perspectives and goals. The amount of calculations also increases linearly with AIP, while the amount of calculations for AIJ is constant.

The fifth and last step involves multiplying the performance value of each alternative with its corresponding weights assigned to the criteria. The weighted values are aggregated to obtain the final score, with the highest score indicating the optimized solution for the decision maker.

4.1.3 Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) II

The PROMETHEE family of methods is a capable yet simple evaluation method used in both single-criteria and multi-criteria decision making (Živković et al. 2025, pp. 32-34). The PROMETHEE methods require a preference function to be defined for each decided criteria, as well as the parameters for the preference function. The preference function describes the value of difference between two alternatives, on a scale of 0 to 1 for each criteria. Determining preference functions and their thresholds is one of the drawbacks of the PROMETHEE methods (Taherdoost & Madanchian 2023, pp. 3-5). While the preference function can have different forms there are 6 commonly used functions known as the "generalized criterion", shown in figure 3. Deciding on a function along with its thresholds is left for the decision makers in each situation. PROMETHEE also doesn't offer a clear way or guidelines for setting weights for each criteria, nor choosing the criteria itself. Choosing criteria with any significant overlap induces the risk of rank reversal (Taherdoost & Madanchian 2023, pp. 3-5; Triantaphyllou & Mann 1994, pp. 609-611). The relation between the compensatory nature of the preference functions and rank reversal is as of yet unknown (Schär, Pohl & Geldermann 2025, p. 17). Compensation refers to how an alternative can perform strongly enough in one criteria to compensate for poor performance in another. The strength of the compensation depends on the range of difference between best and worst performers in each criteria, the criteria weight, and the preference function. Too little compensation makes the model too rigid, and too much can hide poor performance on critical criteria.

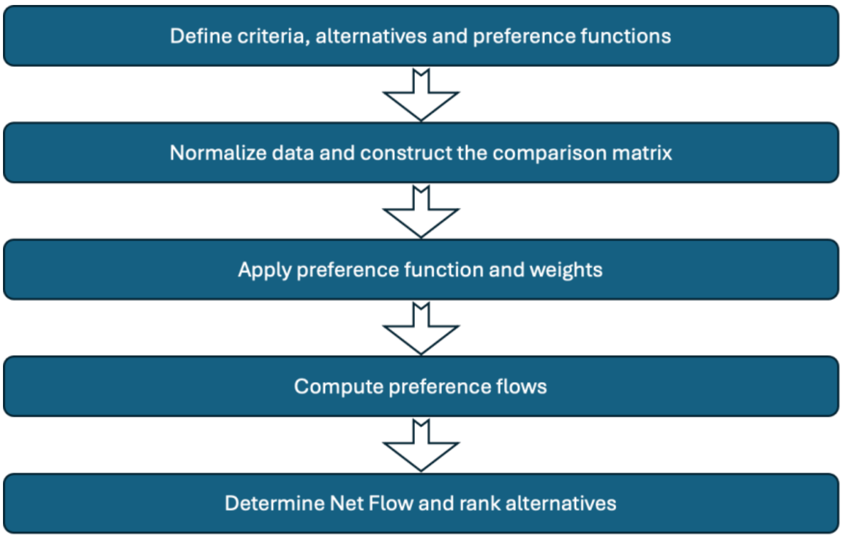

Figure 2: Main steps of PROMETHEE II

The second step when using the PROMETHEE model, as shown in figure 2, is to normalize the different values in a criteria (Brans, JP. & Mareschal, B. 2005, pp. 166-168). This is not strictly necessary, but simplifies the following calculations and has no impact on the calculations. The only downside is the need to normalize any thresholds in the preference functions as well, something that's easily done and itself has no drawbacks. Following this each alternative is compared against each other and put into a matrix, and any negative values are put as zero to avoid counting each comparison twice, since a positive value is mirrored by a negative one in the inverted comparison.

At this point the preference functions are applied to the compared values (Brans, JP. & Mareschal, B. 2005, pp. 169-171), and then the criteria's weights are applied as well.

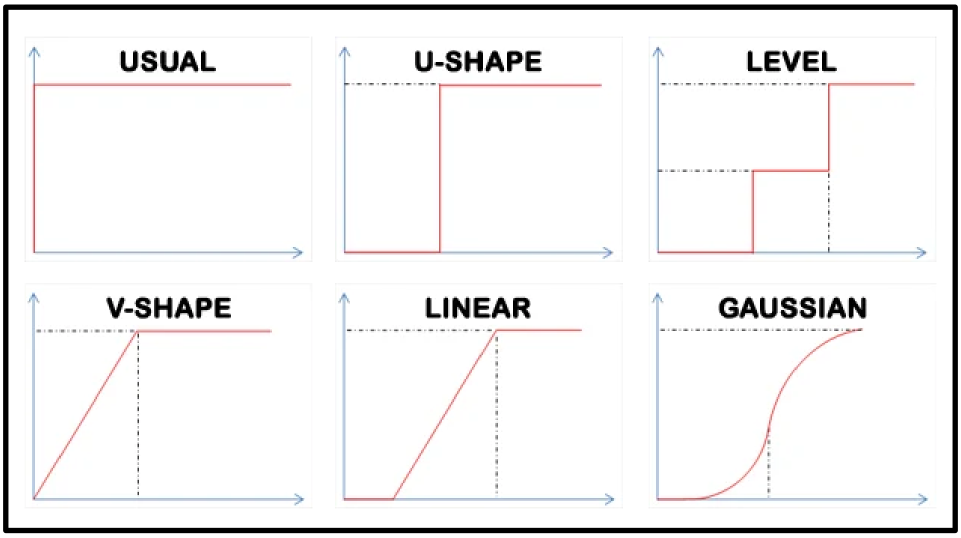

Figure 3: Preference functions, Source D-Sight: - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/PROMETHEE-preference-functions-Step-3-Computation-of-preference-degrees_fig1_262358543 [accessed 20 May 2026]

Each row vector is summed and added into another matrix, with the height and width equal to the square root of the amount of rows in the original matrix. This matrix is used to calculate the Entering- and Leaving Flows. (Brans, JP. & Mareschal, B. 2005, pp. 171-175) The Entering Flows is found by summing each column vector, and the Leaving Flow by summing each row vector. By subtracting the Entering Flow from the Leaving Flow a Net Flow is found, and this Net Flow is the final result of PROMETHEE II, with the highest value being the best alternative and the lowest the worst. The difference between PROMETHEE I and II is the complete ranking, PROMETHEE I only finds the best alternative but provides no information on the rest of the results, while II gives more insight into how other alternatives compare to each other.

4.1.4 Rank Reversal In Multi-Criteria Decision Making

In MCDM, alternatives are evaluated using criteria and weights (Liu, X & Liu, Y 2024, pp. 1-12). A common problem for MCDM methods such as PROMETHEE II, TOPSIS, ELECTRE and AHP is the occurrence of rank reversal. Research on the occurrence of rank reversal is as of yet limited since it's very complex to study in theory and has no unified solution of why it occurs, but an important field to investigate. A reason for rank reversal in TOPSIS is not always the reason for rank reversal in PROMETHEE II. If rank reversal occurs, it cannot be eliminated through minor changes to the MCDM framework. Two reasons for the occurrence of rank reversal is the sensitivity of preference functions and uncertain criteria weights and inaccurate expert judgements. Small changes in the thresholds (q and p) in the preference function can change the Net Flow and may change the ranking of the alternatives (Liu, X & Liu, Y 2024, pp. 1-12).

According to the literature, “for a MCDM method, the rank reversal is called occurrence if the relative ranking of at least two alternatives is changed when a third alternative is deleted” (Liu, X & Liu, Y 2024, pp. 1-12). If it's said to occur, this will affect the trustworthiness of the result as the model may be too sensitive. A sensitivity analysis of the rank reversal for the PROMETHEE II method can be conducted by first evaluating the complete set of alternatives and establishing the final ranking based on the performance values of each alternative and weights of the criteria. Then, one alternative is deleted and the ranking of the remaining alternatives is recalculated. If the relative order of the alternatives is changed, it can be concluded that rank reversal has occurred.

4.1.5 Criteria Selection In Multi-Criteria Decision Making

Multiple conducted MCDM studies often follow a similar process to identify and decide on the key factors, referred to as criteria, that will be used to evaluate and compare the different alternatives in the MCDM framework (Guarnieria & Trojan 2019, pp. 347-355; Wang, Y. & Li, J. 2025, pp 1-4; Hasan, U., Whyte, A. & Aljassmi, H. 2024, pp. 6-9). The identified process of criteria selection begins with an extensive literature review to identify relevant criteria. These criteria are then validated by experts or stakeholders by surveys or structured discussions to ensure that only the most relevant criteria are retained.

However, literature were also found that deviated from the above approach, such as selecting criteria based on statistical reports (Petrovic´, N et al. 2025, p. 10), operational shortcomings and risk factors (Kalaivani, K., Kaliyaperumal, P. & Cebi, S. 2023, pp. 1-5) or through interviews with the stakeholders (Gwarda, K. 2022, pp. 430-440).

Criteria in MCDM can be subjective and dependent on human judgement, such as customer experience (Hou, J. & Zhao, L. 2007, pp. 820-825) or brand reputation (Hamarsheh, K., Thasnim, J., Hassan, M. & Abdelfatah, A. 2025, p. 1). While also being objective such as comparing the cost of alternatives, delivery reliability and quality (Guarnieria & Trojan 2019, p. 351). The subjectivity of stakeholders in the decision making of weights and alternatives could reduce the reliability of the decisions (Madanchian, M. & Taherdoos, H. 2025, pp. 14-15). The quality of the data is crucial for the evaluation of criteria and ranking of alternatives in MCDM. Using the wrong, incomplete or inconsistent data could impact the reliability of the result.

4.2.1 Characteristics of Transport Modes

There are five main modes of transport: rail, road, air, pipeline and water transportation (Liu, D., Zhao, S. & Liu, J. 2012, pp. 179-183). Given the characteristics of the manufactured product from Company X and its operations, pipeline, rail and road as a mode of transportation will not be further considered. Due to Company X producing goods in Europe and shipping them to distribution centers around the world, air and water transport are the only modes that can reach the majority of the destination. In order to facilitate the development of the model these modes are chosen to be included initially, with the potential to add rail and/or road for applicable destinations in the future.

4.2.1.1 Sea Freight

Water transportation refers to all transport of goods on water. Shipping and short sea shipping has been recognized as one of the more environmentally friendly modes of transportation (when taking the long routes and amount of goods into consideration to emissions) as well as highly economically competitive (Chang & Thai 2017, pp. 200-206). Maritime container shipping (MCS) has evolved as the main mode of transport for global transportations due to its low-cost (Bathke, H et al 2022, pp. 10534-10556) MCS industry is transporting approximately 60% of all trade at sea and is developing as the backbone of global supply chains.

But shipping comes at the cost of being a slower mode of transport (Chang & Thai 2017, pp. 200-206). For instance, the transit time between the port of Philadelphia and the port of Rotterdam is 9 days and the average transit time of MCS from North America to Europe is 13 days in transit (Port of Philadelphia 2016). The speed of the vessel highly influences the cost for the line carrier and the CO2 emissions (Tran, N & Lam, J 2022, pp. 1-10). Slow steaming at 20 knots is a widespread cost-leadership strategy at which the liner carrier can leverage competitive advantage by offering cheaper shipping costs. There is yet to be seen a widespread strategy of differentiating by offering fast transit time by smaller vessels, more suitable for shippers with high-value and low volume goods. Moreover, scale economics have resulted in more investments towards bigger ships. As ships become larger, the CO2 emissions and the shipping costs decline. However, this comes at the cost of shippers paying more for inventory in terms of cycle stock, safety stock and inventory carrying costs due to the extended lead time.

The speed of the overall transportation is also influenced by the container port operations efficiency (Su, M., Bae, S & Park, K 2025, pp. 1-16). The time for discharging and loading containers needs to be taken into consideration when investigating the full lead time of MCS. A previously conducted case study collected data for discharging 4323 containers and loading 1020 containers (Mahpour, A., Nazifi, A. & Amiri, A. 2021). The result showed that this process could be done in 4908 min (81,8 hours) using three gantry cranes and 5100 min (85 hours) when using two gantry cranes. The growth of containerization is pushing the port's capacity limits which leads to congestion. Port congestion can significantly impact the supply chain efficiency of manufacturing companies and the overall global cargo management (Su, M., Bae, S & Park, K. 2025). Port congestion can be caused by multiple reasons such as insufficient infrastructure, weather conditions, spikes in demand, global financial crisis or pandemics. The consequences of port congestion is not only impacting the supply chain negatively of multiple stakeholders, but also the environment. Delays due to port congestion are also resulting in uncalled-for consumption of petroleum and increased carbon emissions. Sea Freight also inherently suffers from larger absolute deviations due to its longer estimated lead time (Liu, D., Zhao, S. & Liu, J. 2012, p. 181). This makes it more difficult to plan accurately, and therefore increases the safety margins needed.

4.2.1.2 Air Freight

The air freight logistics industry has become important for global trade of high-value to weight items where speed and timely deliveries are highly prioritized (Debbage, K. & Debbage, N. 2021, p. 361).

Air as a mode of transportation offers rapid and reliable movement of time sensitive goods (Jurgelāne-Kaldava et al. 2025, p. 1). Air freight is a fast mode of transportation for long distance shipping and ensures a high level of security and theft prevention. But air freight comes at the disadvantage of being expensive (Bartulovic´ et al. 2022, p. 126). Transporting the goods with air transport thereby needs to have features that would profit from fast and secure transportation (Brandt, F. & Nickel, S. 2019, p. 400). These features include: urgent, perishable, valuable and dangerous goods.

Shipments with air freight can vary in size from small single items, but are in general the size of a EU pallet 800x1200mm (Brandt, F. & Nickel, S. 2019, p. 400). Shipments follow a structured workflow when arriving at the cargo terminal either as a customer's export or from incoming flights. Cargo can be arrived as single items or packed Unit Load Devices (ULD), which may be stored or broken down to individual items. Depending on the cargo's departure schedules the items can either be sent directly to the build-up section to be prepared for departure or be kept in storage until preparation for departure. The build-up process is the most physical and time-consuming work in the air cargo terminal and consists of several challenges. The process starts with a load planner deciding which type of ULDs should be packed for the flight. A build-up planner then decides which shipments go into each ULD. Workers then pack the ULDs with the goal to pack as manny items as possible in ULDs in a safe and legal manner, while respecting weight limitations, the shape of the ULD and safety constraints. When the ULDs are packed the weight and balance planner decides where in the aircraft each ULD is going to be placed. Once the ULDs are loaded onto the aircraft they are latched in place and the aircraft is ready for departure. This departure and load sequence are regarding combination carriers such as Lufthansa Cargo or Emirates Sky cargo. When shipping with express carriers like UPS or FedEx the shipments are often smaller and require less handling and not conflict with other shipments (Brandt, F. & Nickel, S. 2019, p. 399).

Express carriers also provide collection of the shipper's goods and use their fleet of road vehicles and aircrafts to deliver the shipment at the shipper's requested delivery address, providing door-to-door services (Debbage, K. & Debbage, N. 2021, p. 364).

The deciding factor for which type of airfreight a shipper chooses for the shipment is mainly a commercial decision based on multiple factors: cost, reliability, value of the goods, convenience, required service level etc. The various factors play a crucial role in the shipments operating attributes and the cost structure.

The air freight supply chain is composed of three main parties: shipper, forwarder and carrier Debbage, K. & Debbage, N. (2021, p. 363). The shipper is the actor who needs goods shipped from one destination to another. The forwarder is responsible for the administrative documentation and arrangement of the door-to-door transport. Lastly, the carrier is responsible for transporting the shipment from one airport to another. When a forwarder has additional stops at a transshipment airport both the lead time and the delivery accuracy can be affected as in not only increased flight time, but also connecting and processing times (Ohashi, H. et al. 2005, 151-154). This increase is due to, partly, congestion, administration, loading/unloading and international regulations.

4.2.2 Freight Consolidation

Freight consolidation provides opportunities to benefit from the economies of scale without the required volumes (Venkatadri, U., Krishna, K.S. & Ülkü, M.A. 2016, pp. 1518-1521). Through sharing underutilized aspects in the transportation chain, the transport can be utilized to a higher degree. It is frequently the volume of containers that's underutilized. In those cases several actors can share a container and therefore lower the individual actors' cost of shipping, while still getting the desired benefits of large-scale shipping. There are different ways this sharing is organized, oftentimes utilizing a third party and consolidation centre.

4.2.3 Supply Chain Strategy and Alignment

Managing the supply chain is a complex task due to many reasons such as globalization, increased product assortment and short product lifespan (Lee, H. L. 2002, p 1). But when managed in the right way it can lead to a competitive edge for companies. According to the literature, for a company to be successful in supply chain management (SCM), their supply chain (SC) strategy needs to incorporate a number of factors. The strategy needs to be designed to address the distinct needs of the customer, stable and uncertain products require separate management and there is no one-size-fits-all type of SC strategy. Lee (2004) introduced the practice of Triple A SCM, arguing that the most effective SC consists of three core components: agility, adaptability and alignment (Lee, H.L 2004, pp 102-113). Agility reflects a SC's ability to respond rapidly to short-term fluctuations in demand or supply; adaptability denotes the ability to restructure the SC when market conditions change; and alignment refers to the process of creating shared goals and incentives across all SC collaborators to enhance the effectiveness of the entire SC and improve profits. Multiple studies have drawn attention to a fundamental sustainability issue with efficient supply chains, finding that solely being efficient is not sufficient enough for a lasting competitive advantage (Jia, F. et al. 2025, p 2728). Research confirms the study by Lee (2004), that only by concurrently incorporating agility, adaptability and alignment can companies achieve SC sustainability and enhance both social, environmental and economic performance, thus validating the Triple A framework. However, businesses today face increasing pressure beyond just being profitable (Sodhi, M.S. & Tang, C.S. 2021). Companies face increased expectations of performing in the environmental and social sustainability spectrum. This pressure comes from multiple stakeholders, some which despite not being directly part of the supply chain, still put pressure on the companies to act in their interest of the planet and people. This results in companies having to expand their triple A SCM to people, planet and profit and involving stakeholders who are external to their supply chain in their decision making. By doing this, companies evolve from a traditional isolated view of profit seeking, to a broader view, often referred to as the ecosystem view in their decision making of SCM.

Strategy can be aligned through three different dimensions: vertical alignment (VA), horizontal alignment (HA) or cross-functional coordination and supplier oriented alignment dimensions (Hochrein, S., Muther, M., & Glock, C.H. 2017). Hochrein et al. (2017) further notes that the successful outcome of a company's purchasing and supply management (PSM) strategy is strongly correlated to how well strategic decisions at the PSM level have been aligned with the corporate strategies. Hochrein et al. (2017) propose that a high degree of simultaneous alignment across all three dimensions (vertical, horizontal and supplier related) in terms of goals and strategies leads to significantly better performance outcomes compared to aligning one dimension in isolation.

5. Result

The results and findings identified are presented below. The first part is focused on the defining and construction of the model, while the second part focuses on validating and testing the model.

5.1 Model Construction

In the early stages of the model creation the MCDM-framework needed to be decided upon. After the initial meeting #1, as described in table 2, it was decided to use PROMETHEE II as the primary framework, with the weights calculated using the AHP pairwise comparison. PROMETHEE II was selected over other frameworks largely for its inclusion of preference functions and full ranking. The preference functions were expected to account for thresholds in prioritizations while the full ranking would provide a more comprehensive overview of the ranking that single ranking would. AHP was selected primarily because of its structured pairwise comparisons of criteria, which would be beneficial given the stakeholder involvement as comparing two criteria at a time avoids unnecessary complexity.

Figure 4 displays an overview of the data collection and processes that went into providing the final rank of transport alternatives in the PROMETHEE II method. Each step of the process is presented in detail further in this chapter.

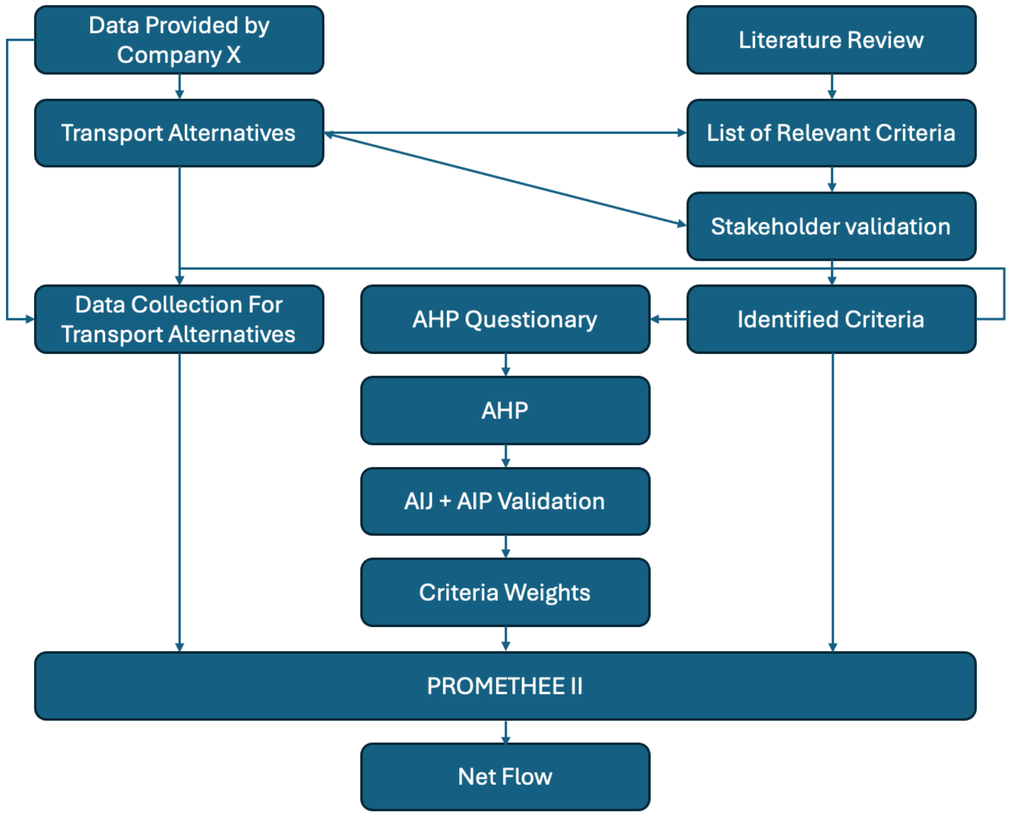

Figure 4: Case specific AHP-PROMETHEE II workflow

5.1.1 Transport Alternatives For Replenishment Orders

The investigated shipping route of replenishment orders between Venlo, NL. to Lancaster, Pennsylvania, U.S. resulted in sea freight and air freight being the only two valid transport modes for comparison. The provided data revealed that both transport modes are used today by the company as a whole when examining all shipments worldwide. But air freight is the only transport alternative used today by Company X for their replenishment orders between Venlo, NL, to Lancaster, Pennsylvania, U.S.

The data further revealed four different service levels of air freight are currently being used: *Parcel, Pallet Express, Pallet Standard and Pallet Consolidated*. From interview #2, described in table 2, it was revealed that Company X is currently only shipping with Parcel, while other entities within the company group are using various Pallet solutions. As the provided data allowed for a comparison between the four different air freight shipments, it was during meeting #3 decided to include all four types in the model.

While the naming of these transport alternatives indicates *unit loads* and not the actual transportation alternatives, these are what the different services are called within Company X due to the LSP using the same naming of their services. From Company X's perspective the actual handling of unit loads is irrelevant, and only the criteria listed in 5.1.2 are considered when selecting a transport alternative. Even though each transport alternative consists of intermodal transport (such as Road-Air-Road or Road-Sea-Road), from the view of Company X, who only desires D2D solutions, the details of how the LSPs structure the transport is inconsequential. Stakeholders 3 and 5 described in meeting #5 how they want complete D2D services for simplicity, and thus always buy D2P and P2D services from the same provider of the P2P provider to minimize administrative effort. For this reason the "main" transport service level of the P2P is used to reference the alternatives.

Hence, the five transport alternatives (and their short form reference) for comparison emerged as:

- *Air Freight Parcel Express (Parcel)*
- *Air Freight Pallet Express (Pallet Express)*
- *Air Freight Pallet Standard (Pallet Standard)*
- *Air Freight Pallet Consolidated (Pallet Consolidated)*
- *Sea Freight Container Consolidated (Sea Freight)*

Air Freight Parcel Express: The currently used transport solution for Company X. Parcel Express is a D2D air freight service and is currently the shipping choice mainly because of its high speed and reliability. Shipments are placed into individual parcels at the origin warehouse. From there, the LSP collects the parcels and through its streamlined process manages a direct delivery to the final destination warehouse. According to the stakeholders 1 to 4, this transport alternative is also very easy to operate in. The short lead times allows Company X to send shipments more frequently, about 3 times a week, with less goods tied up on each shipment. Company X further mentioned during discussions that the high speed also allows for flexibility. If there are sudden shifts in demand or sales, Company X can act quickly by sending additional shipment – knowing the goods will be delivered in a short time period. The discussions also brought up the security of being able to send smaller but more frequent shipments rather than larger but less frequently. An unintended impact of the regularly scheduled order pickups is that any parcels collected is only as that moment put in an order, and as such it's impossible for an order to miss its own pickup. When examining secondary data a significant discount was found for Parcel. When validated during meeting #2 stakeholder 3 explained this discount was due to an agreement to exclusively use the current LSP. Upon questioning if this discount would remain stakeholder 3 reiterated it's contractual nature, so for the foreseeable future any risk of not receiving the discount is unlikely.

Stakeholder 5 mentioned an opposing view in meeting #5 and #6. Other product categories shipped from the Venlo didn't use Parcel, and from previous testing of Parcel the conclusion was that other alternatives were easier to operate.

Air Freight Pallet: According to the stakeholders of Company X, shipping with air freight with the products placed on pallets is the main transport alternative for other entities in the company group. As discovered in the secondary data section, shipments are divided into three legs, the pre carriage (D2P), main carriage (P2P) and post carriage (P2D). When shipping with a pallet, the products are firstly packed into parcels at the origin warehouse, and then placed on pallets before being picked up for transportation to the airport. The pallet(s) are dropped off at the airport and await for its transportation. When the pallet arrives at the destination airport, the goods are picked up again and delivered at the final destination warehouse. Although this service is divided in three legs, the shipment is treated as a single integrated service since Company X always uses the available additional D2P and P2D services. However the agreed lead time for a shipment is only to the destination port, and any P2D is not included in the agreed delivery date. The shipper is only responsible for paying for the service and providing required information about the shipment. There are three types of service levels of Pallet Air Freight: *Express, Standard,* and *Consolidated*. Supplier performance data was requested and received which made it possible to investigate the differences between the service levels.

Air Freight Pallet Express: The supplier performance data revealed that this service level is not used very frequently. Stakeholder 5 at Venlo was asked in meeting #5 about the use case of this service level. The answer revealed that this transport alternative is currently only used by a different department when dangerous goods are shipped, as they are not allowed to share ULD with different goods. According to the transport manager at Venlo, this handling can be time consuming as the dangerous goods need to be handled separately with special services and also implies more administrative handling of documents. Naturally, due to the characteristics of the shipped products, this transport alternative is not frequently needed.

When shipping with Pallet Express, the pallet(s) are placed in their own air freight container. The shipment is then transported directly to the final destination airport, followed by post carriage transportation to the final destination warehouse. This service level has the lowest promised lead time of the pallet air freight alternatives and the only pallet transport alternative with no stopover. This transport alternative is however the most expensive of the three pallet alternatives.

Air Freight Pallet Standard: Based on the supplier performance data it was observed that this service level is the second most frequently used pallet transport alternative. When shipping with Pallet Standard, the pallet(s) is picked up by the LSP and transported to the airport. At the airport the pallet(s) is placed in an air freight container along with other goods. The shipment is then transported to a layover, where other shipments may be dropped off and loaded onto the aircraft. The shipment then continues to the final destination airport where the post carriage transport picks up the parcel(s) and delivers to the final destination warehouse. Since they can be placed along other shipments, the promised lead time is longer than for *Pallet Express.*

Air Freight Pallet Consolidated: From the supplier performance data it was observed that this is the most frequently used service level when shipping with pallets. The logistical flow of the shipments of this transport alternative is similar to the one of Pallet Standard. The biggest difference between the two is that the LSP tries to consolidate as many shipments as possible for this alternative. Hence, this transport alternative has the longest promised lead time among the pallet alternatives. But it is also the cheapest one of the pallet air freight alternatives.

Sea Freight Container Consolidated: The supplier performance data showed that Sea Freight is not used as frequently as Air Freight, but it is used on a monthly basis for longer shipments. There was no data of Sea Freight for replenishment orders between Venlo, NL. to Lancaster, Pennsylvania, U.S. but the data resulted in further insights of the shipping alternatives characteristics. The data available is for Full Container Load (FCL), and no information is available inhouse for LCL.

5.1.2 Criteria Selection

The criteria in the PROMETHEE framework is reflecting Company X's main priorities regarding the transport alternatives performance when shipping replenishment orders. A combination of theoretical findings and semistructured interviews was used to identify the priorities. Firstly, theoretical articles with MCDM frameworks related to logistics and supply chain were thoroughly examined to fully understand the concept of *criteria* and how it was related to the decisions to be made. This resulted in insights of what type of criteria that could be relevant for this MCDM problem. These findings resulted in a list of examples of criteria that was presented for the stakeholders of Company X during a semistructured interview. The criteria was validated by the stakeholders of Company X through an open discussion. Five main priorities emerged, and the relevant criteria was identified. The retained criteria were:

- *Transport cost*
- *Lead time (days)*
- *Delivery reliability*
- *Operational feasibility*
- *Environmental impact*

Transport cost is referring to the cost of shipping the goods. From the discussion it was revealed that having a low transport cost is important, but any numbers of what “low” is were not mentioned. It was not clear at the moment how much was paid for one shipment, but there was significant interest to provide data of historical payment to allow for calculating the transport cost of the current transport provider.

Lead time is regarding the D2D lead time measured in days. Meeting #1 brought up that having a short lead time was important for several reasons. The shorter lead time provided Company X with flexibility, low uncertainty, agility and safety. It was revealed that the short lead time meant that shipments could be sent short upon when there was a need. This resulted in the amount of goods shipped being the amount of goods needed. An example of a hypothetical scenario with a longer lead time was brought up and explained how a longer lead time would increase the uncertainty, since demand may change during transit time. If demand changed during the transit time of a short lead time, Company X could be agile and quickly send more goods and the customers would not be affected as much compared to longer lead times.

Delivery reliability refers to a transport alternative's ability to consistently deliver the correct shipment within the agreed lead time. It was evident from the discussion that on-time delivery is a non-negotiable criteria and strategically important for Company X.

Operational feasibility is regarding the total work load that is required for a transport alternative to operate functionally. This includes both the planning effort from the material and production perspective, the handling of the administrative and order picking tasks in the warehouse and lastly the order receiving of the shipped goods.

Environmental impact is regarding the carbon emissions that come as a result of a transport alternative. Meeting #1 showed that there is an interest among the stakeholders to include environmental impact in the comparison of the transport alternatives.

5.1.2.1 Freight Cost

The cost per order formula was designed to be flexible enough to accommodate all cost structures for the investigated alternatives. Since parcel shipping is D2D with no fixed cost, the pre and post carriage cost was set to zero and the cost per kilo was set as the main carriage cost. For sea freight, it’s a fixed cost for each container. Since D2P and P2D are still needed, the main carriage cost was set to zero. The cost for each container was set as a fixed cost since no order could fill the whole volume of a container due to the product's characteristics.

Formula (5) was made to calculate the cost of transport for each transport mode. The model was built to be dynamic enough to allow for new data sets to be added to allow for comparison between shipments containing products with different characteristics which may result in a different outcome of optimized transport alternatives.

The transport cost for each transport alternative is found by an iterative process of calculating order volume at different order frequencies. An optimized order frequency was found based on the resulting total costs, and will be expanded in the Optimized Order Frequency chapter.

The order volume is used to determine the chargeable weight, hence to calculate transport cost per order. Due to the characteristics of the products, the volume was used for almost every item compared to the weight. Only 6 out of 1442 items in the primary dataset used the weight instead of the chargeable weight. To make the model usable for more datasets, a dynamic check was added to select the highest of the two and use that as the basis for the cost.

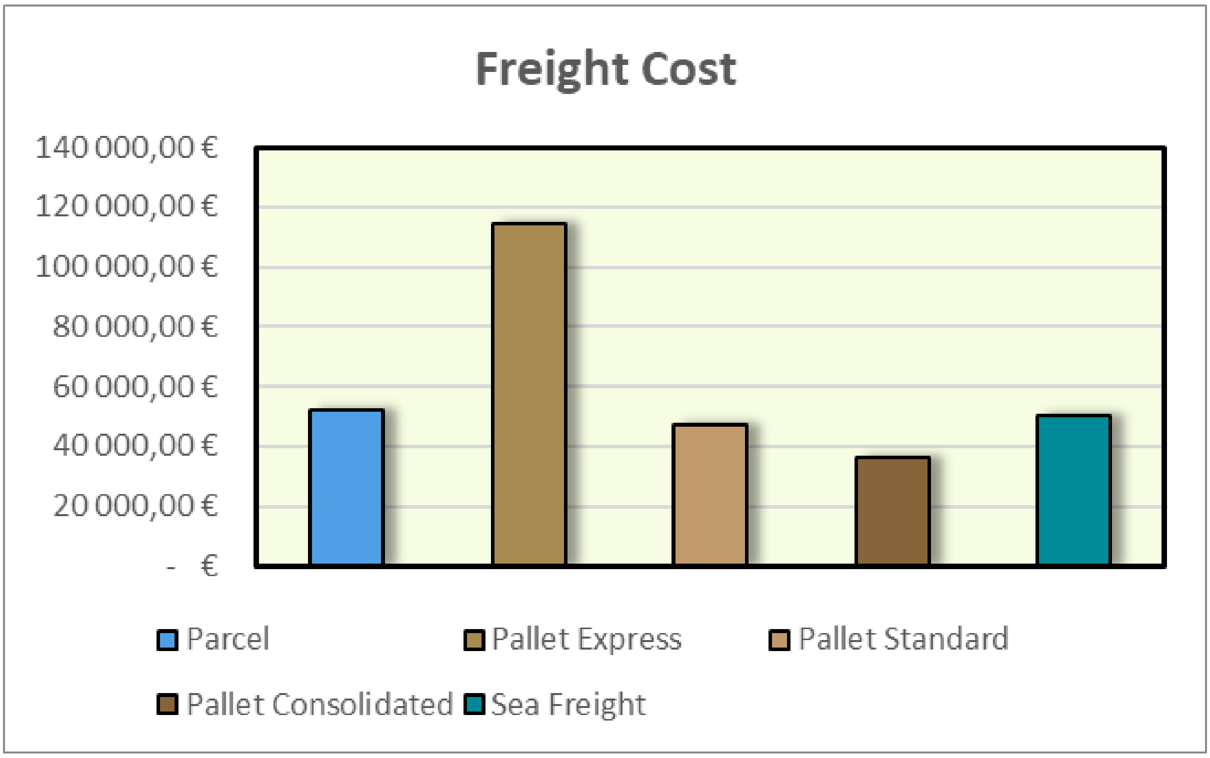

Figure 5: Primary Dataset Freight Costs

Figure 5 shows the annual freight cost of each transport alternative. The result reveals that Pallet Consolidated is the cheapest alternative with a freight cost of 36400,00€. Pallet Standard is the second cheapest option with a freight cost of 47168,73€. This is followed by Sea Freight with a freight cost of 50596,78€, Parcel with 52294,44€ and lastly Pallet Express with 114626,00€.

5.1.2.2 Lead Time

Three different meanings of Lead Time were identified. Company X often referred to lead times as the time from when a replenishment order came in to the time it was delivered. Occasionally, lead times were referred to as D2D, or P2P. To account for these distinctions, a "planning time" was defined as the time from receiving an replenishment order to the order being shipped. From discussions with stakeholders this time was set to 4 days. Most carriers and alternatives considered by Company X have provided lead times for their services, but these lead times were in most cases D2P. Company X internally assumed an extra 3 days for the P2D. Only one alternative considered was D2D. In addition to the planning time is the order frequency, described further in the Optimized Order Frequency chapter.

Depending on the calculation, different lead time definitions were used. For cost of capital only the door-to-door (D2D) lead time was relevant, since pipeline capital is tied up only while the goods are in transit, not before. Planning time and order frequency were therefore not included in those calculations. For order quantity calculations, however, they had to be considered. When a replenishment order is placed, the remaining stock must be sufficient to cover the time until the new order arrives. This means the lead time must include not only the D2D transport time, but also planning time and order frequency. The latter is important because a shipment opportunity may just be missed, requiring the order to wait until the next departure. This is particularly relevant because most transport alternatives have minimum charges or relatively high fixed shipment costs, which makes daily shipments of every product unrealistic. Batches of products are instead sent periodically. In addition, daily demand is estimated as an average based on three months of data, even though actual demand varies by product. Some products are consumed faster than average, while others are used more slowly.

The model therefore simplifies reality. It assumes that each shipment contains a small, often fractional, quantity of each item. In practice, however, most products were not shipped with every departure, but only when warehouse levels dropped below a certain point. This means actual shipments usually contained larger quantities than the minimum needed to cover demand during the lead time. For high-variation items, shipments often covered more than 30 days of demand. Lower-variation items may have been shipped in more regular quantities, but to keep the model general, this difference was not reflected directly in order quantity assumptions and was instead captured through the cost of capital. Because of this, the lead time definition had to ensure that high-variation items would cover at least the period until the next possible delivery.

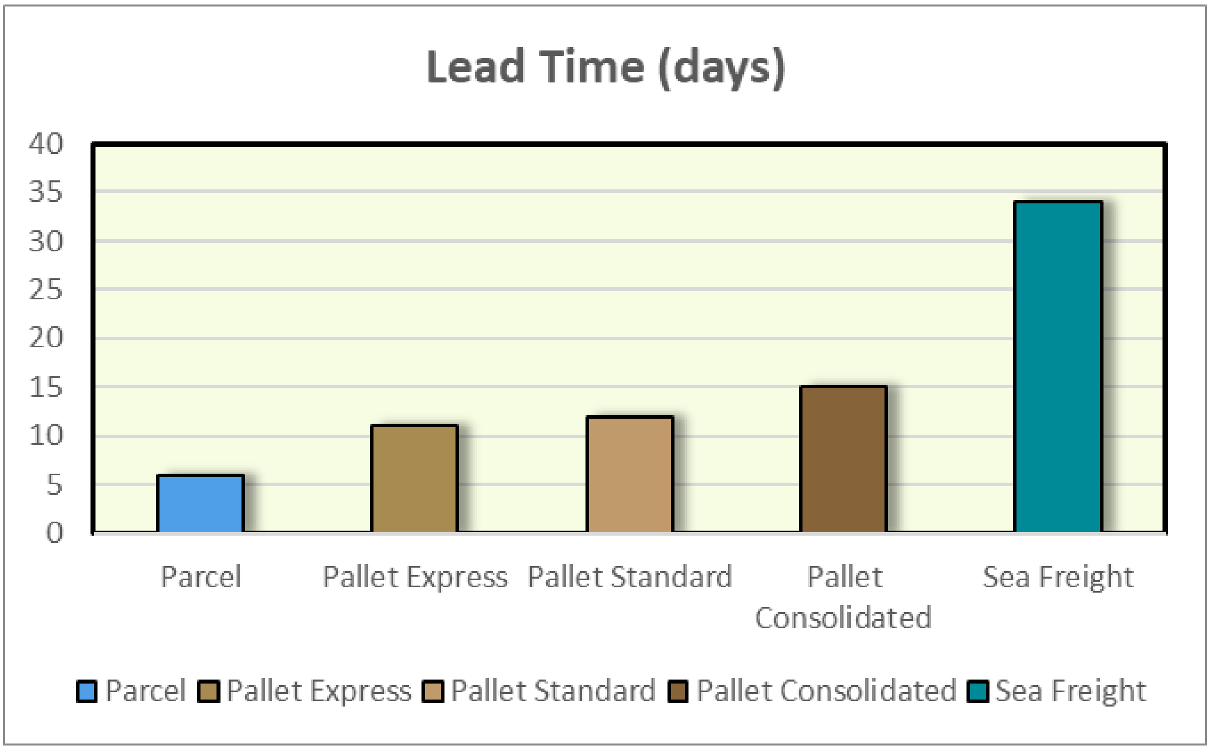

Figure 6: Primary Dataset Lead Times

The result shows that Parcel has the shortest lead time of 6 days, as illustrated in figure 6. The lead times increase with 5 days to the second fastest option – Pallet Express with 11 days of lead time. This is followed by Pallet Standard with 12 days of lead time, Pallet Consolidated with 15 days of lead time and lastly Sea Freight with 34 days of lead time.

5.1.2.3 Delivery Reliability

Delivery reliability is regarding a transport mode's ability to deliver the complete shipment within the agreed lead time. Air freight is a well established mode of transport for Company X and both shipments with parcel and pallet are frequently used for replenishing orders worldwide. Container freight is occasionally used regarding shipments of very large products, but shipments occur much less frequently than air freight. Hence, to compare the delivery reliability for the different modes of transport, supplier performance data of previous shipments for existing suppliers was requested to analyze its performance. The company provided data to analyze both air freight shipments with parcel, pallet express, pallet standard, pallet consolidated and data regarding container freight.

Air freight regarding parcel shipments are express deliveries that provide D2D shipments. Data was received for the shipments with parcels for the investigated route. To get a measurable delivery reliability index the amount of on-time deliveries were divided with the total amount of deliveries.

Air freight regarding pallet shipment comes in the three different service levels; pallet express, pallet standard and pallet consolidated. The different service levels offer different lead times, measured from the point of pickup + P2P and the agreed lead time varies depending on the destination of the shipment. To get the most accurate data measurement of each service level the data was filtered to only display the deliveries of shipment regarding the investigated route. Pallet express offers the fastest lead time and pallet consolidated offers the longest lead time. The data was then filtered to display one service level at a time. The agreed lead time was then compared to the actual lead time and the total of on-time deliveries was divided with the total of shipments to get a delivery reliability index in percent for each service level.

Shipments regarding container freight were lacking in data for the investigated route. Data existed for other routes but the terms differed compared to air freight. The shipments did not have an agreed lead time or delivery date, rather an estimated date of delivery. Hence, it was not possible to measure delivery performance of container freight equivalently to air freight. To overcome this, an assumption was made that an accurate delivery index of container freight is 50%. The assumption is based on theoretical findings that displays several reasons for affecting the shipments being delayed or port congestion that may affect the delivery, resulting in a potential longer lead time than firstly estimated.

When examining the data a discrepancy was found where a shipment could be marked as on-time when the actual delivery date is later than the agreed delivery date. Stakeholder 5 clarified in meeting #6 that when the delay is not caused by the LSP, it’s contractually agreed to mark it as on-time. Reasons for these delays tend to be when correct documentation has not been provided to the LSP in time (such as customs forms or goods declaration), or when an order is not ready for pickup when it should have been. As these delays are outside what the LSP can handle an agreement has been made to not account these delays to the LSP, as it would lower their KPIs. However, to evaluate transport alternatives the reason behind a delay is not as important as the fact it’s delayed. As such the Delivery Reliability instead compares the actual on-time deliveries, regardless of if it's marked as on-time or not.

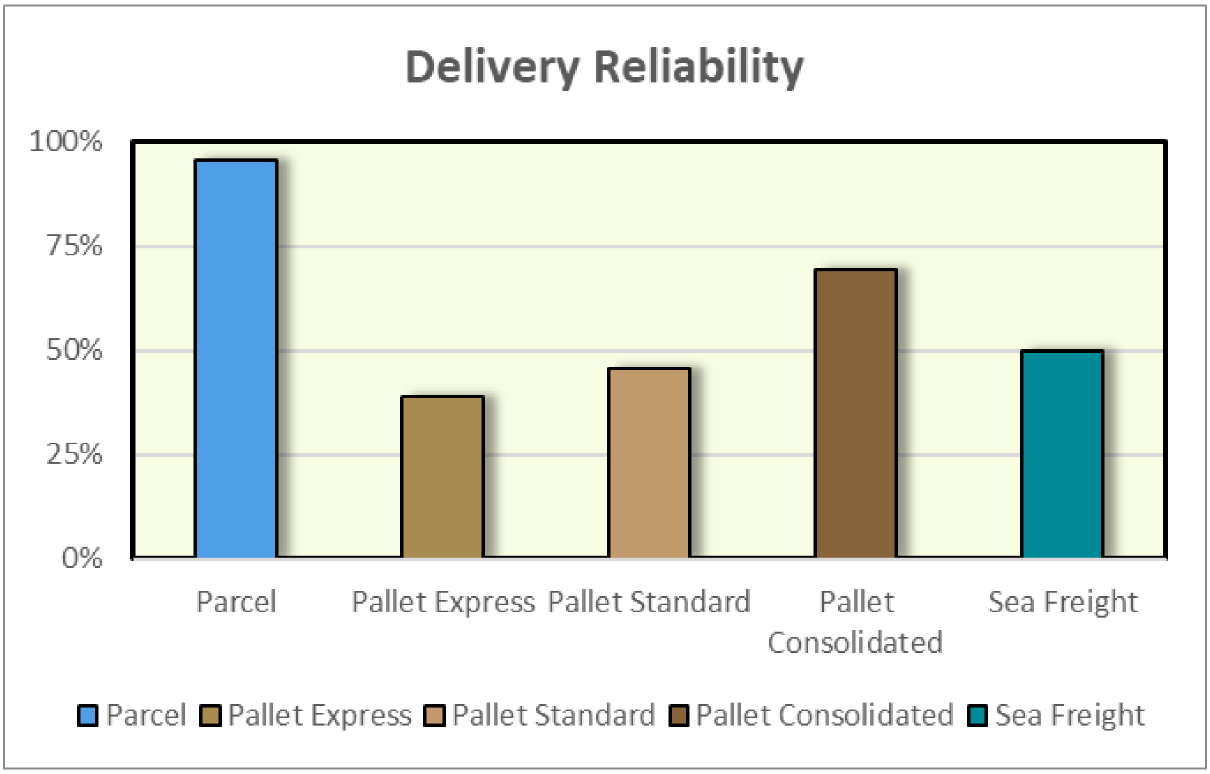

Figure 7: Primary Dataset Delivery Reliabilities

Figure 7 shows parcel shipment being the most reliable alternative with 95,7% delivery reliability. Pallet Consolidated is the second best performing option with a delivery reliability of 69,5%. Sea Freight is the third best alternative with 50% delivery reliability, followed by Pallet Standard (45,9%) and Pallet Express (39%).

5.1.2.4 Operational Feasibility

Meeting #3 revealed that operational feasibility is regarding the amount of effort needed in daily operations to prepare the shipments of each transport alternative.

From Company X's perspective during meeting #3, it was revealed that different transport alternatives could increase uncertainty related to changes in demand and sales during lead times. According to Company X during meeting #3, a hypothetical scenario of a shipment with a transport alternative with longer lead time could imply a need to send additional shipments with express delivery to complement the existing shipment for products with high variability in demand and sales. This could lead to a higher workload as the shift would need to be detected and then initiating an extra shipment – assuming additional stock of finished products are available for an additional shipment. Meeting #3 further revealed that having a transport solution that allows for shipping less volume but at a higher order frequency reduces the potential risk and damage as a result of products missing a shipment.

During meeting #6, a different perspective was shared when stakeholder 5 was asked if the different transport alternatives implied different amounts of workload. The answer revealed different amounts of work needed for the different transport alternatives. Parcel requires about 1 day for packaging and administrative handling while pallets need two days to handle some extra administrative tasks. Container freight requires 3 days of waiting time for delivery of a container before it can be loaded with pallets and shipped. Loading the container and awaiting pickup is assumed to add an additional 1 day to the workflow depending on the time of arrival of the container and the scheduled pickup. The results of the collected data that was measurable are concluded in table 3.

Parcel	Pallet Express	Pallet Standard	Pallet Consolidated	Sea Freight
1	2	2	2	4

Table 3: Operational Feasibility as additional days

Furthermore, efforts were put into finding ideas of how to measure the effect on the workload of different transport alternatives in the materials and production planning perspective to have usable data for this criteria in the PROMETHEE II framework. Due to time restrictions it was not possible to map the workflow of all transport alternatives. Upon discussing the lack of data for this criteria with the stakeholders of Company X it was agreed to discard this criteria from the model due to lack of measurable data.

However, the criteria is still considered a strong prioritization for Company X. Hence, the findings are still considered relevant to present and discuss further in the analysis of this report.

5.1.2.5 Environmental impact

Environmental impact is assessed based on annual carbon emissions, expressed in kg CO2-eq/year, for each transport mode. The routes for air freight were provided through the supplier performance data and the route for container freight is assumed to travel from P2P with no stops in between. The routes were input to the EcoTransIT World software to estimate carbon emissions. The carbon emission for 1 shipment was then multiplied with the annual amount of shipments for each transport alternative to account for transport frequency.

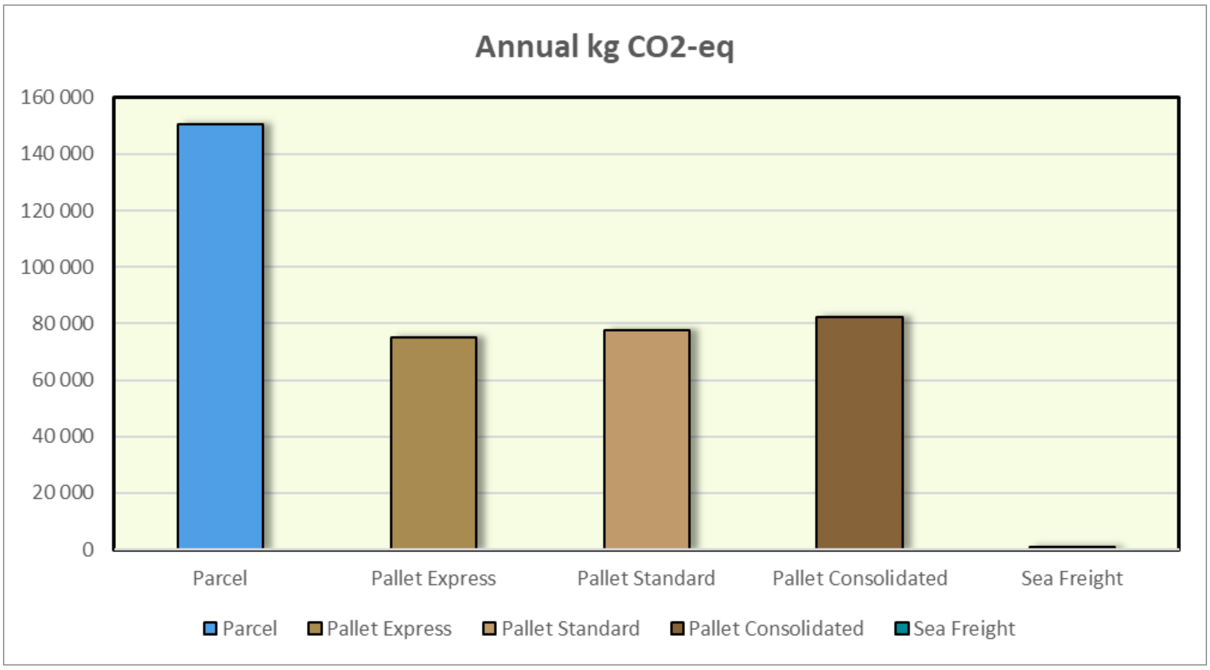

Figure 8: Primary Dataset Environmental Emissions

Figure 8 reveals Sea Freight performing remarkably better compared to the air freight alternatives with annual carbon emission of 900,46 kg CO2-eq, displayed in figure 8. Parcel is the worst performing alternative with 150423,30 kg CO2-eq. The Pallet transport alternatives are emitting almost the same amount of kg CO2-eq per year. Pallet Express is the second best performing alternative with 75286,59 kg CO2-eq, followed by Pallet Standard (77711,94 kg CO2-eq) and then Pallet Consolidated (82317,09kg CO2-eq).

5.1.3 Weights

To account for the fact that all criteria weren't considered equally important, they were each assigned a weight. The weights were calculated based on key stakeholders answers of a query sent to them. Designing the query and calculating the weights from it were done using the AHP framework. For the query this meant it contained a total of 10 pairwise comparisons, since the ones unasked would be the inversion of another comparison. The number of comparisons needed follows the formula Q=(x^2-x)/2, and as such limiting the amount of criteria was important to ensure a manageable amount of comparisons. The query took the form of two question sets, the first being what's more important of two criterias, and the second how much more important.

Once the query was answered individual answers were combined using AIJ. Since the stakeholders answering the query were all from the same department it was decided that AIJ was more appropriate than AIP. The results were put in a matrix with the corresponding inverted values calculated. Each column was then normalized, and then each normalized row were summed for the total weight. The weights were then used as a vector to calculate the dot product from the pre-normalized matrix. The dot product was then divided with the calculated weight in order to get a consistency vector. The highest value in the consistency vector is called the Lambda max, and from it the consistency index was calculated. After dividing with the Random Index for N(4)=0,9 a Consistency Ratio is provided. A CR below 0.1 is indicative of a good, stable result with negligible inconsistency in answers. The calculated CR was at about 0.04, making the results very usable.

To investigate if there were any outliers another AHP was done with the same data, but AIP was used instead of AIJ. This meant calculating a complete AHP for each individual, and only after the final weights were done were they arithmetically averaged. This meant individual CRs were calculated, and could be discussed with the stakeholders. The individual CR were in most cases higher than the aggregated one, often above 0.1 but safely below 0.2, a limit where the data can't be seriously considered usable anymore. Since AIP takes individual preferences and outliers more into account, a deviation from the results of the AIJ was expected. However, the results were very similar. Upon further investigation this was largely due to 2 individuals with more outlying answers almost perfectly mirroring each other, and the remaining 2 individuals answering near the average of the 2 outliers. With the two major aggregation methods both tested, the weights provided by the AIJ were more usable. Since stakeholders 1 to 4 are working in the same department they act as a single entity, and any outlying opinion was balanced by someone else.

When the Operational Feasibility-criteria was discarded the AHP was updated. Due to time constraints a new query was not feasible, so instead the criteria was simply removed from the AHP calculations. Due to AHPs transitive properties this is possible; the weights might change but the order of them won't.

The figure below shows the result of the AHP and weight of each criteria.

Freight Cost	**Lead Time (Days)**	**Delivery Reliability**	**Environmental Impact (kg CO2-eq/tonne)**
0,206	0,281	0,408	0,105

Table 4: Primary Dataset's AHP-weights

The result from the AHP demonstrates that Delivery Reliability is weighted highest among the criteria with a weight of 0,408. The second highest weighted criteria is Lead Time with a weight of 0,281. This is followed by Freight Cost with a weight of 0,206 and Environmental Impact with a weight of 0,105.

During meeting #6 stakeholder 5 presented the opinion that for different product categories, the Freight Cost was most important. Attempts were made to have stakeholder 5 complete a query to get accurate weights for other product categories, but these attempts were unsuccessful. An assumption was made with agreement from stakeholder 3 to rank the importance as, from most to least important; Freight Cost, Delivery Reliability, Lead Times, Environmental Impact. The weights for the primary dataset were then repurposed and ordered as described to use when investigating the secondary dataset, as shown below. These will be referred to as the secondary weights.

Freight Cost	Lead Time (Days)	Delivery Reliability	Environmental Impact (kg CO2-eq/tonne)
0,408	0,206	0,281	0,105

Table 5: Secondary Dataset's Rearranged Weights

5.1.4 PROMETHEE II

With the described criterias defined and gathered for the alternatives, the PROMETHEE model began. For each criteria, the minimum and maximum values of the alternatives were gathered. The alternatives were then normalized. If the criteria was a benefit and should have been maximized, it was normalized with the highest value as 1 and the lowest as 0. If it was a cost and therefore should have been minimized, it was then inverted so the lowest value was 1 and the highest 0.

Each alternative within a criteria was then compared to each other by subtraction. At this stage the preference functions should have been applied, however since the data had been normalized and it was decided to use a V-shaped (linear) preference function, no calculations were needed apart from setting any negative values to 0. The decision to only use V-shape preference functions was decided by consensus in meeting #4. The primary reason for this was from an understanding that if an alternative performed better than another in a metric, that difference mattered no matter how small it might have seemed.

By multiplying in the calculated weight for the respective criterias in alternatives, they were ready to be used for calculating the Entering- and Leaving Flow. To do this all weighted criteria values were summed for each comparison, and added to a matrix. Each row was the one others are compared against, and each column was the one compared. The first row, second column could therefore be described as "how much better was Parcel than Pallet Express?". Once the matrix was completed, each row was summed into a Leaving Flow. Each column was also summed into an Entering Flow, essentially communicating how much better other alternatives were than the compared alternative.

With both Entering- and Leaving Flow calculated, a Net Flow could be computed by subtracting the Entering Flow from the Leaving Flow. The Net Flow is the final score of the PROMETHEE model, and since PROMETHEE II was used all net flows are present and can be used for a full ranking, simply by ranking the scores from highest to lowest.

The table below shows the result of the final score of the PROMETHEE II model.

Alternative	Leaving Flow	Entering Flow	Net Flow	Rank
Parcel	0,4399	0,0794	0,3605	1
Pallet Express	0,0366	0,3937	-0,3571	5
Pallet Standard	0,1083	0,1783	-0,0700	3
Pallet Consolidated	0,2380	0,1036	0,1345	2
Sea Freight	0,1838	0,3594	-0,1756	4

Table 6: Primary Data PROMETHEE II flows and ranking

The result from the PROMETHEE II model shown in table 6, reveals how the different transport alternatives perform relative to each other based on their Net Flow values. The highest ranking transport alternative is Parcel, gaining a clearly positive Net Flow of 0,3605. The second highest ranked alternative is Pallet Consolidated with a positive Net Flow of 0,1345. This is followed by Pallet Standard with a negative Net Flow of -0,0700, Sea Freight with a negative Net Flow of -0,17564 and lastly Sea Freight with a negative Net Flow of -0,3571.

5.2 Model Validation

To evaluate the model, artificial scenarios and synthetic data were used to imagine different settings, scenarios and limitations of the model. Real data was primarily added from a master data file, providing most of the data needed for the scenarios. Synthetic data was made in collaboration with stakeholders to ensure a degree of realism where no data was available or reliable. The final model was validated through a series of complimentary and independent approaches. The robustness of the model was assessed through sensitivity testing where rank reversal was investigated, followed by inducing rank reversal. Moreover, the strength of the highest ranked transport alternative was evaluated by a set of unfavorable conditions, order frequency was evaluated, comparisons of the result produced from dataset 1 and 2, and a SWOT analysis to evaluate the model itself.

5.2.1 Total Cost

Historically, the total cost of transport amounted to the cost of the transport without consideration to the inventory carrying cost. Since the inventory carrying cost provides a holistic view of the inventory cost for the company it was decided to include this cost in the total cost. The total cost of each transport mode consists of two segments: total inventory carrying cost and cost of transport.The total inventory carrying cost is in turn composed of the pipeline carrying costs and the cycle stock carrying cost.

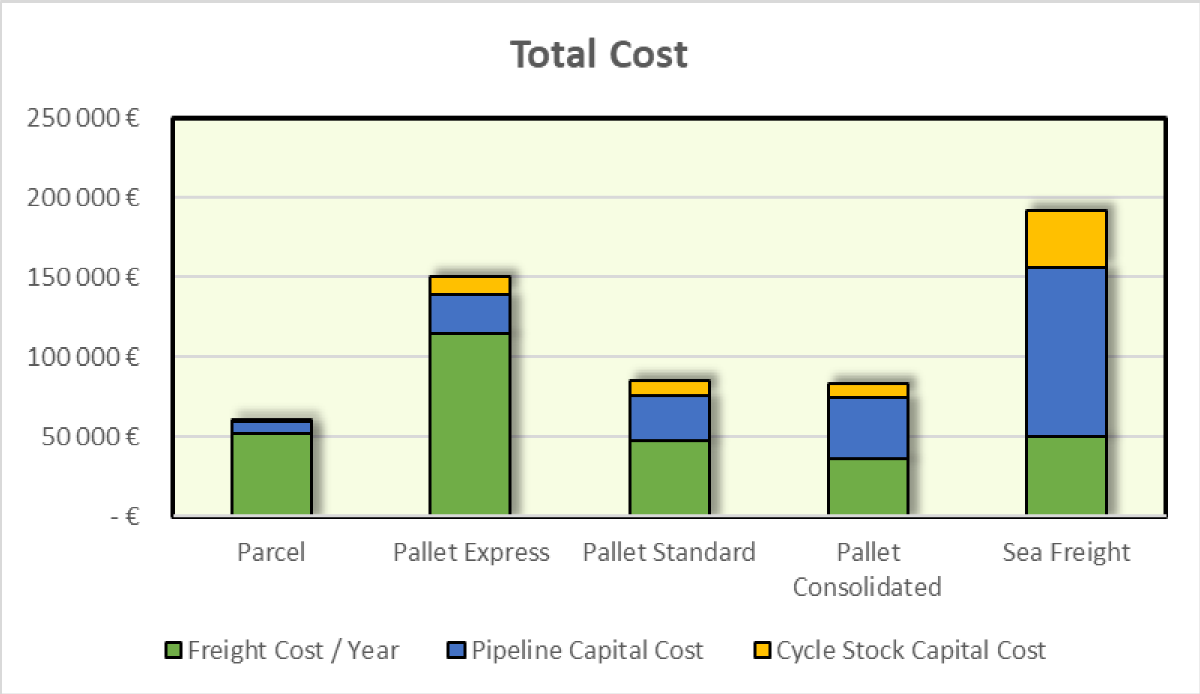

Figure 9: Primary Dataset Total Costs

Figure 9 displays annual Freight Cost, Pipeline Capital Cost and Cycle Stock Capital Cost by assigning each cost a color to show the differences among them. The costs are then added together to show the Total Cost of the alternatives.

Parcel had the lowest Total Cost of 60664,08€, with a Freight Cost of 52294,44€ , Pipeline Capital Cost of 7048,12€ and a Cycle Stock Capital Cost of 1321,52€. The low Pipeline Capital Cost was a direct result of a lower transit time of 2 days, hence binding up capital for a shorter period. Additionally, the Cycle Stock Capital Cost was very low partly due to the high optimized order frequency. Calculating based on averages meant the Cycle Stock also benefited from theoretical small frequent orders, while in reality individual items are sent more infrequently in larger quantities.

Sea Freight had the highest Total Cost of 191559,17€, composed of a Freight Cost of 50596,78€, a Pipeline Capital Cost of 105721,79€ and a Cycle Stock Capital Cost of 35240,60€.

Alternative	Freight Cost / Year	Pipeline Capital Cost	Cycle Stock Capital Cost	Total Cost
Parcel	52 294,44 €	7 048,12 €	1 321,52 €	60 664,08 €
Pallet Express	114 626,00 €	24 668,42 €	11 453,19 €	150 747,61 €
Pallet Standard	47 168,73 €	28 192,48 €	9 691,16 €	85 052,37 €
Pallet Consolidated	36 400,00 €	38 764,66 €	7 929,13 €	83 093,79 €
Sea Freight	50 596,78 €	105 721,79 €	35 240,60 €	191 559,17 €

Table 7: Detailed overview of primary dataset Total Cost

5.2.2 Optimized Order Frequency

By considering the Total Cost as a function of the order frequency an optimized order frequency was found for each transport alternative, as described by formula (12).The found Optimized Order Frequencies are shown in table 8.

Parcel	Pallet Express	Pallet Standard	Pallet Consolidated	Sea Freight
0,75	6,5	5,5	4,5	20

Table 8: Optimized Order Frequencies

5.2.3 Rank Reversal Assessment

A rank reversal investigation was conducted for dataset 1 and 2 when the PROMETHEE framework was finalized to validate trustworthiness of the result. The final framework included five alternatives A = {A1, A2, A3, A4, A5} = {Parcel, Pallet Express, Pallet Standard, Pallet Consolidated, Sea Freight}. Primary weights were used for dataset 1 and secondary weights, dispalyd in table 5, were used for dataset 2. The operations was carried out in the following order:

- Run PROMETHEE II framework with alternatives A = {A1, A2, A3, A4, A5}.
- Remove alternative A1 → run PROMETHEE II → compare ranking of {A2, A3, A4, A5}.
- Restore A1, remove A2 → run PROMETHEE II → compare ranking of {A1, A3, A4, A5}.
- Restore A2, remove A3 → run PROMETHEE II → compare ranking of {A1, A2, A4, A5}.

- Restore A3, remove A4 → run PROMETHEE II → compare ranking of {A1, A2, A3, A5}.
- Restore A4, remove A5 → run PROMETHEE II → compare ranking of {A1, A2, A3, A4}.

Detailed results of each operation on dataset 1 can be found in Appendix A. The result shows that no rank reversal is occurring in any of the operations when dataset 1 was tested. The transport alternatives are maintaining their relative order despite an alternative being removed throughout all operations. Parcel is consistently the highest performing alternative with its strongest net flow in operation 5 (0,4614). Pallet consolidated is consistently the second best option, except when parcel is removed and becomes the best option with a Net Flow of 0,4108.

Status quo: Unchanged Dataset 2 A = {A1, A2, A3, A4, A5}.

Alternative	Leaving Flow	Entering Flow	Net Flow	Rank
Parcel	0,3751	0,0972	0,2779	1
Pallet Express	0,0314	0,5174	-0,4860	5
Pallet Standard	0,1700	0,1369	0,0331	3
Pallet Consolidated	0,2801	0,0851	0,1950	2
Sea Freight	0,2589	0,2629	-0,0040	4

Table 9: Status quo of rank reversal assessment dataset 2 with secondary weights

Result operation 1 A = {A2, A3, A4, A5}.

Alternative	Leaving Flow	Entering Flow	Net Flow	Rank
Pallet Express	0,0323	0,5546	-0,5223	4
Pallet Standard	0,2326	0,1354	0,0973	3
Pallet Consolidated	0,4757	0,0657	0,4100	1
Sea Freight	0,3929	0,2682	0,1247	2

Table 10: First operation rank reversal assessment dataset 2 with secondary weights

As seen in table 9, Sea Freight is ranked number 4 before removing an alternative. After the first iteration when Parcel is removed, Sea Freight becomes the second best option as seen in table 10. Hence the relative order of ranking has changed and rank reversal has occurred.

A third iteration of rank reversal assessment was conducted where primary weights were used with dataset 2. The result showed no occurrence of rank reversal. The full result of operations is shown in APPENDIX B.

5.2.4 Less Competitive Parcel Scenarios

Three Less Competitive Parcel (LCP) scenarios were assessed to evaluate the competitiveness of the Parcel alternative and the impact on the ranking and Net Flow during unfavourable conditions. The first scenario simulated a significant increase in freight cost for

Parcel. The second scenario simulated a LCP situation where Parcel performed 8-12% worse than status quo to simulate reduced transport performance, while keeping the freight cost unchanged. The third scenario combines the changes from scenario 1 and 2.

Alternative	**Leaving Flow**	**Entering Flow**	**Net Flow**	**Rank**
Parcel	0,3852	0,2595	0,1256	1
Pallet Express	0,0942	0,2368	-0,1426	4
Pallet Standard	0,1213	0,1724	-0,0511	3
Pallet Consolidated	0,2272	0,1036	0,1236	2
Sea Freight	0,2018	0,3497	-0,1478	5

Table 11: Scenario 1 - Increased Parcel Freight Cost results

The result in table 11 shows that Parcel keeps its relative ranking position and remains the highest ranked transport alternative. Net Flow for Parcel drops with 0,2349 and becomes less competitive compared to status quo with a final Net Flow of 0,1256. The results indicate that a significant increase in Freight Cost highly impacts Parcels competitiveness in comparison to the other alternatives.

Alternative	**Leaving Flow**	**Entering Flow**	**Net Flow**	**Rank**
Parcel	0,4202	0,0847	0,3354	1
Pallet Express	0,0389	0,4092	-0,3703	5
Pallet Standard	0,1140	0,1838	-0,0698	3
Pallet Consolidated	0,2669	0,0903	0,1766	2
Sea Freight	0,1841	0,3637	-0,1796	4

Table 12: Scenario 2: 8-12% worse performance results

The result in table 12 shows that Parcel shipments remain the best transport option despite lower transport performance. Net Flow dropped with 0,0251 and received a final Net Flow of 0,3354. The result of a slightly impacted Net Flow indicates that the current performance metrics of parcel is high compared to the other alternatives.

Alternative	Leaving Flow	Entering Flow	Net Flow	Rank
Parcel	0,3654	0,2649	0,1006	2
Pallet Express	0,0965	0,2523	-0,1558	5
Pallet Standard	0,1270	0,1778	-0,0509	3
Pallet Consolidated	0,2560	0,0903	0,1658	1
Sea Freight	0,2021	0,3539	-0,1519	4

Table 13: Scenario 3: Increased Freight Cost and 8-12% worse performance

The result in table 13 shows that when the price is significantly increased and the other criteria is adjusted to perform worse, Parcel is no longer the best transport alternative. Pallet Consolidated, who previously was the second best option, increases its Net Flow with 0,0313 and receives a final Net Flow of 0,1658. Net Flow for Parcel drops significantly with 0,2599 with a final Net Flow of 0,1006.

5.2.5 Sub-optimal order frequencies

Interview #2 revealed the current order frequencies that were used. These deviate from the optimized ones the model suggests. While Parcel is shipped on average every 1,75 days, other product categories using Pallet are sent once a week, i.e. every 5th day as described in table 14. Sea freight was set to an order frequency of 5 days as well, since the historical uses of Sea Freight have been sporadic and an accurate order frequency can't be set. Meeting #6 validated this assumption.

Parcel	Pallet Express	Pallet Standard	Pallet Consolidated	Sea Freight
1,75	5	5	5	5

Table 14: Current order frequencies

Alternative	Leaving Flow	Entering Flow	Net Flow	Rank
Parcel	0,4199	0,0412	0,3786	1
Pallet Express	0,0197	0,3119	-0,2923	4
Pallet Standard	0,0688	0,1858	-0,1171	3
Pallet Consolidated	0,1911	0,1111	0,0801	2
Sea Freight	0,1673	0,5107	-0,3433	5

Table 15: PROMETHEE II results using current order frequencies

By comparing the Net Flows in table 6 and table 15, the impact of order frequencies can be found. When the currently used order frequencies are applied to the model, the Net Flow for Parcel increased with 0,0181. The Net Flow score also increased for Pallet Express with 0,0648, gaining a position in the relative order of ranking. Sea Freight decreases its Net Flow score with 0,1677 and becomes the least favorable transport alternative. The Net Flow score for Pallet Consolidated and Pallet Standard decreased but retained the same ranking.

Alternative	Freight Cost / Year	Pipeline Capital Cost	Cycle Stock Capital Cost	Total Cost	Annual kg CO2-eq
Parcel	52 132,03 €	7 048,12 €	3 083,55 €	62 263,70 €	87909,72
Pallet Express	118 492,40 €	24 668,42 €	8 810,15 €	151 970,97 €	80600,94
Pallet Standard	48 297,60 €	28 192,48 €	8 810,15 €	85 300,23 €	79784,26
Pallet Consolidated	36 279,36 €	38 764,66 €	8 810,15 €	83 854,17 €	79784,26
Sea Freights	167 615,76 €	105 721,79 €	8 810,15 €	282 147,70 €	1146,03

Table 16: Yearly costs and emissions using current order frequency

Alternative	Freight Cost / Year	Pipeline Capital Cost	Cycle Stock Capital Cost	Total Cost	Annual kg CO2-eq
Parcel	52 294,44 €	7 048,12 €	1 321,52 €	60 664,08 €	150423,30
Pallet Express	114 626,00 €	24 668,42 €	11 453,19 €	150 747,61 €	75286,59
Pallet Standard	47 168,73 €	28 192,48 €	9 691,16 €	85 052,37 €	77711,94
Pallet Consolidated	36 400,00 €	38 764,66 €	7 929,13 €	83 093,79 €	82317,09
Sea Freight	50 596,78 €	105 721,79 €	35 240,60 €	191 559,17 €	900,46

Table 17: Yearly costs and emissions using optimized order frequency

As seen in table 17, the Total Cost of transport is lower for each transport alternative compared to the Total Cost in table 16. When comparing the Freight Cost between the two tables, the Freight Cost is slightly more expensive for Parcel and Pallet Consolidated when shipping with optimized order frequencies. The biggest difference can be seen in the Freight Cost of Sea freight that increases by 116718,98€ and results in a Freight Cost of 167615,76€. The Pipeline Capital Cost remains unchanged since lead times are the same. Cycle stock changes as a result of the optimized order frequency. Table 17 further shows that the optimized order frequency impacts the annual emissions of Parcel. Shipping with the current order frequency, as shown in table 16, results in much lower annual emissions of 87909,72 CO_2-eq compared to the 150423,3 CO_2-eq annual emissions as a result of the optimized order frequency. This is due to the model's limitations as it assumes a baseline emission for each transport, where additional emissions are added based on the weight of shipments.

5.2.6 Secondary Dataset

Since the model was built to be flexible enough to use different datasets a secondary dataset was added. To accommodate for quick comparisons, additional datasets can be added to the same file and selected from the main dashboard. The user could then switch between datasets without opening a new file, also ensuring the comparisons are always using the same underlying principles.

As described in section 3.3.2, the secondary dataset was gathered from within Company X, but from a different market. This way different product types, with different characteristics, could be investigated. To select products, 3 shipments with the same transportation start- and endpoints were selected, to ensure the same cost structures could be reused. The products in the secondary dataset were a bit cheaper, larger, and had significantly higher daily demand and had been shipped with Pallet Consolidated. The data was added to the model and the results produced by the model using dataset 2 were compared to the result generated by dataset 1, using the primary weights for both datasets. The weights of the secondary data were then added to compare the results generated by the primary weights.

Alternative	Leaving Flow	Entering Flow	Net Flow	Rank
Parcel	0,4393	0,0767	0,3626	1
Pallet Express	0,0358	0,4002	-0,3643	5
Pallet Standard	0,1111	0,1796	-0,0685	3
Pallet Consolidated	0,2316	0,1105	0,1212	2
Sea Freight	0,2046	0,3543	-0,1497	4

Table 18: PROMETHEE II results of dataset 2 using primary weights

The result of table 18 shows that Parcel is the highest ranked transport alternative when the secondary dataset is applied with the primary weights. The Net Flow result for Parcel increases with 0,0021, becoming an even stronger alternative with a Net Flow of 0,3626. Pallet Consolidated is remaining as the second best transport alternative with a Net Flow of

0,1212, decreasing its Net Flow with 0,0133. The remaining transport alternatives are keeping their relative order of ranking.

Alternative	Freight Cost / Year	Pipeline Capital Cost	Cycle Stock Capital Cost	Total Cost	Annual kg CO2-eq
Parcel	60 536,49 €	2 813,57 €	703,39 €	64 053,46 €	205494,89
Pallet Express	129 028,77 €	9 847,50 €	5 451,30 €	144 327,57 €	120934,73
Pallet Standard	51 746,24 €	11 254,29 €	4 396,21 €	67 396,74 €	125602,76
Pallet Consolidated	42 088,80 €	15 474,65 €	2 813,57 €	60 377,02 €	142730,41
Sea Freight	52 437,84 €	42 203,59 €	14 067,86 €	108 709,29 €	1503,48

Table 19: Yearly costs and emissions of dataset 2

Table 19 shows the annual costs and emissions produced as a result of dataset 2. Table 19 shows that the annual emissions increased for all transport alternatives compared to the result of figure 8. Moreover, the result of annual costs of dataset 2, shown in table 19 is deviating from the annual costs produced by dataset 1, shown in table 7. Freight Cost increased for all transport alternatives when dataset 2 was used. When comparing the Freight Cost in table 19 and 7, the relative order of cheapest to most expensive remains as in the following order: Pallet Consolidated, Pallet Standard, Sea Freight, Parcel and Pallet Express. Table 19 further shows that both pipeline and cycle capital cost decreased significantly compared to table 7 for all transport alternatives. As a result, the Total Cost of each transport alternative is different compared to table 7. From the result shown in table 19 it's evident that Pallet Consolidated is the transport alternative with the lowest Total Cost. From table 7, it can be seen that Parcel was the cheapest transport alternative when dataset 1 was applied in the model, with a Total Cost of transport of 60664,08€. The Total Cost of transport for Parcel has now increased by 5,6% and results in a Total Cost of 64053,46. Pallet Consolidated has decreased its Total Cost by -27,3% and results in a Total Cost of 60377,02. Pallet Standard remains as the third most cost-effective transport alternative. Sea Freight and Pallet Express have switched places. With dataset 1 in table 7, Sea Freight was the least cost-effective transport alternative with a Total Cost of 191559,17€ and Pallet Express had a Total Cost of 150747,61. Table 19 displays that Sea Freight os now the fourth best transport alternative with a Total Cost of 108709,27€. Pallet Express is now the most expensive alternative with a Total Cost of 114327,57.

Parcel	Pallet Express	Pallet Standard	Pallet Consolidated	Sea Freight
1	7,75	6,25	4	20

Table 20: Dataset 2 optimized order frequencies

When applying the second dataset to the model the optimized order frequencies changed as seen in table 20. The order frequency increased slightly for Parcel, Pallet Express and Pallet Standard. Pallet consolidated decreased slightly in order frequency and Sea Freight remained the same.

Alternative	Leaving Flow	Entering Flow	Net Flow	Rank
Parcel	0,3751	0,0972	0,2779	1
Pallet Express	0,0314	0,5174	-0,4860	5
Pallet Standard	0,1700	0,1369	0,0331	3
Pallet Consolidated	0,2801	0,0851	0,1950	2
Sea Freight	0,2589	0,2629	-0,0040	4

Table 21: PROMETHEE II results of dataset 2 using secondary weights

The result from table 21 shows that Parcel has the highest rank when the weights from the second dataset are applied to the model. As seen in table 18 and 15, the Net Flow of Parcel decreased from 0,3605 to 0,2779 while Pallet Consolidated increased its Net Flow from 0,1345 to 0,1950.

6. Analysis

Once the quantitative data and the qualitative data has been gathered, and the model has been created and evaluated, an analysis will be done on the model and the insights it provides. The analysis will mostly be qualitative, with some quantifiable data to support it. The following tools will be used to assist in an accurate analysis and evaluation.

6.1 Lead Time: Depends on More Than Transport Distance

Describing lead times for a transport alternative is difficult when it's represented as a single number, due to the potentially lead time variations of transport alternatives (Liu, D., Zhao, S. & Liu, J. 2012, p. 181). As described in 5.1.4 Company X assumes a 4 day planning time before an order is ready to be sent, but this addition to lead time is not fixed.

Parcel and Pallet Express send without additional stops between the origin and destination airports. Pallet Standard and Consolidated have additional stops at another European airport, further increasing lead times (Ohashi, H. et al. 2005, 151-154). However, as shown in 5.1.2.2 Pallet Express still has a long lead time comparable to Pallet Standard. This is due to Company Y only using this alternative when sending dangerous goods, as described in 5.1.1. As these can't be shipped with other Pallet Alternatives they require their own ULD. This results in increased administrative work, as the dangerous goods need to be declared and cleared before the ULD can be shipped. This process can increase lead times as well as the delivery reliability (Ohashi, H. et al. 2005, 151-154).

When using sea freight the time needed to transfer the order to and from the port is not included in the lead times, and has to be estimated. In meeting #5 Stakeholder 5 estimated 3 days could be added for the P2D and D2P, but these are estimations and subject to the current availability of local haulers and as mentioned in 4.6 the ship load and unloading and port handling. is affected by congestion (Su, M., Bae, S & Park, K. 2025).

The lead times in the model are based on working days. This induces some issues with weekends and other non-working days as some transport alternatives are still shipping over the weekend. This issue especially regards Sea Freight with its longer lead times. Whenever this occurs, it only shortens the lead time and thus has no negative impact, other than perhaps keeping a slightly higher stock level than needed (Venkatadri, U., Krishna, K.S. & Ülkü, M.A. 2016, p. 1518). As such, to avoid unnecessary complexity in the model a year is described as 260 working days with this number being easily changeable, depending on how each user schedules. The model doesn't further account for shipments overlapping with non-workdays.

6.2 Delivery Reliability: Both Operational and Contractual

As shown in table 4 Company X prioritises Delivery reliability highly, as this is a requirement for them to utilize the desired benefits from short lead times. A single day's variation won't affect sea transfers viability significantly, but for Parcel it's a significant increase in relative lead time. Lead time and delivery reliability are therefore closely connected in the model, as time and reliability are central factors in freight transport mode choice (Liu, D., Zhao, S. & Liu, J. 2012, p. 181). From an operational viewpoint Company X also prefers a high Delivery Reliability, as it simplifies planning.

These priorities are represented in the current alternative, Parcel. The low lead time along with the high Delivery Reliability makes it easier to plan. The Pallet alternatives perform significantly worse than Parcel regarding delivery reliability. One of the things identified to cause this is the handling of ULDs. As described in 4.6 it takes time to pack and handle ULDs, whether it's packaged and handled in an internal warehouse or the LSP is contracted to handle it (Brandt, F. & Nickel, S. 2019, pp. 400-404). Pallet Standard and Pallet Consolidated both have an additional stop before they land in the destination airport, described in 5.1. This additional stop then includes some unloading of some ULDs and loading of others. Loading and unloading an aircraft often takes on average 4 to 5 hours, depending on the airport (Ohashi, H. et al. 2005, 152). While the ULDs going from the origin to the destination airports are not opened during this middle landing, any loading and unloading of ULDs increases risks of delays. This can in turn increase an aircraft's transfer time, potentially resulting in missing departure windows (Brandt, F. & Nickel, S. 2019, pp. 407-410).

When investigating the actual Delivery Reliability it was revealed several shipments are reported as On-time when their actual delivery date was later than the agreed delivery date, mentioned in 5.1.2.3. This was due to shipments counting as "on-time" when the delay was contractually not defined as caused by the LSP. Examples such as an order not being ready for pickup on the agreed day, customs delaying the delivery or when documentation was not completed in time. While the delay was not caused by the LSP, the fact is orders are still delayed. These situations were compared to Parcel, which is counted in the same way. However, Parcel performs significantly better than any Pallet alternative. This is accredited to higher order frequencies, and the established contract with the Parcel LSP makes documentation for each order much simpler to handle. As mentioned in 5.1.1 a quirk of this agreement is that an order for transportation is not "placed" until a parcel is collected. This makes the issue of a parcel being delayed due to a missed collection impossible to measure with the available data, potentially presenting Parcel as more reliable.

Parcel also avoids many issues with ULD handling, since as mentioned in 5.1.1 all parcels on an aircraft are destined for the same destination; there's no middle landings. Furthermore, the Parcel transport provider has round-the-clock operations, avoiding issues of congestion at airports during peak times (Brandt, F. & Nickel, S. 2019, pp. 407-410). Operating during off-peak also benefits from more available workers and workstations, providing more flexibility to the Parcel LSP. As mentioned in 5.1.1 The Parcel LSPs are also responsible for the P2D delivery, whereas Pallet LSPs offer the P2D as an additional service. In 5.1.1 it's mentioned how the additional time for Pallet's P2D is not included in the agreed lead time and in 5.1.4 how an additional 3 days is assumed for this time. The Delivery Reliability doesn't account for this time in the agreed lead time, as it only covers the P2P (and thus indirectly D2P, as a delay in D2P will delay P2P as well) but not any delays in the P2D transports due to limitations in the data. Only Parcel accounts for delays in the P2D, since the Parcel alternative is completely D2D and there's no specific data when a port is reached.

6.3 Operational Feasibility: Current Operations Shape Current Priorities

How Company X describes the Operational Feasibility is essentially how well-aligned the alternative is with their current operation. This is the same for Company Y. Initially this was simplified to how much time was needed to manage an alternative, but this instead overlapped with the planning time that's included in the lead time metric. Due to time limitations, it was not possible to gather accurate data for evaluating the criteria in the PROMETHEE II model. It is therefore decided to remove it from the model.

As mentioned in section 5.1.2.4, upon investigating the Operational Feasibility criteria, two different perspectives emerged, namely the perspective of stakeholders 1-4 and stakeholder 5. Stakeholder 1-4 highly values a transport alternative that allows for flexibility and agility in their supply chain operations. Thus, shipping with Parcel, with its short lead times and at a higher frequency allows Company X to have flexibility. Section 5.1.2.4 further mentions that short lead times reduce the uncertainty of needing to send additional shipments if demand changes. Consequently, the result in section 5.1.4 validates Company X priorities regarding the operational feasibility criteria. Section 5.2.2 further shows that Parcel is the only transport alternative that is feasible at a high shipping frequency, reaching the lowest Total Cost at an order frequency of 0,75. The second highest frequency is at 4,5 for Pallet Consolidated. But as seen in section 5.1.2.2, Pallet Consolidated has 15 days lead time, compared to Parcel's 6 days of lead time. The 15 days lead time would thus reduce flexibility and increase uncertainty in Company X's current operations.

Furthermore, a correlation was found between alternatives best performing criteria and the highest weight. This trend follows, with the current alternative's best performing criterias being the ones weighted highest. A cyclical relation was found where the currently highest weights (priorities) are used to decide on a transport alternative fitting these priorities. When an alternative is chosen and used daily operations are then finetuned and adjusted to fit with said alternative.

Company X have very frequent shipment pickups and high delivery reliability, and thus have designed their daily operations to send just what's needed now, with a close time horizon. Company Y instead has weekly shipment pickups, and if a specific item isn't ready it has to be sent the following week instead. This means working with higher inventory levels over a longer time horizon. Both Company X and Y express issues with the other's solution, as their operations aren't tailored for it. Company X reasons their items are more expensive and should therefore have lower inventory levels, and thus they need lower lead times and high delivery reliability. Company Y on the other hand argue shipping with Parcel is more time consuming, as they need to keep track of significantly more individual packages and this proved a significant challenge. During a pilot program where Company Y tried to use Parcel all described issues can be attributed to unfamiliarity with the workflow. Stakeholder 5 who has deep insight into both Company X's and Y's shipment practices is of the opinion each company has solutions that work for them.

6.4 Environmental Impact: Low Emissions Are Not Enough

Environmental impact is a significant downside of Air Freight, as seen in 5.1.2.5, and all stakeholders agreed on this. For the route investigated there's only Air- and Sea Freight available. Since all Air Freight alternatives are similar, with only Parcel being higher due to the significantly higher order frequency, the best environmental alternative is Sea Freight by far. However, the poor performance in other criteria compared to the other alternatives greatly limits arguments supporting limiting environmental impact. Furthermore, Environmental Impact has the lowest weight of the selected criteria, shown in table 4. When taking into account the cost of bound capital, Sea Freight is even less competitive.

The model has underlying calculations to optimize the order frequency based on total costs. This optimization doesn't account for environmental emissions, best shown in how the optimized order frequency for Parcel would be more than one shipment per day. This leads to a higher environmental impact from Parcel, even though the same amount of weight is shipped over a year. The way environmental impact is calculated makes the model disregard all other potential orders on an aircraft. In reality, an aircraft would fly whether Company X's products are on it or not. An effort was made to adjust the model to more accurately account for environmental impact, but the issues above proved difficult to account for without significant changes to the model. Optimizing order frequency for environmental impact also proved difficult, as the calculation would need to be overhauled, or the optimized order frequency would simply be the highest allowed order frequency due to the absence of a counter-variable.

6.5 Total Cost: Both Freight and Capital

In order to make the PROMETHEE II model as trustworthy as possible, significant effort was made to calculate the freight cost for the alternatives. The formulas shown in 3.4 are simply combinations of established formulas, and are adaptable enough to account for different datasets. Another reason the freight cost was prioritized is its transparent nature. Since capital costs are indirect, as mentioned in 5.2.1 Company X has not directly prioritized them. They have been indirectly prioritized through short lead times and minimizing inventory levels, seen in both 5.1.2.2 and 5.1.2.3 as there's a desire to limit the amount of bound capital.

The current transport solution relies on a mix of reorder points, runout time, and safety stock. This makes it difficult to calculate the Cycle Stock and its capital costs in an accurate manner. The model currently uses the historical yearly demand as a basis to calculate the daily demand. The assumption that partial products can be sent is key here, as the quantities are too low to round it to an integer. However, this assumption makes the cycle stock appear lower than it actually is. Attempting to investigate how significant the impact this simplification has on the cycle stock is difficult, as there's varying levels of safety stock/runout day-levels. Using daily demand to calculate cycle stocks circumvents calculational complexity by sacrificing accuracy, as it fundamentally accounts for all sold goods. The reorder points for each product is described as the runout time-stock, so a product with 30 days runout time would deviate as much above as below this level. To exemplify, a product with 30 day runout time might place an order when 30 days stock remain, and assuming a 5 day lead time would get the order with 25 days stock left. This delivery would then put the actual stock level at 35 days. This assumption is not accurate on a product-to-product basis, but simplifies calculations by converting what's best described as a poisson distribution into an even flow. This assumption makes both freight cost- and pipeline calculations accurate enough. Only cycle stock is impacted, and thus the safety stock levels would be too. Although the simplifications in the model influence the estimated cycle stock, the resulting impact on safety stock is assumed to be negligible and approximately equal across all transportation alternatives. Therefore, safety stock capital costs were excluded from the analysis. Since the model is primarily designed to evaluate transportation solutions, not inventory levels, this is out of scope for the current model. An argument could be made that the characteristics of transportation alternatives have an impact on the actual stock levels, but to account for that in the model significant changes would need to be made to account for individual products, essentially converting it from a MCDM model into a S&OP model.

6.6 Model Evaluation

The model was evaluated through four independent methods as seen in section 5.2.

6.6.1 Rank Reversal in PROMETHEE II Remains a Relevant Concern

The rank reversal assessment was conducted to assess the sensitivity of the model and the trustworthiness of the result for dataset 1 and 2. The result of no occurred rank reversal for dataset 1 implies that the result is trustworthy and the model is not overly sensitive (Liu, X & Liu, Y 2024, pp. 1-12). For this reason, the result of the model in section 5.1.4 is credible.

The result of rank reversal for dataset 2 implies that the result can't be completely trustworthy for that dataset (Liu, X & Liu, Y 2024, pp. 1-12). As mentioned in section 4.4, there can be various underlying causes for occurrence of rank reversal (Liu, X & Liu, Y 2024, pp. 1-12), it is thereby not possible to immediately determine if the data will cause rank reversal. The only way to determine this is to test the model and examine if rank reversal occurs. As further stated in section 4.4, rank reversal can be influenced when the thresholds of preference function are changed (Liu, X & Liu, Y 2024, pp. 1-12). When dataset 2 is used as input to the PROMETHEE II model the thresholds (q and p) of the preference function automatically change as this dataset is compiled of products with different weights, sizes and costs. As a result, the Freight Cost and Environmental impact will have different thresholds. Since PROMETHEE II preference function parameters look at the maximum and minimum value, removing an alternative with the maximum or minimum threshold-value will change the threshold. This could influence the outranking Net Flow and influence the relative order of ranking of alternatives. As seen in figure 8, Sea Freight has significantly lower emissions compared to the other alternatives. Removing Sea Freight from the alternatives will hence influence the threshold of the preference function. The lowest threshold will move from 900,46 kg CO2-eq to 75286,59 kg CO2-eq, as this is the second lowest emission.

Section 4.4 further states that uncertain weights and inaccurate expert judgements can influence the occurrence of rank reversal (Liu, X & Liu, Y 2024, pp. 1-12). As mentioned in section 5.1.3, in the case of dataset 2, unsuccessful attempts were made to acquire accurate weights to the dataset. Hence, the weights that represent dataset 2 were manually adjusted to fictitiously reflect the priorities of stakeholder 5. As said in section 5.1.3, there were clear signs that priorities of criteria were not the same as for stakeholder 1-4. As a result, assumption was made that the most likely highest weighted criteria would be Freight Cost, secondly Delivery Reliability, thirdly Lead Times and lastly Environmental Impact. Consequently, it can be concluded that the weights for dataset 2 are uncertain. As seen in section 5.2.3, in the third iteration, primary weights were assessed together with dataset 2. When dataset 2 was assessed together with the primary weights, no rank reversal occurred in any of the operations. Purely based on this result, it’s not possible to conclude that the secondary weights are the only reason for the occurrence of rank reversal. Since the relative order of ranking did not change before an alternative was removed, it could also be the sensitivity of preference functions that is the underlying cause of rank reversal. It’s also possible that a combination of both uncertain weights and sensitive preference functions are the reason for rank reversal. It is however concluded that the rank reversal assessment provided insights to interpret the PROMETHEE II results with caution when dataset 2 combined with weights have been used together as this result can’t be completely trustworthy. This further confirms that rank reversal remains a relevant concern in PROMETHEE II and serves as an example to not draw any conclusions before a rank reversal assessment is conducted.

6.6.2 Less competitive Parcel Scenario Indicates Robustness

The competitiveness of Parcel was tested through three scenarios in section 5.2.4. The result of scenario 1 and 2 shows that parcel is the better transport alternative, despite operating under less favourable conditions. As demonstrated in table 13, it’s first during scenario 3, when parcel is performing worse on all criteria where Pallet Consolidated gains a higher outranking Net Flow and Parcel becomes the second best option. Table 11 displays the result of the Net Flow after scenario 1. The impact on the Net Flow is substantially larger than the impact observed in scenario 2, as seen in table 12. Hence, if shipping with Parcel would become a lot more expensive, the competitiveness of the alternative would decrease drastically. The result from scenario 2 indicates that Parcel would still remain very competitive even if it performs worse on the three criterias: Delivery Reliability, Lead Time and Environmental Impact. As seen in table 12, there is only a slight drop in Net Flow when Parcel performs worse on these criteria. Consequently, Parcel shipments would be very competitive if performance drops on one criteria. Scenario 1 and 2 thus demonstrates the high competitiveness of Parcel and strengthening the result of parcel being the optimal shipment alternative as shown in section 5.1.4.

6.6.3 Order Frequency Optimization Offers Marginal Gains

As seen in table 14, the currently used order frequencies for Parcel and Pallet shipments are close to the optimized ones found by the model as shown in table 8. This validates the currently used frequency of both Parcel and Pallet shipments. When comparing table 17 and 16, the improvements of shipping at the optimized order frequency would be mostly marginal. Parcel shipments would see the biggest difference by shipping even more frequently than today's routines. According to the result in table 17 and 16, there would be a saving of 1600€, a saving of 2,56% in Total Cost. The biggest effect can be seen in reduced cycle stock capital cost. Contrary, the actual Freight Cost is marginally lower at the currently used frequency for Parcel and Pallet Consolidated. Thus validating their currently used order frequencies further. Furthermore, when planning time deviates the order frequency determines the actual impact said deviation would have. Missing a weekly order pickup has significantly more impact than missing a daily pickup.

However, when the optimized order frequency is calculated, it only takes the financial aspect into account and does not include an operational perspective. Strictly investigating the most economically beneficial order frequency ignores the broader picture of day to day operations. As mentioned in section 4.8, solely striving to be an efficient supply chain is not a sustainable supply chain strategy (Jia, F. et al. 2025, p 2728). The optimized order frequency finder is not incorporating the environmental emissions of the transport alternatives or the social perspective of handling more or less workload per shipment. According to Jia, F. et al (2025), for companies to achieve a long lasting competitive supply chain strategy, both social, environmental and economic performance need to be incorporated. As further mentioned in section 4.8, companies should strive to evolve from an isolated profit seeking view to an ecosystem view in their supply chain management (Sodhi, M.S. & Tang, C.S. 2021). Consequently, since the optimized order frequency is calculated in an isolated profit seeking view, it should be investigated further by incorporating the ecosystem view in the calculation.

6.6.4 One Transport Strategy Does Not Fit All Products

From the rank reversal assessment in section 5.2.3 it was concluded that dataset 2 combined with the secondary weights have rank reversal. The result in the model thereby needs to be interpreted with scepticism. As shown in table 21, when the secondary weights were used together with dataset 2, the Net Flow of Parcel decreased from 0,3605 to 0,2779, while Pallet Consolidated increased its Net Flow from 0,1345 to 0,1950 and became closer to the highest ranked alternative. This result could imply that Parcel is a less competitive alternative during different prioritizations but still the best alternative. Nevertheless, because of rank reversal it's not possible to draw any trustworthy conclusion from the model of which transport alternative is the optimal one.

Furthermore, table 20 displays the optimized order frequencies for each transport alternative when using dataset 2. These frequencies also resulted in a different Total Cost for each transport alternative compared to Dataset 1, as shown in table 19. As this result is not influenced by the weights of the criteria or the outranking Net Flow, the overview of the costs can be a tool to examine the differences between transport alternatives when comparing dataset 1 and 2.

As shown in table 19, the pipeline capital cost decreased significantly when dataset 2 was applied to the model. One reason for the pipeline capital cost to decrease is the cost of the products of dataset 2. As described in section 3.3.2, dataset 2 is compiled of less expensive products than dataset 1. Hence, a transport alternative with a longer lead time is not as punished with a high cost of bound capital. The cycle stock capital cost also benefits from the less expensive products. Since the products of dataset 2 are cheaper, it will be more beneficial to send larger shipments at a lower ordering frequency, as the pipeline and cycle stock cost is not affected as much. In turn, the larger shipment volume increases the Freight Cost as seen in table 19. When the costs are added together to the Total Cost, Parcel is the most cost effective transport alternative when shipping the products of dataset 1. However, as table 19 displays, Pallet Consolidated is the most cost-effective transport alternative when shipping the products of dataset 2.

This result is in line with the theory as stated in section 4.8, there is no one-size-fits-all type of supply chain strategy (Lee, H. L. 2002, p.1) and all types of products should not have the same supply chain strategy. Parcel and Pallet Consolidated are consistently ranked as number 1 and 2 for all model evaluations made in section 5.2. But they have significantly different service levels and characteristics. Hence, the alternatives are suited for different strategies and products. As seen in figure 6, the lead time of the alternatives are very different. Parcel is an express carrier with short lead times of 2 days in transit. Pallet Consolidated has a much longer lead time of 11 days in transit with a layover. As seen in figure 7, the delivery reliability of the transport alternatives are also very different. Parcel has a 95,7% delivery reliability while Pallet Consolidated performs at 69,5%. As stated in section 4.6, it's mainly a commercial decision based on a number of factors that decides which type of airfreight will be used for the shipments (Debbage, K. & Debbage, N. 2021, pp. 361-364.). Among these factors are: value of the goods, cost, reliability and service level, closely related to the criteria chosen by the stakeholders of Company X. The value of the goods in dataset 1 are small high-value items. As seen in table 7, the shipper will suffer negatively by extended lead time. As stated in section 4.6, the result of larger vessels and extended lead time of shipping with Sea Freight is affecting the shipper with higher costs of bound capital and cycle stock. Hence, not suitable for shippers with high-value items (Chang & Thai 2017, pp. 200-206). This statement is verified by the result of figure 9, as pipeline capital cost becomes larger for the other transport alternatives with longer lead times. Contrary, as seen in figure 5 and 6, the transport alternatives with the longest lead times have the lowest Freight Cost.

Given the findings from meeting #6 with stakeholder 5, freight cost were assumingly the highest weighted criteria. Furthermore, as stated in 5.1.1, Pallet Consolidated has historically been the most frequently used transport alternative among the pallet options. Hence, assumingly lead time or high delivery reliability is not as highly prioritized as for stakeholders 1-4. Thereby, the choice of choosing to ship the products of dataset 2 with Pallet Consolidated is highly supported by the result in section 5.2.6. It's both aligned with the prioritizations of stakeholder 5 and has the lowest Freight Cost and Total Cost as seen in table 19. Contrary, shipping the products of dataset 1 with Parcel is highly supported by the result of the model and Parcel's performance on the criteria. Hence, strengthening the statement of not having a one-size-fits-all.

Even though the model can't give a trustworthy result for dataset 2 because of rank reversal, the cost overview and empirical findings of meetings is supporting the result of Pallet Consolidating being the more beneficial transport alternative for the products of dataset 2. This is also strengthening the result of Parcel being the better transport alternative for the products of dataset 1. It is worth noting, however, that dataset 2 is only compiled of products from 3 shipments and may not represent the whole picture.

6.7 Current Solutions Shape Current Priorities

A correlation was found where the currently used solution performed best in the criteria with highest weights. This is an identified limitation of not only PROMETHEE but many MCDM models: the "best" solution will be the one currently used, as that solution is shaping current priorities. If the criteria could be prioritized without bias and existing strategy, an actual optimal solution could be found. However, without strategy there can't be prioritizations, and without prioritizations there can't be a MCDM model to act as a foundation for a strategy. This cyclical relationship makes MCDM models inappropriate for problems with both existing solutions and without strategy, greatly limiting the usability of them.

PROMETHEE II provides a full ranking of alternatives. It gives consideration to aspects that are harder to compare between each other in an easily comparable way. It can be difficult to explain how PROMETHEE II reaches a ranking as there are several matrix operations. In order for the PROMETHEE model to be useful, the user needs to be able to trust the results. Furthermore, the users of PROMETHEE need to agree that both weights and preference functions are accurate. Even in this case where weights and preference functions were agreed on there were some differences in individual weights. If stakeholder 5, who primarily worked with other product categories, is considered the differences were even more pronounced. The weights and preference functions have strong impact on the results of PROMETHEE.

6.8 SWOT

A SWOT analysis is conducted to evaluate the result of the model and to discuss the result.

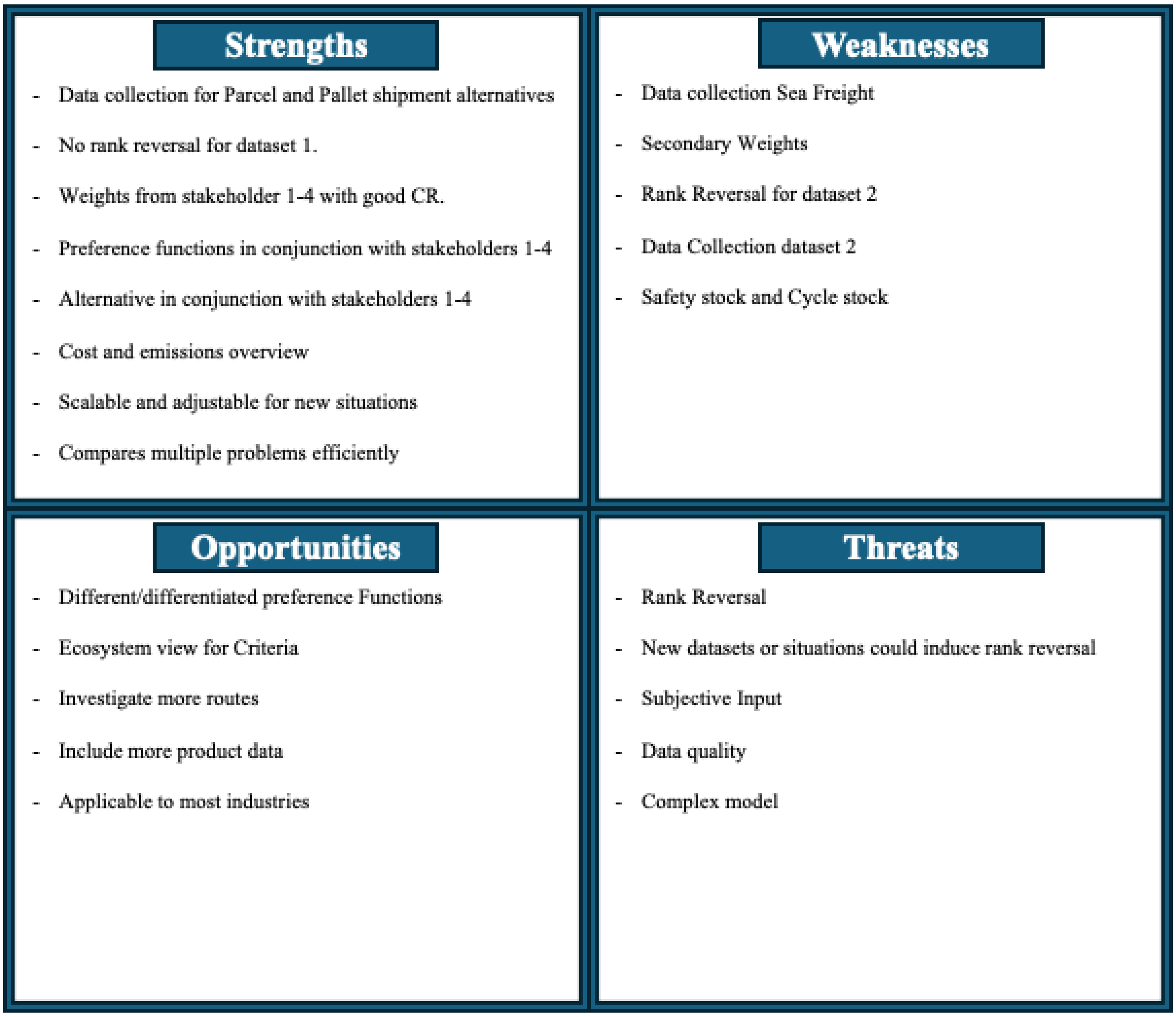

Figure 10: SWOT Model

Strengths

As seen in section 5.2.3, dataset 1 has no occurrence of rank reversal, implying that the result is trustworthy. The data quality in the model is very high for Parcel and Pallet shipping alternatives. As seen in section 3.4 the acquired secondary data allowed for accurate data of all criteria and to calculate Freight Cost, Pipeline and Cycle stock capital cost. As elaborated on in section 6.6.1, the cost overview can be used as a complement to the ranking of the model, regardless of rank reversal. As seen in section 5.2.6, the framework was built to allow the model to be scalable with additional datasets. As a result, the model can efficiently compare multiple criteria for transport alternatives. As seen in section 5.1.3, a CR of 0,04 was calculated which indicates a really good consistency in the responses, indicating the primary weights in the model are representative and usable (Saaty, W.R. 1987, p. 165).

Weaknesses
When the secondary dataset is applied to the model with secondary weights as shown in table 5, rank reversal is present and the rankings are not trustworthy. As mentioned in section 5.1.3, the secondary weights are fictitiously created to represent the priorities of stakeholder 5, and this might influence the rank reversal. Furthermore, as mentioned in 3.3.2, dataset 2 only consists of three shipments. There is no way of telling if these products are a reasonable comparison or if 3 other shipments would have provided more products with even more deviating characteristics. Moreover, the data collection regarding Sea Freight is deviating in regards to quality in comparison to Parcel and Pallet Consolidated. The data was sufficient enough for all criteria except for delivery reliability.

The Total Cost was calculated as outlined in section 3.4. As described in section 6.5, safety stock is not accounted for in the calculation of the Total Cost as the model assumes that safety stock levels remain mostly consistent with current levels. Moreover, cycle stock calculation in the model is based on average daily demand and not the actual discrete ordering behavior. As a result, the calculated Total Cost is not as accurate as it could be if safety stock was accounted for and if cycles stock was based on current order behavior instead of an averaged one.

Opportunities
The preference functions for the model were decided in conjunction with stakeholder 1-4. An unexplored opportunity with the current model is to investigate the impact on the result by having differentiated preference functions. As said in section 4.3, there exists various preference functions, which in its nature influences the outranking Net Flow. Since no rank reversal occurred for dataset 1 it would be hard to conclude if the model would be more or less stable with differentiated or another preference function. The criteria was also decided upon in conjunction with stakeholder 1-4, leaving an opportunity to include stakeholders that are external but affected by their supply chain operations. This could result in other than traditional criteria.

One of the strengths of the model is its ability to be scalable with new datasets. This enables adding more datasets to the model for a more thorough comparison of transport alternatives of different products. It's further possible to investigate transport alternatives for other routes. It’s also possible for most industries to apply their product data to the model and compare transport alternatives. Although, the weights and criteria will be different for another user and need to be adjusted before the model can be used fully.

Threats
Rank reversal is a clear threat to the model. As outlined in section 4.4, the subject of rank reversal is complex and appears uniquely to each MCDM method. For PROMETHEE it’s subject to limited research. Any new data may induce rank reversal.

As mentioned in section 5, the criteria, weights and alternatives were made in conjunction with the stakeholders. Thus, the decisions are made in an isolated view of the 4 stakeholders and their subjectivity could interfere with the decisions (Madanchian, M. & Taherdoos, H. 2025, pp. 14-15). Thus, the subjectivity is a threat to the reliability of the model's result. Another threat to model is the quality of the data. If false data is added to the model, it will naturally display a false result. Lastly, for people unfamiliar with the model it may be challenging to comprehend how the result is obtained, due to the underlying matrix calculations.

7 Conclusion

The purpose of the study was to develop, through a case study, a structured decision-support model to evaluate and compare transport alternatives for replenishment orders, and to assess a currently used transport solution compared to a theoretically optimized one based on the decision-support model's output. To fulfill this purpose, two research questions was created:

RQ1 *What aspects are considered when choosing a transportation solution for replenishment orders and how do they compare to each other?*

Company X considers several requirements when choosing transport solutions. Five recurring criteria were found: Freight Cost, Lead Time, Delivery Reliability, Operational Feasibility, and Environmental Impact. As Company X desires to make data driven decisions, the abstract nature of Operational Feasibility is not included in the otherwise data-available criteria.

Company X's weights can be seen in table 4. Delivery Reliability is currently the undoubtedly highest priority. The second highest priority is Lead Time. This aligns with the perspective found when investigating Operational Feasibility. Priorities are focused on keeping operations simple and flexible to enable rapid responses to changed circumstances. Historically Environmental Impact has not been prioritized, but with a MCDM model lower priorities could be included in the alternative evaluation.

The considered aspects define the criteria the solutions needs to fill. Selecting criteria is inherently subjective, as the opinions of decision makers are the only real basis for selection. While more data driven criteria can be selected, to do so an original set of criteria has to be created to then pick the most important from. As such, even if criteria are chosen by data driven methods the original set of alternatives has a subjective component.

RQ2 *How does the currently used transportation solution compare to a theoretically optimized one based on the identified decision factors?*

Based on the identified factors, the currently used transport solution aligns closely to the theoretically optimized one. Parcel is consistently ranked first in the PROMETHEE model across av evaluations using the primary dataset, except for scenario 3 in 5.2.4. Parcel has a Net Flow of 0,3605, significantly higher than the second-ranked Pallet Consolidated (0,1345), hence validating Company X's existing transport solution.

While Parcel does not have the lowest annual Freight Cost (52 294€ compared to Pallet Consolidated's 36 400€), it has the lowest total cost at 60 664€ when pipeline and cycle stock capital are included. This is primarily a result of Parcel's short lead times of 2 days in transit. The high value of the goods in the primary dataset drives up the pipeline capital cost for transport alternatives with longer lead time. Hence, making the transport alternatives with longer lead times more expensive in terms of tied up capital. When dataset 1 and 2 are compared, a key supply chain theory is supported: there is no one-size-fits-all supply chain strategy. The results show that shipping with Parcel is more beneficial for high-value, low-volume products while Pallet Consolidated is more beneficial for lower-value, higher-volume products. Consequently, validating Parcel further as the better transport solution.

As seen in section 5.1.3, Delivery Reliability obtained the highest AHP weight (0,408) and Parcel performed at 95.7%, far above the second best alternative, Pallet Consolidated at 69.5%. The second highest weighted criterion, lead time (0.281) similarly favour Parcel with a total lead time of 6 days compared to the second best alternative, Pallet Express with 11days of lead time. This pattern, where the currently used transport solution performs best in the highest weighted criterion, reflects a cyclical relationship where Company X's priorities are shaped by the solution already in use, and the solution already in use is selected based on the highest priorities.

Moreover, the currently used order frequency at 1.75 days is close to the optimized one at 0,75, further validating the currently used practice. Company X could see savings in Total Cost by shipping more frequently but the difference is marginal. As Parcel is the only alternative that allows for a high order frequency and reduces uncertainty of shipping less frequently with longer lead times, it further validates the Operational Feasibility criteria.

In consideration to the above, the model confirms that Company X's current transport solution is aligned with a theoretically optimized one.

7.1 Limitations

Due to time constraints the model currently uses averages to estimate costs and performance. This leads to issues mainly regarding the cycle stock, and some minor impact on the freight cost as well. Another limitation due to time is the considered criteria and alternatives. While the alternatives are somewhat limited, other LSPs could have been considered for the same alternative. The criteria is more difficult, as there's no real limit on what can be a criteria or not. To keep progressing a handful of criteria were selected, but more criteria could have been selected to get a more complete perspective. Increasing either the alternatives or criteria would have come at the cost of more data collection, one of the drawbacks of MCDM models.

7.2 Managerial recommendations

For Company X the recommendation is to let Parcel remain as the primary transport alternative, as both the ranking and total cost imply Parcel is the best available alternative. If a more accurate model is desired the expansion of the model to work at product-level is recommended. This would circumvent the current issues stemming from working with averages. This is hypothesised to improve Parcel's performance further.

Company X should also expand their scope to include Total Cost in their decision making process, instead of focusing on the Freight Cost. This shift to a Total Cost-perspective could be incorporated in more aspects of the company other than transportation as well, if there's a desire to optimize the business further.

For future companies or users of this MCDM model the recommendation is to design the model to work at a product-level from the beginning. While this does require some extra work, the upfront time cost is significantly decreased if this decision is made in the early stages of the model creation. In addition extra care should be taken to gather as objective and correct data as possible.

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Appendix

Appendix A

Status quo unchanged Dataset 1 A = {A1, A2, A3, A4, A5}.

Alternative	Leaving Flow	Entering Flow	Net Flow	Rank
Parcel	0,4399	0,0794	0,3605	1
Pallet Express	0,0366	0,3937	-0,3571	5
Pallet Standard	0,1083	0,1783	-0,0700	3
Pallet Consolidated	0,2380	0,1036	0,1345	2
Sea Freight	0,1838	0,3594	-0,1756	4

Result operation 1 A = {A2, A3, A4, A5}.

Alternative	Leaving Flow	Entering Flow	Net Flow	Rank
Pallet Express	0,0366	0,4317	-0,3951	4
Pallet Standard	0,1559	0,1717	-0,0158	2
Pallet Consolidated	0,4794	0,0686	0,4108	1
Sea Freight	0,3361	0,3627	-0,0266	3

Result operation 2 A = {A1, A3, A4, A5}.

Alternative	Leaving Flow	Entering Flow	Net Flow	Rank
Parcel	0,3863	0,1664	0,2199	1
Pallet Standard	0,0755	0,2965	-0,2210	3
Pallet Consolidated	0,2937	0,1317	0,1619	2
Sea Freight	0,1365	0,4846	-0,3481	4

Result operation 3 A = {A1, A2, A4, A5}.

Alternative	Leaving Flow	Entering Flow	Net Flow	Rank
Parcel	0,4504	0,0843	0,3661	1
Pallet Express	0,0490	0,4493	-0,4003	4
Pallet Consolidated	0,2577	0,1270	0,1307	2
Sea Freight	0,2337	0,4027	-0,1690	3

Result operation 4 A = {A1, A2, A3, A5}.

Alternative	Leaving Flow	Entering Flow	Net Flow	Rank
Parcel	0,5337	0,0769	0,4568	1
Pallet Express	0,0324	0,4103	-0,3779	4
Pallet Standard	0,1611	0,1715	-0,0104	2
Sea Freight	0,2608	0,3569	-0,0961	3

Result operation 5 A = {A1, A2, A3, A4}.

Alternative	Leaving Flow	Entering Flow	Net Flow	Rank
Parcel	0,5809	0,1195	0,4614	1
Pallet Express	0,0915	0,4602	-0,3686	4
Pallet Standard	0,1475	0,2597	-0,1122	3
Pallet Consolidated	0,2539	0,2345	0,0194	2

Appendix B

Status quo unchanged Dataset 1 A = {A1, A2, A3, A4, A5}

Alernative	Leaving Flow	Entering Flow	Net Flow	Rank
Parcel	0,4393	0,0767	0,3626	1
Pallet Express	0,0358	0,4002	-0,3643	5
Pallet Standard	0,1111	0,1796	-0,0685	3
Pallet Consolidated	0,2316	0,1105	0,1212	2
Sea Freight	0,2046	0,3543	-0,1497	4

Result operation 1 A = {A2, A3, A4, A5}.

Alernative	Leaving Flow	Entering Flow	Net Flow	Rank
Pallet Express	0,0404	0,4354	-0,3950	4
Pallet Standard	0,1620	0,1677	-0,0057	2
Pallet Consolidated	0,4767	0,0733	0,4034	1
Sea Freight	0,3355	0,3560	-0,0205	3

Result operation 2 A = {A1, A3, A4, A5}.

Alernative	Leaving Flow	Entering Flow	Net Flow	Rank
Parcel	0,3863	0,1913	0,1950	1
Pallet Standard	0,0892	0,2892	-0,2000	3
Pallet Consolidated	0,2700	0,1388	0,1312	2
Sea Freight	0,1835	0,4495	-0,2660	4

Result operation 3 A = {A1, A2, A4, A5}.

Alernative	Leaving Flow	Entering Flow	Net Flow	Rank
Parcel	0,4495	0,0815	0,3680	1
Pallet Express	0,0475	0,4561	-0,4085	4
Pallet Consolidated	0,2509	0,1343	0,1165	2
Sea Freight	0,2600	0,3984	-0,1385	3

Result operation 4 A = {A1, A2, A3, A5}.

Alernative	Leaving Flow	Entering Flow	Net Flow	Rank
Parcel	0,5298	0,0785	0,4513	1
Pallet Express	0,0281	0,4136	-0,3856	4
Pallet Standard	0,1600	0,1751	-0,0151	2
Sea Freight	0,2830	0,3541	-0,0711	3

Result operation 5 A = {A1, A2, A3, A4}.

Alernative	Leaving Flow	Entering Flow	Net Flow	Rank
Parcel	0,5803	0,1160	0,4643	1
Pallet Express	0,0981	0,4614	-0,3633	4
Pallet Standard	0,1559	0,2586	-0,1027	3
Pallet Consolidated	0,2469	0,2452	0,0017	2

Appendix C

Project deliverables

The following deliverables summarize the main target of this project and have been presented to Company X:

- A functioning model for evaluating possible transportation solutions and alignment with current strategy.
- Overview of CO_2 emissions and costs of different transportation solutions.

Appendix D

Model Dashboard and PROMETHEE II

Alernative	Leaving Flow	Entering Flow	Net Flow	Rank	Freight Cost / Year	Pipeline Capital Cost	Cycle Stock Capital Cost	Total Cost	Annual kg CO2-eq
Parcel	0,4399	0,0794	0,3605	1	52 294,44 €	7 048,12 €	1 321,52 €	60 664,08 €	150423,30
Pallet Express	0,0366	0,3937	-0,3571	5	114 626,00 €	24 668,42 €	11 453,19 €	150 747,61 €	75286,59
Pallet Standard	0,1083	0,1783	-0,0700	3	47 168,73 €	28 192,48 €	9 691,16 €	85 052,37 €	77711,94
Pallet Consolidated	0,2380	0,1036	0,1345	2	36 400,00 €	38 764,66 €	7 929,13 €	83 093,79 €	82317,09
Sea Freight	0,1838	0,3594	-0,1756	4	50 596,78 €	105 721,79 €	35 240,60 €	191 559,17 €	900,46

Data Set	Implants Venlo-Lancas	Product class	Everything		Yearly value of Class	12 216 740,26 €

Alternatives \ Criteria	Total Freight Cost	Lead Time (Days)	Dedlivery reliability index	Enviromental impact (kg CO2-eq/year)
Weight	0,206	0,281	0,408	0,105
Parcel	52 294,44 €	6	95,7%	150423,3
Pallet Express	114 626,00 €	11	39,0%	75286,6
Pallet Standard	47 168,73 €	12	45,9%	77711,9
Pallet Consolidated	36 400,00 €	15	69,5%	82317,1
Sea Freight	50 596,78 €	34	50,0%	900,5

Max	**114626**	**34**	**0,95696068**	**150423,3**	
Min	**36400**	**6**	**0,390243902**	**900,5**	
Minimize/Maximize	Minimize	Minimize	Maximize	Minimize	Minimize

Attribute or Criteria	Total Cost Transport	Lead Time (Days)	Dedlivery reliability index	Enviromental impact (g CO2-eq/tonne-km)
Parcel	0,80	1,00	1,00	0,00
Pallet Express	0,00	0,82	0,00	0,50
Pallet Direct	0,86	0,79	0,12	0,49
Pallet Consolidated	1,00	0,68	0,54	0,46
Sea Freight	0,82	0,00	0,19	1,00
P-P	0,00	0,00	0,00	0,00
P-PE	0,80	0,18	1,00	-0,50
P-PD	-0,07	0,21	0,88	-0,49
P-PC	-0,20	0,32	0,46	-0,46
P-SF	-0,02	1,00	0,81	-1,00
PE-P	-0,80	-0,18	-1,00	0,50
PE-PE	0,00	0,00	0,00	0,00
PE-PD	-0,86	0,04	-0,12	0,02
PE-PC	-1,00	0,14	-0,54	0,05
PE-SF	-0,82	0,82	-0,19	-0,50
PD-P	0,07	-0,21	-0,88	0,49
PD-PE	0,86	-0,04	0,12	-0,02
PD-PD	0,00	0,00	0,00	0,00
PD-PC	-0,14	0,11	-0,42	0,03
PD-SF	0,04	0,79	-0,07	-0,51
PC-P	0,20	-0,32	-0,46	0,46
PC-PE	1,00	-0,14	0,54	-0,05
PC-PD	0,14	-0,11	0,42	-0,03
PC-PC	0,00	0,00	0,00	0,00
PC-SF	0,18	0,68	0,34	-0,54
SF-P	0,02	-1,00	-0,81	1,00
SF-PE	0,82	-0,82	0,19	0,50
SF-PD	-0,04	-0,79	0,07	0,51
SF-PC	-0,18	-0,68	-0,34	0,54
SF-SF	0,00	0,00	0,00	0,00

p		14	0,9	0
q		0	0,5	0
p(norm)	0	0,5	0,9	0
q(norm)	0	0	0,5	0
Preferensmodifierat	Linear	Level criterion	V-shape with indifference	V-shape Criterion

Attribute or Criteria	Total Cost Transport	Lead Time (Days)	Dedlivery reliability index	Enviromental impact (kg CO2-eq/tonne)
P-P	0,00	0,00	0,00	0,00
P-PE	0,80	0,18	1,00	0,00
P-PD	0,00	0,21	0,88	0,00
P-PC	0,00	0,32	0,46	0,00
P-SF	0,00	1,00	0,81	0,00
PE-P	0,00	0,00	0,00	0,50
PE-PE	0,00	0,00	0,00	0,00
PE-PD	0,00	0,04	0,00	0,02
PE-PC	0,00	0,14	0,00	0,05
PE-SF	0,00	0,82	0,00	0,00
PD-P	0,07	0,00	0,00	0,49
PD-PE	0,86	0,00	0,12	0,00
PD-PD	0,00	0,00	0,00	0,00
PD-PC	0,00	0,11	0,00	0,03
PD-SF	0,04	0,79	0,00	0,00
PC-P	0,20	0,00	0,00	0,46
PC-PE	1,00	0,00	0,54	0,00
PC-PD	0,14	0,00	0,42	0,00
PC-PC	0,00	0,00	0,00	0,00
PC-SF	0,18	0,68	0,34	0,00
SF-P	0,02	0,00	0,00	1,00
SF-PE	0,82	0,00	0,19	0,50
SF-PD	0,00	0,00	0,07	0,51
SF-PC	0,00	0,00	0,00	0,54
SF-SF	0,00	0,00	0,00	0,00

Weighted				
Attribute or Criteria	Total Cost Transport	Lead Time (Days)	Dedlivery reliability index	Enviromental impact
P-P	0,00	0,00	0,00	0,00
P-PE	0,16	0,05	0,41	0,00
P-PD	0,00	0,06	0,36	0,00
P-PC	0,00	0,09	0,19	0,00
P-SF	0,00	0,28	0,33	0,00
PE-P	0,00	0,00	0,00	0,05
PE-PE	0,00	0,00	0,00	0,00
PE-PD	0,00	0,01	0,00	0,00
PE-PC	0,00	0,04	0,00	0,00
PE-SF	0,00	0,23	0,00	0,00
PD-P	0,01	0,00	0,00	0,05
PD-PE	0,18	0,00	0,05	0,00
PD-PD	0,00	0,00	0,00	0,00
PD-PC	0,00	0,03	0,00	0,00
PD-SF	0,01	0,22	0,00	0,00
PC-P	0,04	0,00	0,00	0,05
PC-PE	0,21	0,00	0,22	0,00
PC-PD	0,03	0,00	0,17	0,00
PC-PC	0,00	0,00	0,00	0,00
PC-SF	0,04	0,19	0,14	0,00
SF-P	0,00	0,00	0,00	0,11
SF-PE	0,17	0,00	0,08	0,05
SF-PD	0,00	0,00	0,03	0,05
SF-PC	0,00	0,00	0,00	0,06
SF-SF	0,00	0,00	0,00	0,00

Weighted Sum	Parcel	Pallet Express	Pallet Direct	Pallet Consolidated	Sea Freight	Leaving Flow
Parcel	0,0000	0,6222	0,4189	0,2786	0,6095	0,439902961
Pallet Express	0,0530	0,0000	0,0117	0,0450	0,23	0,036587253
Pallet Direct	0,0648	0,2269	0,0000	0,0333	0,2294	0,108332817
Pallet Consolidated	0,0899	0,4256	0,1987	0,0000	0,37	0,238047325
Sea Freight	0,11	0,30	0,08	0,0574	0,0000	0,183814022
Entering Flow	0,0794	0,3937	0,1783	0,1036	0,3594	

Appendix E

AHP

Klass 1

Personer	Transportkostnad VS Tran	Transportkostnad Vs Ledt	Transportkostnad VS leve	Transportkostnad vs Plan	Transportkostnad Vs klim	Ledtid Vs Transportkostn	Ledtid Vs Ledtid	Ledtid Vs Lev.pålitlighet	Ledtid Vs Planeringsanst	Ledtid Vs Klimat	Lev.pålitlighet Vs Transpc	Lev.pålitlighet Vs Ledtid	Pålitlighet VS Pålitlighet	Lev.pålitlighet Vs Lev.ans	Lev.pålitlighet Vs klimat
Michael	1,00	0,25	0,20	0,33	2,00	4,00	1,00	0,20	2,00	4,00	5,00	5,00	1,00	4,00	4,00
David	1,00	0,33	0,33	2,00	4,00	3,00	1,00	2,00	3,00	5,00	3,00	0,50	1,00	3,00	4,00
Åse	1,00	0,33	0,33	0,33	2,00	3,00	1,00	0,50	3,00	3,00	3,00	2,00	1,00	3,00	3,00
Johan	1,00	0,50	0,50	0,50	2,00	2,00	1,00	0,50	2,00	3,00	2,00	2,00	1,00	2,00	2,00
GeoMedel	1,00	0,34	0,32	0,58	2,38	2,91	1,00	0,56	2,45	3,66	3,08	1,78	1,00	2,91	3,13

Klass 2

Personer	Transportkostnad VS Tran	Transportkostnad Vs Ledt	Transportkostnad VS leve	Transportkostnad vs Plan	Transportkostnad Vs klim	Ledtid Vs Transportkostn	Ledtid Vs Ledtid	Ledtid Vs Lev.pålitlighet	Ledtid Vs Planeringsanst	Ledtid Vs Klimat	Lev.pålitlighet Vs Transpc	Lev.pålitlighet Vs Ledtid	Pålitlighet VS Pålitlighet	Lev.pålitlighet Vs Lev.ans	Lev.pålitlighet Vs klimat
Michael	1,00	0,33	0,25	0,33	3,00	3,00	1,00	0,25	3,00	3,00	4,00	4,00	1,00	5,00	5,00
David	1,00	0,50	2,00	3,00	3,00	2,00	1,00	2,00	3,00	4,00	0,50	0,50	1,00	3,00	4,00
Åse	1,00	0,50	0,50	0,50	2,00	2,00	1,00	0,33	2,00	2,00	2,00	3,00	1,00	2,00	2,00
Johan	1,00	0,50	0,50	0,50	2,00	2,00	1,00	0,50	2,00	2,00	2,00	2,00	1,00	2,00	2,00
GeoMedel	1,00	0,45	0,59	0,71	2,45	2,21	1,00	0,54	2,45	2,63	1,68	1,86	1,00	2,78	2,99

Klass 3

Personer	Transportkostnad VS Tran	Transportkostnad Vs Ledt	Transportkostnad VS leve	Transportkostnad vs Plan	Transportkostnad Vs klim	Ledtid Vs Transportkostn	Ledtid Vs Ledtid	Ledtid Vs Lev.pålitlighet	Ledtid Vs Planeringsanst	Ledtid Vs Klimat	Lev.pålitlighet Vs Transpc	Lev.pålitlighet Vs Ledtid	Pålitlighet VS Pålitlighet	Lev.pålitlighet Vs Lev.ans	Lev.pålitlighet Vs klimat
Michael	1,00	0,25	0,25	0,33	3,00	4,00	1,00	0,33	3,00	3,00	4,00	3,00	1,00	4,00	4,00
David	1,00	3,00	3,00	3,00	3,00	0,33	1,00	0,33	3,00	3,00	0,33	3,00	1,00	3,00	3,00
Åse	1,00	1,00	0,50	2,00	2,00	1,00	1,00	0,33	2,00	2,00	2,00	3,00	1,00	2,00	2,00
Johan	1,00	2,00	0,50	2,00	2,00	0,50	1,00	0,50	2,00	2,00	2,00	2,00	1,00	2,00	2,00
GeoMedel	1,00	1,11	0,66	1,41	2,45	0,90	1,00	0,37	2,45	2,45	1,52	2,71	1,00	2,63	2,63

Plan.ansträngning Vs Trai	Plan.anstr. VS Ledtid	Plan.anstr. VS Lev.Pålitlig	Planering VS Planering	Plan.ansträgning Vs klim	Klimat VS Kostnad	Klimat VS Ledtid	Klimat VS Lev. Pålitlighet	Klimat VS Planeringsanst	Klimat Vs Klimat
3,00	0,50	0,25	1,00	3,00	0,50	0,25	0,25	0,33	1,00
0,50	0,33	0,33	1,00	4,00	0,25	0,20	0,25	0,25	1,00
3,00	0,33	0,33	1,00	3,00	0,50	0,33	0,33	0,33	1,00
2,00	0,50	0,50	1,00	2,00	0,50	0,33	0,50	0,50	1,00
1,73	0,41	0,34	1,00	2,91	0,42	0,27	0,32	0,34	1,00

Plan.ansträngning Vs Trai	Plan.anstr. VS Ledtid	Plan.anstr. VS Lev.Pålitlig	Planering VS Planering	Plan.ansträgning Vs klim	Klimat VS Kostnad	Klimat VS Ledtid	Klimat VS Lev. Pålitlighet	Klimat VS Planeringsanst	Klimat Vs Klimat
3,00	0,33	0,20	1,00	4,00	0,33	0,33	0,20	0,25	1,00
0,33	0,33	0,33	1,00	3,00	0,33	0,25	0,25	0,33	1,00
2,00	0,50	0,50	1,00	2,00	0,50	0,50	0,50	0,50	1,00
2,00	0,50	0,50	1,00	2,00	0,50	0,50	0,50	0,50	1,00
1,41	0,41	0,36	1,00	2,63	0,41	0,38	0,33	0,38	1,00

Plan.ansträngning Vs Trai	Plan.anstr. VS Ledtid	Plan.anstr. VS Lev.Pålitlig	Planering VS Planering	Plan.ansträgning Vs klim	Klimat VS Kostnad	Klimat VS Ledtid	Klimat VS Lev. Pålitlighet	Klimat VS Planeringsanst	Klimat Vs Klimat
3,00	0,33	0,25	1,00	3,00	0,33	0,33	0,25	0,33	1,00
0,33	0,33	0,33	1,00	3,00	0,33	0,33	0,33	0,33	1,00
0,50	0,50	0,50	1,00	2,00	0,50	0,50	0,50	0,50	1,00
0,50	0,50	0,50	1,00	2,00	0,50	0,50	0,50	0,50	1,00
0,71	0,41	0,38	1,00	2,45	0,41	0,41	0,38	0,41	1,00

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