POLITECNICO MILANO 1863

SCUOLA DI INGEGNERIA INDUSTRIALE E DELL'INFORMAZIONE

EXECUTIVE SUMMARY

International Trade between Europe and China in the context of the Belt and Road Initiative: a Multi-Criteria Decision Model to compare different freight transport solutions

MSc. DISSERTATON, MANAGEMENT ENGINEERING – INGEGNERIA GESTIONALE

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1. Introduction

China's economic growth has been exceptional since the early 1980s, when the reform-and-opening strategy was implemented. China's story, under Xi Jinping's leadership, has recently taken a new turn, signalling a major shift toward a more expansive and outward-looking economic policy ***[5]***. In particular after the outbreak of Covid-19 pandemic, China has overtaken the United States in becoming the European Union's top trading partner, thanks to considerable growth in both imports and exports compared to 2019 ***[11]***.
It becomes of fundamental importance and even more interesting than in previous years to analyse trade flows between Europe and China by studying the main modes of transport and the main routes used to exchange goods. In this respect, considering that shipping and rail transport are the most widely used modes of transport for international trade and that rail is becoming increasingly important and valued ***[1]***, it seems at least useful to analyse the opportunities offered by the Belt and Road in this respect, thanks to the implementation of the Silk Road Economic Belt and the 21st century maritime silk road, which represent two main trade routes on rail and ship respectively ***[13]***.
This project, first unveiled in 2013 by the General Secretary of Communist Party of China Xi Jinping, wanted China to take an active and leading role in the context of Eurasian and Africa commercial trades. It aims, thanks to a massive infrastructure development to improve China's linkages with Central Asia, Europe and Africa through the implementation of six main economic corridors ***[6]***. Since its announcement, China's ambitious vision is altering the global economic landscape in a variety of ways and the implementation of the BRI is reshaping the global logistic network ***[7, 5]***.

2. Objectives and Research Questions

The objectives of the present master thesis are to provide a decision model that integrates different types of decision factors, prioritize them and support decision makers to find the optimal freight solutions throughout the Belt and Road. The model can be used by each European company which exports/imports goods from/to China with the purpose of understand which are the decision drivers that impact the most on the basis of the product category. Therefore, the first research question to which the work aims to answer is:

RQ1. Which are the main decision drivers in the selection of the optimal freight mode for European companies trading goods with China throughout the Belt and Road?

Once the main decision drivers considered by managers are known, it must be considered that the prioritization of the variables considered is strongly influenced by the product characteristics traded by the company ***[13]***. For this reason, the second research question about this has been defined as follow:

RQ2. How does the importance attributed by managers to freight mode decision drivers change with respect to specific product characteristics?

The pursue of the optimal solution usually doesn't include the selection of the best freight mode, since this latter is almost always taken for granted. Since the model is meant to evaluate the different transportation modes in the context of the B&R on the ground of all the relevant drivers, the third research question is:

RQ3. Comparing the available freight alternatives to ship goods between Europe and China in the context of the Belt and Road Initiative, which is the optimal solution with respect to the importance attributed by managers to the decision drivers?

Product characteristics are certainly the factor influence and impact the most in the managers' decision-making process, but considering the impact of two global factors – the emergence of Covid-19 pandemics and the increasing awareness of supply chain sustainability and environmental issues – and the relative change in some drivers, the resulting optimal solution might change ***[15]***. On the ground of these two phenomena, two research questions are formulated:

RQ4.1. How does the optimal freight solution change when considering the impact of Covid-19 pandemics?
RQ4.2. How does the optimal freight solution change when considering the increasing awareness of environmental issues emerged in the last years?

3. Methodologies

Methodology used so far followed a logical sequence characterized by different steps: the first has been the review of the literature review in order to identify the main gaps; then the model that best addressed the identified gaps was selected, developed, explaining how each of its components fit into the context that is under investigation and finally implemented, in order to come up with relevant results and considerations.
The first step mentioned, the literature review, has been done selecting 102 articles from the main science search engines – Google Scholar, Science Direct, Scopus, Emerald Insight and SpringerLink – regarding mainly topics related to Belt and Road and International Logistics. The articles were then filtered on the basis of their consistency with the objective of the thesis *[14]* and finally from the resulting 65 articles the main gaps emerged.
The second step has been the model selection. Decision-making models have been evaluated on the ground of the nature of the problem that this dissertation aimed to solve. Among rational decision models, Multi-Criteria Decision Models (MCDM) have been selected as the ones being the most suitable for the defined objectives *[10]*. Moreover, considering the nature of the problem, the discrete number of alternatives, the features of problem variables and the status of the decision environment, the final selection has been a Multi-Attribute Decision Model (MADM), which exploits fuzzy logics to convert uncertain decision-maker's ordinal preference information into cardinal values *[3]*.
Once the type of model has been selected, this latter has been designed on the ground of the research problem. The set of freight modes alternatives has been composed by sea freight, rail freight and air freight *[1]*, evaluated according to three criteria: economic, strategic and environmental. These latter have been broken up into nine attributes, which represents the decision drivers used by the decision-maker within his decision process:

- Transportation cost;
- Inventory carrying cost;
- Maximum load capacity;
- Lead time;
- Lead time variability;
- Accessibility;
- Damage risk;
- Theft risk;
- Emissions.

Decision-maker is asked to select a linguistic variable among the proposed ones to assign a level of importance to each attribute, giving rise to the so-called preference vector. A fuzzy set of number has been defined to convert decision-maker's preferences into numeric values *[4]*.

Linguistic Variable	Fuzzy Numbers
Very Low	(0,0,0,3)
Low	(0,3,3,5)
Medium	(2,5,5,8)
High	(5,7,7,10)
Very High	(7,10,10,10)

Table 1: Linguistic variables and related fuzzy set.

Given $\widetilde{w_j} = (a_j, b_j, c_j, d_j)$ as the set of fuzzy numbers associated with a specific linguistic variable, the scalarization that convert the fuzzy variable $\widetilde{w_j}$ into a cardinal value $d(\widetilde{w_j})$ is performed by applying the following formula:

$$d(\widetilde{w_j}) = \frac{1}{4}(a_j + b_j + c_j + d_j), \quad j = 1, \dots, n \quad (1)$$

In addition, freight alternatives have been evaluated according to the defined attributes, in order to build a decision matrix A. Performances of the three alternatives with respect to the attributes have been defined by relying on academic papers, journals and technical reports. Then, in order to make them comparable, they have been rationalized respect to the best performance. For those attributes characterized by the lowest value as the best performance, the applied formula is:

$$x_{i\bar{j}} = \frac{10 * \min_i p_{i\bar{j}}}{p_{i\bar{j}}} \quad (2)$$

Where $p_{i\bar{j}}$ and $x_{i\bar{j}}$ represents respectively the performance and the relative performance of the i-th alternative respect to the attribute $\bar{j}$. On the contrary, those attributes characterized by the highest value as the best performance imply to use the following formula:

$$x_{i\bar{j}} = \frac{10 * p_{i\bar{j}}}{\max_i p_{i\bar{j}}} \quad (3)$$

Once performances have been evaluated for each alternative with respect to all the attributes, their global score is calculated as the vector product of the preference vector defined by the decision maker and the decision matrix:

$$W \otimes A_i \stackrel{\text{def}}{=} \sum_{j=1}^{n} d(\widetilde{w}_j) x_{ij} \qquad (4)$$

The optimal solution A^* of the problem is represented by the ones having the highest global score. Therefore, the model's objective function is defined as follows:

$$A^* = \left\{ A_i : \max_i W \otimes A_i \ \forall i = 1, \dots, m \right\} \qquad (5)$$

The following phase is represented by the model application. Indeed, in order to validate the model and to provide also empirical findings to the master thesis, a survey has been conducted to a group of 96 managers working in European companies. They have been asked to indicate the product category they deal with, the related product flow (import from/export to China) and their job position, along with a linguistic variable per each attribute, according to their preferences.
Data have been gathered and clustered according to two main product characteristics, product flow and product value density (PVD). This latter is defined by product value and product weight, according to the following formula *[13]*:

$$PVD = \frac{Product\ value}{Chargeable\ weight} \qquad (6)$$

On the ground of these two factors, nine product categories have been split into two groups, high and low PVD (respectively above and beyond the straight line), taking as reference the threshold defined by *[1]*, as showed in Figure 1.

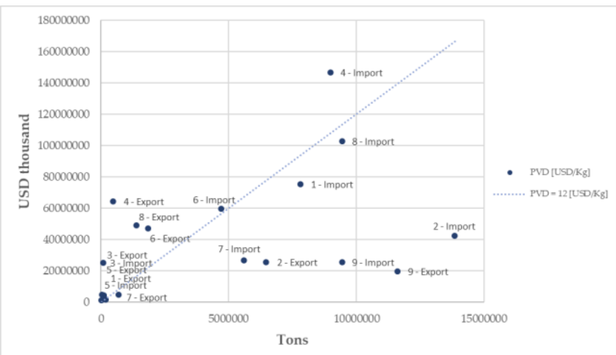

Figure 1: Product categories and PVD.

In the end, according to the distinction between high and low PVD previously defined, and import/export product flow, four clusters have been built:

- Import/High-PVD;
- Import/Low-PVD;
- Export/High-PVD;
- Export/Low-PVD.

According to the data gathered, the steps previously defined has been applied to come up with the optimal solution for every defined cluster.
Last, a sensitivity analysis has been carried out in order to evaluate the impact of two relevant factors affecting business and logistics strategies in the last years: Covid-19 pandemics and sustainability awareness. For the first topic, the performance of the different alternatives has been evaluated according to pre- and post-pandemics transportation fares, while keeping unchanged the performance values respect to the other attributes. This analysis applies a cost perspective, in order to verify whether optimal solutions have been subject to changes due to the increase in transportation costs caused by Covid-19.
On the other side, as the as sustainability awareness within companies is widely taking hold during the last years, the second analysis imposes a medium-high fixed level of importance given to the environmental attribute, and evaluates whether an increase in its weight within the preference vectors leads to a shift in the optimal solutions.

4. Results and Findings

The literature review analyzed both International Logistics and the Belt and Road, where the first one made some topics emerge, such as International Distribution, Cross-Border E-Commerce and Product Diversity. On the other side, BRI has been evaluated on the ground of Network Design, International Trade and Technological Innovations. The gaps highlighted, related to the lack of a comprehensive view of the international freight problem within the context of the BRI, led to the formulation of the research questions and the development of the model.
Analyzing the data gathered from the survey, the first considerations regard the level of importance given by managers to the attributes:

- Attributes are weighted more by managers dealing with export compared to those dealing with import. This may suggest that most of the Incoterms used belongs to the cluster of Freight Prepaid Terms, which allocate to the exporter higher responsibilities and costs respect to the importer, who therefore assign higher levels of importance to attributes.
- Transportation cost, lead time and lead time variability are highly considered by managers, regardless any product characteristics
- Damage and theft risk, inventory carrying cost and maximum load capacity are strictly connected to product flow and PVD.
- Environmental criterion is never a priority for managers, and always have one of the lowest weights.

On the ground of the preference information provided by managers, as well as the decision matrix previously defined, the following outcomes came out:

- Air freight results to be the optimal solution for goods characterized by high PVD in both import and export activities (Tables 2 and 4).
- Rail freight results to be the optimal solution for goods characterized by low PVD in both import and export activities (Tables 3 and 5).

IMPORT/HIGH-PVD	
Freight Solution	Global Score
Air Freight	397,81
Rail Freight	394,28
Sea Freight	367,86

Table 2: Import/High-PVD Global Scores.

IMPORT/LOW-PVD	
Freight Solution	Global Score
Rail Freight	324,56
Sea Freight	318,41
Air Freight	292,74

Table 3: Import/Low-PVD Global Scores.

EXPORT/HIGH-PVD	
Freight Solution	Global Score
Air Freight	411,30
Rail Freight	406,47
Sea Freight	383,17

Table 4: Export/High-PVD Global Scores.

EXPORT/LOW-PVD	
Freight Solution	Global Score
Rail Freight	371,95
Sea Freight	369,28
Air Freight	328,49

Table 5: Export/Low-PVD Global Scores.

The sensitivity analysis performed on the ground of transportation cost variations caused by Covid-19 pandemics led to the following results:

- Air freight is confirmed as the optimal solution for goods characterized by high PVD considering both import and export activities also in the pre-pandemic environment (Figures 2 and 4).
- Sea freight results to be the optimal solution for goods characterized by low PVD considering both import and export activities in the pre-pandemics environment (Figures 3 and 5).

Figure 2: Covid-19 Sensitivity – Import/High-PVD

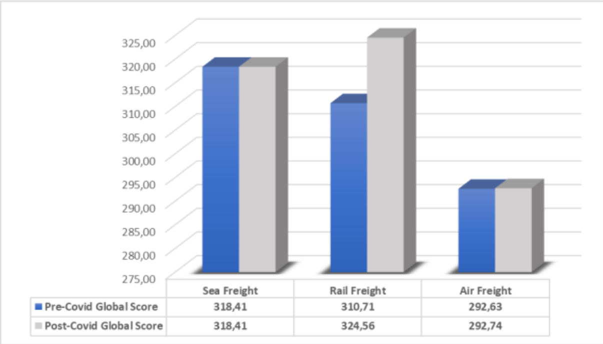

Figure 3: Covid-19 Sensitivity – Import/Low-PVD

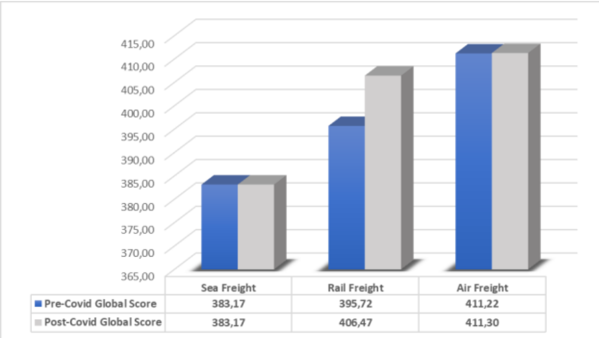

Figure 4: Covid-19 Sensitivity – Export/High-PVD

Figure 5: Covid-19 Sensitivity – Export/Low-PVD

Moreover, within the survey, managers have been asked to provide the freight solution they adopt. Answers have been clustered according to company's country, and compared to the optimal solutions in pre- and post-Covid situations emerged from the sensitivity analysis. Therefore, it has been possible to carry out some considerations on the impact that the shift in the optimal solutions due to pandemics had on companies' logistics strategies:

- Countries like Germany and Poland, thanks to important logistics rail hubs such as respectively Duisburg and Lodz, have been able to exploit the opportunities opened up by BRI and to help national companies optimizing their logistics choices.
- Italy, Spain and France, which are not provided with an appropriate rail infrastructure connected with the Belt and Road network, are not able to ride the change in international freight strategy and take advantages from the new solution offered by BRI.

The second sensitivity analysis, regarding the environmental awareness and its impact on attributes' weights, led to the following results:

- Rail freight is confirmed as the optimal solution for goods characterized by low PVD considering both import and export activities also considering a medium-high importance given to the environmental criteria (Figures 6 and 8).
- Rail freight results to be the optimal solution also for goods characterized by high PVD considering a medium-high importance given to the environmental criteria (Figures 7 and 9).

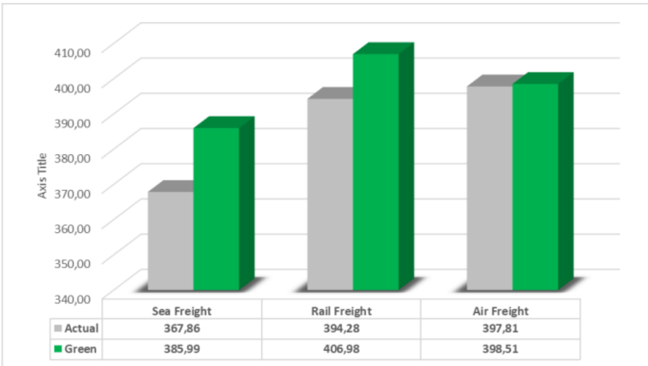

Figure 6: Green Sensitivity – Import/High-PVD

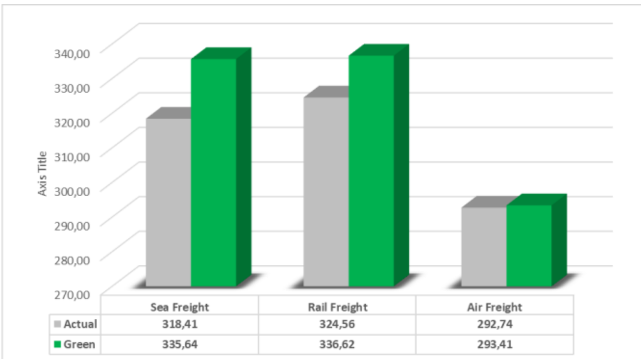

Figure 7: Green Sensitivity – Import/Low-PVD

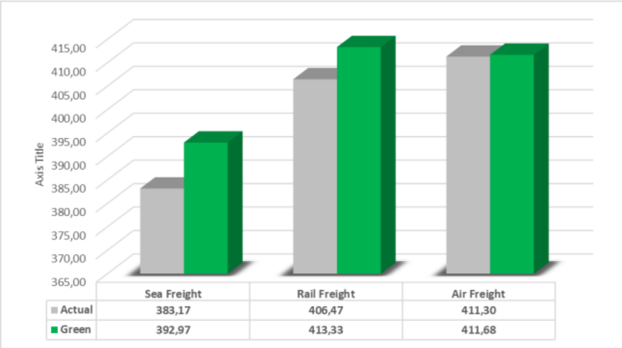

Figure 8: Green Sensitivity – Export/High-PVD

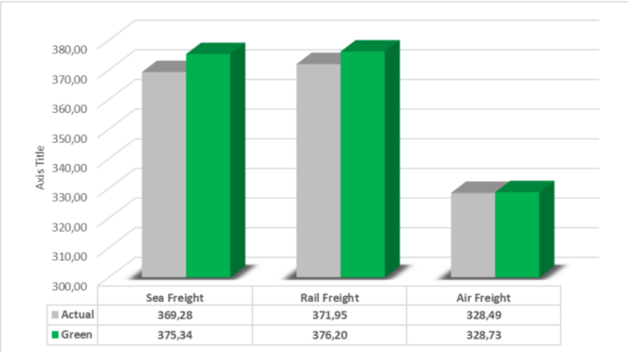

Figure 9: Green Sensitivity – Export/Low-PVD

5. Conclusions

The present master thesis ground its basis on the impact that the Belt and Road Initiative has and will have in the future on the international trade between Europe and China. In particular, rail freight has been proved to be the optimal solution in case of both low and high PVD in present and future scenarios for both import and export activities. This result is enhanced by the disruption occurred due to Covid-19 pandemics, which shifted the optimal solutions from air and sea freight respectively for high and low PVD in the pre-pandemic situation, and the increasing relevance that the environmental factor is assuming within companies. Therefore, this dissertation gives a contribution to the literature, filling the gaps related to international freight decision-making in the context of the Belt and Road Initiative. Moreover, the developed model provides decision-makers with an overview of the available international freight solutions as well as the main decision drivers to consider while designing the distributive strategy, and helps them to compare different freight solutions on the ground of the selected decision drivers.
However, this research thesis can be improved by considering also food product categories, characterized by further peculiar features such as perishability. Another aspect to deepen is represented by domestic transport, which is crucial to provide an overall understanding of the distribution problem, from the origin to the destination point.

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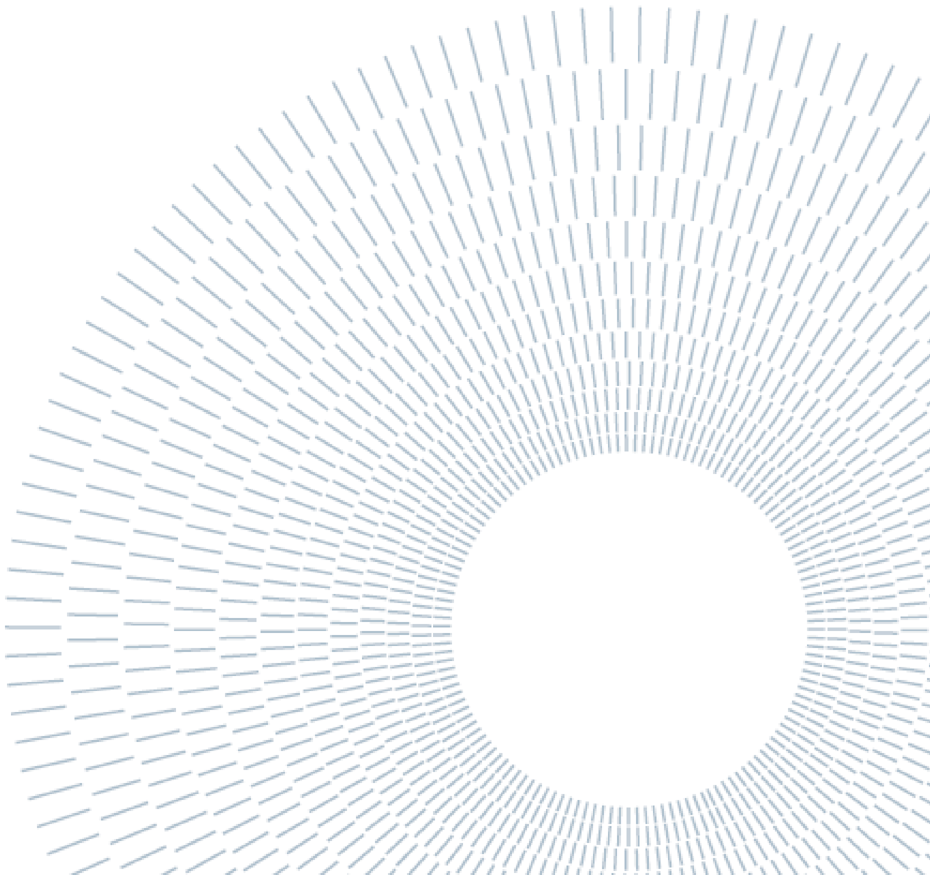

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Abstract

English Version

It is called 'Belt & Road Initiative', abbreviated in the acronym "BRI" or "Obor" ("One Belt One Road"), the Chinese project announced in 2013 by Chinese President Xi Jinping consisting of a network of infrastructural, maritime and land links, intended to connect 65 countries, Asia to Europe and Africa, but above all to put modern China at the centre of international trade and redesign the world's economic and geopolitical balances. In the light of this initiative, therefore, considering the central role that China plays and will play more and more in the future in the context of international trade flows, this thesis aims to provide business managers of major European countries with a tool that can support them in the decision-making process of exporting and importing goods. Specifically, this thesis aims to offer a complete and comprehensive framework with respect to all variables - economic, strategic and environmental - that intervene in the decision-making process, providing an optimal freight solution between Europe and China with respect to different categories of imported and exported products.

Key-words: Belt & Road, Logistic Network, Product types

Italian Version

Si chiama 'Belt & Road Initiative', abbreviato nell'acronimo "BRI" o "Obor" ("One Belt One Road"), il progetto cinese annunciato nel 2013 dal presidente cinese Xi Jinping costituito da una rete di collegamenti infrastrutturali, marittimi e terrestri, destinato a collegare, coinvolgendo 65 Paesi, l'Asia all'Europa e all'Africa, ma soprattutto a mettere la Cina moderna al centro dei traffici internazionali e a ridisegnare gli equilibri economici e geopolitici mondiali. Alla luce di questa iniziativa, considerando quindi il ruolo centrale che la Cina ricopre e ricoprirà sempre di più nel futuro nel contesto dei flussi commerciali internazionali, il presente lavoro di tesi si pone l'obiettivo di fornire ai manager aziendali dei principali paesi europei uno strumento che possa affiancarli nel processo decisionale di esportazione e importazione di merci. Nello specifico, la presente tesi vuole offrire un quadro completo e omnicomprensivo rispetto a tutte le variabili - economiche, strategiche ed ambientali - che intervengono nel processo decisionale, fornendo una soluzione di trasporto ottimale tra Europa e Cina rispetto a diverse categorie di prodotti importati ed esportati.

Parole chiave: Belt & Road, Logistic Network, Product types.

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1. International Trade between Europe and China in the context of the Belt and Road Initiative

The present master thesis grounds its basis on the impact that the Belt and Road Initiative is having and will have in the future on international trade flows between Europe and China. The two phenomena studied in this dissertation are therefore interconnected and cannot be considered independently. However, in this brief introduction, the two concepts will be presented as independent: the first one related to the growing importance and centrality of China in the context of trade with Europe in recent years, and the other related to the influence and growing importance of the Belt and Road, concerning the redesigning of the logistic network that BRI is determining. Deepening this master thesis, it will be clarified the interrelation between these two concepts, and how they influence each other's development.

China's economic growth has been exceptional since the early 1980s, when the reform-and-opening strategy was implemented. China's story, under Xi Jinping's leadership, China's story has recently taken a new turn, signaling a major shift toward a more expansive and outward-looking economic policy, as evidenced by Xi's newly articulated "Chinese Dream" vision and related "Belt and Road Initiative," as well as his call for a new model of great power relations. It appears to be on track to overtake the United States as the world's largest economy within the next decade, and by 2050, it will be more than double the size of the US economy. Precisely in relation to the above mentioned After the outbreak of Covid-19 pandemic, China has overtaken the United States in becoming the European Union's top trading partner, thanks to considerable growth in both imports and exports compared to 2019. This overtaking is mainly due to the rigorous and timely counter-measures that China adopted to deal with the Covid-19 emergency, which allowed it, according to the International Monetary Fund, to be the only major economy in the world to record a growth in Gross Domestic Product in 2020 of 2.3%, compared to a contraction suffered by the global economy of around 3.5%.

It is exactly because of what has just been explained that it becomes of fundamental importance and even more interesting than in previous years to analyze trade flows between Europe and China by studying the main modes of transport and the main routes used to exchange goods.

In this respect, considering that shipping and rail transport are the most widely used modes of transport for international trade and that rail is becoming increasingly important and valued, it seems at least useful to analyze the opportunities offered by the Belt and Road in this respect, thanks to the implementation of the Silk Road Economic Belt and the 21st century maritime silk road, which represent two main trade routes on rail and ship respectively.

The Belt and Road Initiative (BRI) was first unveiled in 2013 by Xi Jinping, General Secretary of Communist Party of China, during visits in Astana, Kazakhstan, in which he announced the Silk Road Economic Belt (One Belt) and in Jakarta, Indonesia, in which he announced the 21st Century Maritime Silk Road (One Road) *[28, 70]*. The main message that Xi Jinping wanted to transmit was that China is ready to take an active and leading role in the context of Eurasian and African commercial trade, thanks to a and massive infrastructure developments to facilitate trade and promote regional collaboration, financial integration, free trade and scientific cooperation.

In its infancy, the BRI planned to improve China's linkages with Central Asia and Europe through infrastructure development, first and primarily the construction of railways, but including also oil and gas pipelines, power plants, and telecommunications networks, in addition to ports, trains, and roadways, as a natural progression of the "Western Development Strategy" ***[63]***. Less than four years later, the BRI had grown to encompass most of the Eurasian continent's countries and all economic sectors, from trade to banking, as evidenced by newly established financial organizations such as the Asian Infrastructure Investment Bank (AIIB) and the Silk Road Fund ***[31]***.

Going into more detail, on one side the Silk Road Economic Belt program focuses on central Eurasia, particularly the former Soviet republics of Central Asia and Europe, while on the other southeast Asia, Pakistan, East Africa, and territories around the Mediterranean Sea are all part of the Maritime Silk Road. Six major economic corridors are expected to emerge from these areas. In particular the corridors are: New Eurasia Land Bridge Economic Corridor, China-Mongolia-Russia Economic Corridor, China-Central Asia-West Asia Economic Corridor, China-Indochina Peninsula Economic Corridor, China-Pakistan Economic Corridor and Bangladesh-China-India-Myanmar Economic Corridor.

Since the announcement of the Belt and Road in 2013 to the last few years, and in particular after the outbreak of the Covid-19 pandemic, China's ambitious vision is steadily altering the global economic landscape in a variety of ways, resulting in a number of ramifications for the corporate environment and logistics activities. According to the World Bank study group, the BRI is one of the "key new international initiatives that address logistical concerns," which not only has an economic goal, although this is primary, but as it can be understand from the above, also geopolitical consideration play a key role within this project ***[4]***.

This master thesis will therefore study in detail the contribution that the Belt and Road can make in the context of trade between China and Europe and the impact that the potential new routes will have in identifying optimal transport solutions.

Before getting deeper into the details of such exploration, an analysis of the current literature is carried on with the aim to perform a structured identification of research gaps for what concerns CBEC logistics in light of the B&R Initiative.

2. Literature review

The main theme around which the master thesis revolves is the Belt & Road Initiative. This principal topic was then linked to other secondary and complementary themes that contributed to enriching and completing the research. The topics covered related to the Belt and Road are International Distribution and the Commercial Trade with China. The following chapters will clarify the methodology that was applied to carry out the study, then the results of the literature review will be presented using graphs, charts and general findings. The main gaps identified in the literature and the conclusions of the literature review will then be analyzed.

2.1 Methodology

Review methodology followed in this master thesis is mainly based on the seven steps of Comprehensive Literature Review (CLR) approach ***[143]***. A flow chart of literature search procedure is depicted in the following figure in order to provide a clear framework of how the review process has been structured.

2.1.1 Phase 1: Literature Search Criteria

The first step in the literature review was to define the search criteria used.

- Firstly, mostly recent publications have been selected, with the majority of the articles being distributed between 2015 and 2021, the years in which interest in the Belt & Road Initiative has become increasingly insistent and topical. The selected older articles, the oldest of which dates back to 1979, deal with more general topics that can still be considered solid reference points today, such as the choice of transport method or the best supply chain configuration by product.

- The search of the papers was carried out by relying on the main science search engines such as Google Scholar, Science Direct, Scopus, Emerald Insight and SpringerLink. Through these search engines a systematic search was carried out by using a number of selected keywords in order to retrieve relevant papers (i.e., *"Belt & Road"*, *"e-commerce"*, *"logistics"*, *"Supply chain"*, *"International Distribution"*) and all their possible combinations.

- The various keywords mentioned in the previous step led to the collection of 102 articles. After classifying all these articles according to the main topic, they dealt with, we proceeded to exclude the articles that were less relevant for our research. First of all, the 102 articles were divided into two macro-groups according to the topic they dealt with: Belt and Road and International Logistics were the two topics chosen for the first classification. The next step was to deepen the classification of the two macro-topics identified in subsequent sub-topics. The Belt and Road topic was divided into the respective sub-topics: Innovation and technology, world trade and international distribution, Logistic Network design, Supply chain management. While the topic International Logistics has been segmented into the sub-topics Logistics and International Distribution, Logistics and Product types, Logistics and E-commerce. Once the articles were classified into topics and sub-topics, an initial screening was carried out in which the search field was narrowed down by excluding all those articles whose analysis did not include a focus on China and its trade with Europe. In this way, 25 articles were discarded. Subsequently, the criterion used to further reduce the number of articles considered was to verify the alignment of the different purposive and findings of the papers with those of our research. In this way, a further 12 articles were eliminated, resulting in a final number of 65 articles.

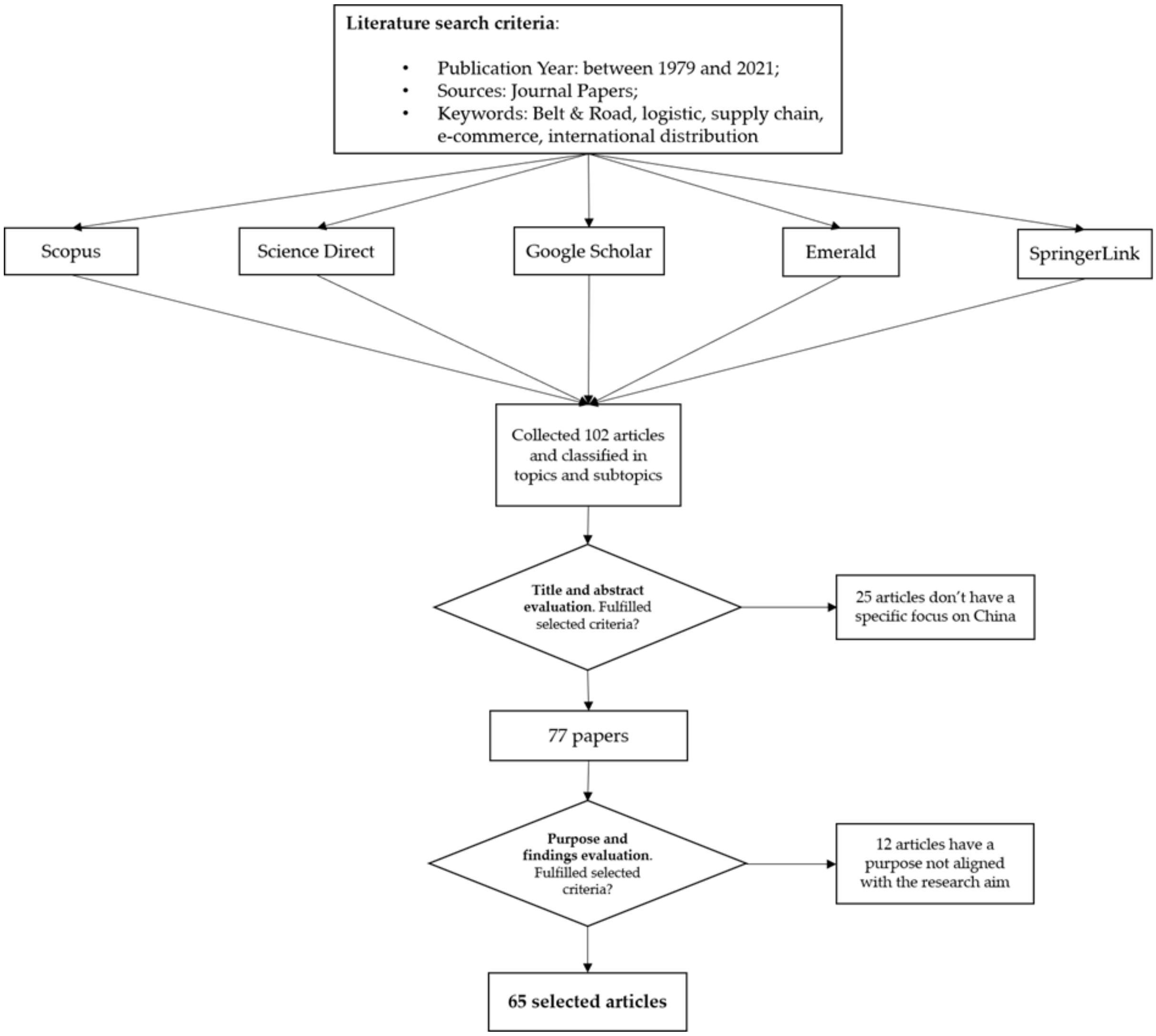


Figure 2.1: *Literature Review Methodology.*

2.1.2 Phase 2: Literature Analysis

In order to analyze and classify the articles selected from the literature resulting from the first phase, the following parameters were used:

- Main features of the article (i.e. year of publication, name of journal or conference, name and number of authors, nationality of authors);
- Methods used in the papers;
- Main themes tackled.

2.1.3 Phase 3: Research Gaps

In this stage, gaps identification spontaneously emerged from the analysis of the above-mentioned literature. Certainly, the research gaps that appear most evident are those of a limited contribution of literature analyzing the connection between the Belt & Road Initiative and International Logistic, the two main topics of our master thesis, and the lack of an analysis that considers a set of variables in addition to the economic and/or socio-political ones. Then is spontaneously followed the development of the research questions.

2.2 Literature Analysis

In this paragraph, the selected articles are first presented on the ground of different descriptive criteria, such as main topic, date of publication, source and research method. Then, the analysis focuses on the specific contents covered by the literature, splitting the papers in different clusters and highlighting for each one the main findings.

N.	Author	Year	Type of Source	Name of Source	Title	Topic	Sub-Topic	Research Method
1	Fisher	1997	Journal Paper	Harvard Business Review	What is the Right Supply Chain for Your Product?	International Logistics	Product Diversity	Conceptual Model
2	Leung et al.	2002	Book Chapter	Mathematical and Computer Modelling	A Robust Optimization Model for a Cross-Border Logistics Problem with Fleet Composition in an Uncertain Environment	International Logistics	International Distribution	Mathematical Model
3	Jiang & Prater	2002	Journal Paper	International Journal of Physical Distribution & Logistics Management	Distribution and logistics development in China: the revolution has begun	International Logistics	International Distribution	Literature Review
4	Christopher et al.	2002	Journal Paper	International Journal of Logistics Management	Developing Market Specific Supply Chain Strategies	International Logistics	Product Diversity	Literature Review
5	Zhang	2003	Journal Paper	Air Transport Management	Analysis of an international air-cargo hub: the case of Hong Kong	International Logistics	International Distribution	Conceptual Model

6	Wang et al.	2004	Journal Paper	International Journal of Production Economics	Product-driven supply chain selection using integrated multi-criteria decision-making methodology	International Logistics	Product Diversity	Mathematical Model
7	Lovell et al.	2005	Journal Paper	International Journal of Logistics Management	Product value-density: managing diversity through supply chain segmentation	International Logistics	Product Diversity	Conceptual Model
8	Tian et al.	2010	Journal Paper	International Journal of Physical Distribution & Logistics Management	Third-party logistics provider customer orientation and customer firm logistics improvement in China	International Logistics	International Distribution	Survey
9	Zhang & Figliozzi	2010	Journal Paper	Transport Reviews	A Survey of China's Logistics Industry and the Impacts of Transport Delays on Importers and Exporters	International Logistics	International Distribution	Survey
10	Coley et al.	2011	Journal Paper	British Food Journal	Food miles: time for a re-think?	International Logistics	Product Diversity	Case Study
11	Jiao	2016	Book Chapter	Contemporary Logistics in China - Proliferation and Internationalization	Modes and Development Characteristics of China's Cross-border E-commerce Logistics	International Logistics	Cross-Border E-Commerce	General Review

12	Wang et al.	2015	Conference Paper	International Conference on Engineering Management, Engineering Education and Information Technology	Comparative Research on Chinese Logistics Models of Cross-Border E-Commerce	International Logistics	Cross-Border E-Commerce	General Review
13	Liu et al.	2015	Journal Paper	International Journal of Intelligent Information Systems	The Operation of the Cross-Border e-commerce Logistics in China	International Logistics	Cross-Border E-Commerce	General Review
14	Nakandala et al.	2015	Journal Paper	Industrial Management & Data Systems	Cost-optimization modelling for fresh food quality and transportation	International Logistics	Product Diversity	Mathematical Model
15	Wang	2016	Conference Paper	International Conference on Service Science, Technology, and Engineering	Forecast on Development of China's Air Cargo Market	International Logistics	International Distribution	Conceptual Model
16	Giuffrida et al.	2016	Conference Paper	Workshop on Business Models and ICT Technologies for the Fashion Supply Chain	Logistics Solutions to Support Cross Border E-Commerce Towards China: The Case of the Apparel Industry	International Logistics	Cross-Border E-Commerce	Case Study

17	Liu & Shi	2016	Conference Paper	2016 International Conference on Logistics, Informatics and Service Sciences (LISS)	Relationship of Trade and China's Logistics Capability under "the Belt and Road"	Belt and Road	World Trade and International Relations	General Review
18	Rezk et al.	2016	Journal Paper	Journal of International Business Studies	The impact of product attributes and emerging technologies on firms' international configuration	International Logistics	Product Diversity	Conceptual Model
19	Kharlamov et al.	2016	Book Chapter	Engineering Systems and Networks	Data-Driven SKU Differentiation Framework for Supply Chain Management	International Logistics	Product Diversity	Conceptual Model
20	Liu & Yan	2017	Book Chapter	Adaption of Logistical Distribution Networks with Complexity and Efficiency Considerations for Cross-Border E-Commerce in China	Adaption of Logistical Distribution Networks with Complexity and Efficiency Considerations for Cross-Border ECommerce in China	International Logistics	Cross-Border E-Commerce	General Review
21	Yue et al.	2017	Journal Paper	Studies in Asian Social Science	Analysis on the Development and Bottlenecks of China's Cross - Border E – Commerce	International Logistics	Cross-Border E-Commerce	General Review

22	Giuffrida et al.	2017	Journal Paper	International Journal of Physical Distribution & Logistics Management	Cross-border B2C e-commerce to Greater China and the role of logistics: a literature review	International Logistics	Cross-Border E-Commerce	Literature Review
23	Sun et al.	2017	Journal Paper	Boletin Tecnico	Research on Logistics Mode of Cross Border E-commerce in China	International Logistics	Cross-Border E-Commerce	General Review
24	Lun	2017	Journal Paper	Revista de la Facultad de Ingenieria	Research on the Cross Border E-commerce Logistics Mode Innovation and Countermeasures in China	International Logistics	Cross-Border E-Commerce	General Review
25	Cho & Lee	2017	Journal Paper	The Asian Journal of Shipping and Logistics	Searching for Logistics and Regulatory Determinants Affecting Overseas Direct Purchase: an empirical national study	International Logistics	International Distribution	Case Study
26	Wang & Yeo	2017	Journal Paper	Maritime Policy & Management. The flagship journal of international shipping and port research	Intermodal route selection for cargo transportation from Korea to Central Asia by adopting Fuzzy Delphi and Fuzzy ELECTRE I methods	International Logistics	International Distribution	Mathematical Model

27	Choi et al.	2017	Journal Paper	Maritime Policy & Management. The flagship journal of international shipping and port research	Development of an IoT-based container tracking system for China's Belt and Road (B&R) initiative	Belt and Road	Innovation and Technology	Case Study
28	Shao et al.	2017	Journal Paper	Transportation Research Part E: Logistics and Transportation Review	Evaluation of large-scale transnational high-speed railway construction priority in the belt and road region	Belt and Road	Network Design and Infrastructures	Mathematical Model
29	Sheu & Kundu	2017	Journal Paper	Transportation Research Part E: Logistics and Transportation Review	Forecasting time-varying logistics distribution flows in the One Belt-One Road strategic context	Belt and Road	Network Design and Infrastructures	Mathematical Model
30	Xu et al.	2017	Conference Paper	4th International Conference on Transportation Information and Safety (ICTIS)	Multimodal Transport Routing Problem considering Transshipment and Accessibility: the case of the "One Belt One Road" Initiative	Belt and Road	Network Design and Infrastructures	Mathematical Model
31	Yang et al.	2017	Journal Paper	Transportation Research Part E: Logistics and Transportation Review	On service network improvement for shipping lines under the one belt one road initiative of China	Belt and Road	Network Design and Infrastructures	Mathematical Model

32	Zhang et al.	2017	Journal Paper	Maritime Policy and Management	Foldable container in empty container repositioning in intermodal transportation network of Belt and Road Initiative: strengths and limitations	Belt and Road	Innovation and Technology	General Review
33	Zhaoa et al.	2017	Journal Paper	Transportation Research Part E: Logistics and Transportation Review	Evaluation of consolidation center cargo capacity and locations for China railway express	International Logistics	International Distribution	Mathematical Model
34	Memon et al.	2017	Journal Paper	Industrial Management & Data Systems	Semantic transportation planning for food products supply chain ecosystem within difficult geographic zones	International Logistics	Product Diversity	Conceptual Model
35	Wang et al.	2018	Journal Paper	Journal of Geographical Sciences	An organizational model and border port hinterlands for the China-Europe Railway Express	Belt and Road	Network Design and Infrastructures	Conceptual Model
36	Liu et al.	2018	Journal Paper	Transportation Research Part E: Logistics and Transportation Review	Analysis of logistics service supply chain for the One Belt and One Road initiative of China	Belt and Road	Network Design and Infrastructures	Mathematical Model

37	Wang et al.	2018	Journal Paper	Journal of Transport Geography	Case studies on transport infrastructure projects in belt and road initiative: An actor network theory perspective	Belt and Road	Network Design and Infrastructures	Case Study
38	Leavy	2018	Journal Paper	Strategy & Leadership	China's "New Silk Road" initiative – implications for competitors and partners, near and far	Belt and Road	Network Design and Infrastructures	General Review
39	Fan	2018	Conference Paper	International Conference on E-commerce and Contemporary Economic Development	Cross-border Logistics Risks and the Countermeasures	International Logistics	International Distribution	General Review
40	Guixiang & Qingzheng	2018	Conference Paper	5th International Conference on Business, Economics and Management	Discussion on Operation Mode of Regional Cross-border E-commerce Industrial Park	International Logistics	Cross-Border E-Commerce	General Review
41	Giuffrida et al.	2018	Conference Paper	XXIII Summer School "Francesco Turco" – Industrial Systems Engineering	Entering China via cross border e-commerce: Logistics solutions and related challenges	International Logistics	Cross-Border E-Commerce	General Review

42	Li	2018	Conference Paper	International Conference on E-commerce and Contemporary Economic Development	The Cross-border E-commerce Logistics for Chinese Small and Micro Businesses: Analysis and Suggestion	International Logistics	Cross-Border E-Commerce	Case Study
43	Jiang et al.	2018	Journal Paper	Transportation Research Part E: Logistics and Transportation Review	Hinterland patterns of China Railway (CR) express in China under the Belt and Road Initiative: A preliminary analysis	Belt and Road	Network Design and Infrastructures	General Review
44	Ye et al.	2018	Conference Paper	International Conference on Dynamic Logistics	Impacts of the BRI on International Logistics Network	Belt and Road	Network Design and Infrastructures	General Review
45	Yang et al.	2018	Journal Paper	Transportation Research Part A	One Belt one Road, but several routes: A case study of new emerging trade corridors connecting the Far East to Europe	Belt and Road	Network Design and Infrastructures	Case Study
46	Rakhmangulov et al.	2018	Book Chapter	Transport Systems and Delivery of Cargo on East–West Routes	Sustainable development of transport systems for cargo flows on the east-west direction	Belt and Road	Network Design and Infrastructures	Conceptual Model

47	Li et al.	2018	Journal Paper	Journal of Chinese Economic and Business Studies	The effect of the New Silk Road railways on aggregate trade volumes between China and Europe	Belt and Road	World Trade and International Relations	Mathematical Model
48	Rimbekov et al.	2018	Book Chapter	Transport Problems	The effectiveness of logistics development and its impact on the economies of the countries along the silk road passing through Kazakhstan	Belt and Road	World Trade and International Relations	Conceptual Model
49	Wei et al.	2018	Journal Paper	Maritime Policy & Management. The flagship journal of international shipping and port research	The role of dry port in hub-and-spoke network under Belt and Road Initiative	Belt and Road	Network Design and Infrastructures	Mathematical Model
50	Benrqya	2018	Journal Paper	International Journal of Business & Management Science	Impact of the product characteristics on the distribution strategy selection: a literature	International Logistics	Product Diversity	Literature Review
51	Chen & Song	2019	Journal Paper	Journal of Coastal Research	Evaluation of Port Logistics Competitiveness in China along the Belt and Road	Belt and Road	Network Design and Infrastructures	Conceptual Model

52	Wei et al.	2019	Journal Paper	Computers&IndustrialEngineering	Import-export freight organization and optimization in the dry-port-based cross-border logistics network under the Belt and Road Initiative	Belt and Road	Network Design and Infrastructures	Mathematical Model
53	Chana et al.	2019	Journal Paper	Transportation Research Part E: Logistics and Transportation Review	Logistics and supply chain innovation in the context of the Belt and Road Initiative (BRI)	Belt and Road	Innovation and Technology	Literature Review
54	Alon et al.	2019	Journal Paper	Business Process Management Journal	Supply Chain - marketing integration: How do European SMEs go to China via the New Silk Road	Belt and Road	World Trade and International Relations	General Review
55	Wei et al.	2019	Book Chapter	The New Silk Road Leads through the Arab Peninsula: Mastering Global Business and Innovation	The Analysis of "Online Silk Road" from the Perspective of Big Data	Belt and Road	Innovation and Technology	Mathematical Model
56	Visvizi et al.	2019	Book Chapter	The New Silk Road Leads through the Arab Peninsula: Mastering Global Business and Innovation	The Belt and Road Initiative: Strategy, Collaboration, Innovation	Belt and Road	World Trade and International Relations	General Review

57	Kauf et al.	2019	Book Chapter	LogForum	The Location of an International Logistics Center in Poland as a part of the One Belt One Road Initiative	Belt and Road	Network Design and Infrastructures	Case Study
58	Brakman et al.	2019	Journal Paper	Cambridge Journal of Regions, Economy and Society	The New Silk Roads: An introduction to China's Belt and Road Initiative	Belt and Road	World Trade and International Relations	General Review
59	Kozlowski	2019	Book Chapter	The New Silk Road Leads through the Arab Peninsula: Mastering Global Business and Innovation	The Past, the Present, and the Future of the New Silk Road: China as a Leader or a Free-Rider in International Relations	Belt and Road	World Trade and International Relations	General Review
60	Zhang et al.	2020	Journal Paper	International Journal of Logistics Management	Assessing the market niche of Eurasian rail freight in the belt and road era	Belt and Road	World Trade and International Relations	Mathematical Model
61	Lee et al.	2020	Journal Paper	Journal of Management Science and Engineering	Supply chain and logistics innovations with the Belt and Road Initiative	Belt and Road	Innovation and Technology	General Review
62	Jiang	2020	Book Chapter	Governance and Sustainability	The Critics and Development of China's 'One Belt One Road' Initiative for Global Economic Development and Sustainability	Belt and Road	World Trade and International Relations	General Review

63	Awad et al.	2020	Journal Paper	International Journal of Logistics Management	Vehicle routing in cold food supply chain logistics: a literature review	International Logistics	Product Diversity	Literature Review
64	Zhang et al.	2021	Journal Paper	Physica A: Statistical Mechanics and its Applications	An evolutionary model of the international logistics network based on the Belt and Road perspective	Belt and Road	Network Design and Infrastructures	Conceptual Model
65	Cameron et al.	2021	Journal Paper	Journal of International Trade Law and Policy	Identifying export opportunities for China in the 'Belt and Road Initiative' group of countries: a decision support model approach	Belt and Road	World Trade and International Relations	Mathematical Model

Table 2.1: *Papers' categorization.*

2.2.1 Main Features of the Papers

As previously explained, the two main themes of this literature review are the Belt and Road Initiative (BRI) and International Logistics, which results to be well balanced in terms of contributions. Indeed, 49% of the selected articles regards the first subject (32), while 51% is related to the second one (33).

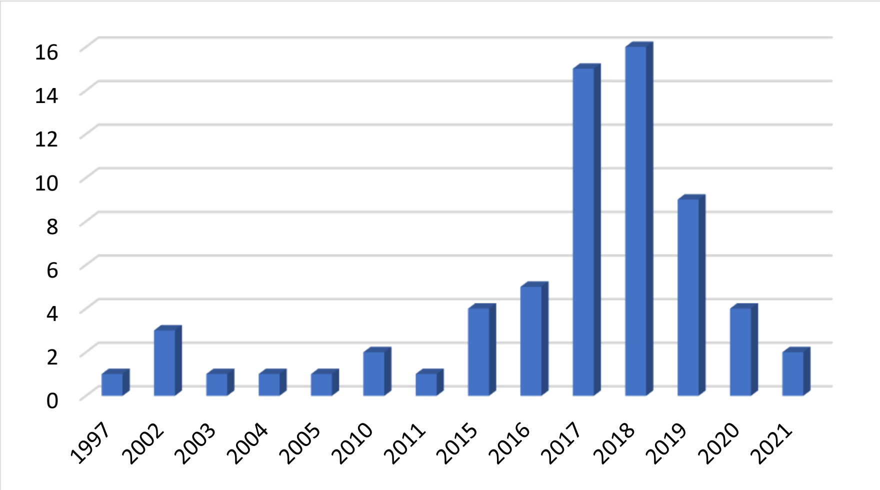


Figure 2.2: *Papers' publication year distribution.*

As data suggests, more than two out of three selected articles (71%) have been published in the last five years. This outcome is mostly related to the fast-growing interest that the Belt and Road generated among both scholars and practitioners. Indeed, this subject gained momentum only recently, confirmed by the peaks of publications in 2018 (11) and 2019 (9), compared to 2016 (1) and the absence of contributions in the previous years.

As regards the sources of publications, most of the papers has been gathered from academic journals (68%), while the remaining ones belong to book chapters (17%) and conference papers (15%). Among the different international journals, the main ones include the Transportation Research Journal, The International Journal of Logistics Management and The International Journal of Physical Distribution and

Logistics Management. However, since the review regards two transversal and multilateral topics, many sources have been consulted (48).

Papers have been further studied according to the adopted research method. The analysis is based on the classification presented by ***[94]***, which pointed out 7 research methodologies applied in the supply chain and logistics management research articles:

- *Survey;*
- *Simulation;*
- *Interviews;*
- *Mathematical model;*
- *Case study;*
- *Conceptual model;*
- *Others (literature review, insights from the industry, etc.).*

On the ground of this classification, the most used methods are literature and general reviews (42%), mathematical model (25%) and conceptual model (18%). The first one is almost equally applied for both topics, while the mathematical approach is predominant in the Belt and Road research articles, suggesting the strong interest in this field coming also from scholars.

Research Method	Papers	%
Literature and General Review	27	42%
Mathematical Model	16	25%
Conceptual Model	12	18%
Case Study	8	12%
Survey	2	3%

Table 2.2: *Papers' research methods used.*

2.2.2 Main themes tackled

As previously presented, the two main themes covered by the selected papers are the Belt and Road and International Logistics. However, to provide a deeper representation of the extant literature, articles have been further categorized according to the specific content they tackle. In particular, three sub-topics for each main research field are highlighted:

- *Belt and Road Initiative (BRI).*
    - *Network Design and Infrastructures;*
    - *World Trade and International Relations;*
    - *Innovation and Technology;*
- *International Logistics.*
    - *International Distribution;*
    - *Logistics and Product Types;*
    - *Cross-Border E-Commerce;*

In the next paragraphs, a brief review of the papers is presented for each topic covered, according to the subdivision reported above. In particular, articles are analyzed according to their focus, research methodology applied and results, highlighting also the main findings.

2.2.3 Belt and Road Initiative (BRI)

Among the articles dealing with the Belt and Road, half of them analyze the problem of network design (53%), followed by World Trade and International Relations (31%) and Innovation and Technology (16%).

2.2.3.1 Network Design and Infrastructures

Logistic Network Design is a strategic subject for business, involving the definition of the number, location and size of plants and warehouses, as well as the configuration of the physical flows between the different facilities. The design of the logistic network along the Belt and Road trade corridors is a key point in the promotion of the BRI strategy, and is strictly related to the infrastructure development of the involved countries. Although many of the BRI branded projects have already been started before the BRI was unveiled in 2013, they gained momentum under the Initiative, raising also the interest of scholars and practitioners. Indeed, as pointed out by *[138]*, many countries such as Pakistan, Kazakhstan and Thailand have embraced the BRI by exploiting human and non-human resources to become key nodes in the B&R network and hence to enhance their economic strength in global trade. Also *[53]*, focusing on the Polish environment, stresses the importance of BRI as an opportunity for European countries to become a logistic hub and distribution center of the physical flows between China and Europe.

The reason of these positive feedbacks is linked to the massive impact that the B&R may have on a country. *[51]* studies the effects of BRI on international logistics networks, analyzing the main aspects affected, which are in turn the decisional variables considered by countries for the adhesion to the initiative. The authors clustered the main divers as economic factors, political factors, or other transportation and social factors, highlighting the importance of both quantitative and qualitative views in the evaluation of BRI results.

Economic factors	Market demand and prices, production costs, transportation costs, import tariffs/export taxes, monetary exchange rates, inflation and interest rates, duty drawbacks, transfer prices, etc.	(Vidal and Goetschalckx 1997a; Vos 1997; Alles and Datar 1998; Schmidt and Wilhelm 2000a)
Political factors	Political stability, trade regulations, local content rules, financial incentives, etc.	(Schmidt and Wilhelm 2000a; MacCarthy and Atthirawong 2003; Chen and Paulraj 2004)
Others	Labor characteristic, infrastructure, telecommunication technologies, culture differences, etc.	(Canen and Canen 2001; MacCarthy and Atthirawong 2003)

Figure 2.3: *BRI adhesion drivers (Ye and Haasis, 2018).*

A crucial role within the B&R network design is played by logistic infrastructures. Sea transportation has always been the most widespread solution to ship goods between China and Europe, and therefore the interest in ports development is not a novelty. However, the 21st Century Maritime Silk Road project has breathed new life into the ancient oceanic routes, allowing new research fields to emerge. First of all, this new initiative showed the need of evaluating the adequacy and competitiveness of the extant facilities, which are included in the B&R network. ***[18]*** studied the logistic capabilities of 15 Chinese ports through a factor-analysis method, that impact on the development of the BRI. Moreover, the Maritime Silk Road has significantly increased the investments in dry ports, which are facilities used to connect seaports to inland destinations. They operate as distribution centers for the transshipment of sea cargo to inland locations, usually through road or rail transport, with the objective to stimulate inland regions' economy on one side, and to reduce congestion and hence lead time within ports on the other. According to ***[140]***, the role of dry ports has become crucial in order to link seaports with inland transportation routes, creating synergies between the New Silk Road and the 21st Century Maritime Silk Road projects. This result comes from the application of a logistic gravity model, through which they positively evaluate the impact of the connections between dry ports and seaports on B&R network design. Moreover, ***[142]*** expands the previous work, by presenting a mixed-integer linear programming (MILP) model to analyze the optimization problem of inland transport for dry-port-based logistics networks, through which dry ports are proved to be crucial to improve the efficiency of inland logistics networks.

Along with the Maritime Silk Road, the Silk Road Economic Belt, also known as New Eurasian Land Bridge (NELB), has the objective to enhance the inland network of the B&R through the empowerment of extant and new logistics infrastructures, such as airports, motorways and railways. The investments made in the latter's development are huge and allowed train transportation to be considered as a new logistic solution to ship goods from Europe to China and vice versa. ***[97]*** evaluates the problem of construction priority of high-speed railway within the BRI, and implements a decision-making process for the selection of the most urgent railway infrastructure to realize on the ground of road characteristics, political stability, national cooperation and many others. Comparing the results with the B&R ongoing or future projects, some differences arise, maybe because different factors like climate impact or natural disasters have not been considered.

However, as presented by ***[137]***, from the opening of the China Railway Express (CRE) in 2011, 57 alternative routes involving 35 Chinese central cities and 34 European cities from 12 different countries were available after only 6 years, increasing exponentially also the number of annual trains within the same time span (from 17 to 3673), for a cumulative freight traffic of 220,000 TEUs and a cargo value of 20.5 billion USD.

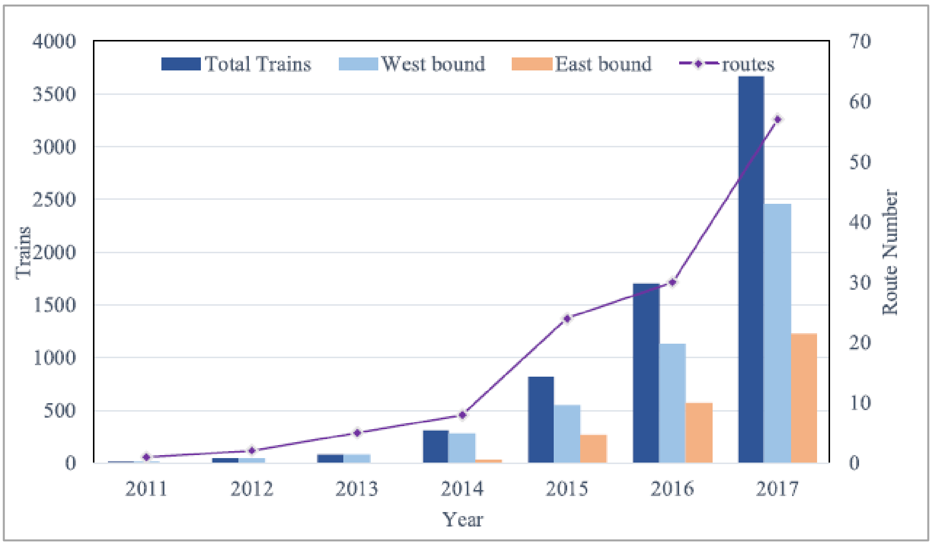


Figure 2.4: *B&R routes and train number per year (Wang, 2015).*

The realization of the CRE opened new research questions in the logistics field related to the optimization of goods' international delivery and the choice between different transportation modes considering also the train solution. ***[49]*** gives an important contribution by comparing the CRE with the seaborne container shipping in terms of freight cost structure. By means of a binary logit model, governmental subsidies are proved to be crucial in the reduction of CRE freight cost, which will allow to attract approximately 5% of the total Sino-European freight. Moreover, results show that IT products and other high-value density goods are the most likely to be shipped through CRE network. In addition, *[139]* proposes a "hub-and-spoke" organizational model able to optimize transports in terms of shipping volumes and freight costs. In this study, Moscow is selected as the best distribution point for the flows between China and Europe, and 314 Chinese cities are considered to evaluate the cost of the alternative routes. From the results it's possible to conclude that the most cost-effective solution is the route passing through the economic hinterland of Manzhouli, for which some policy recommendations are also provided.

The development of the Silk Road Economic Belt has increased scholars' interest into another topic, the transportation routing, which has become more and more complex as train transportation has been introduced as a new solution and additional variables have now to be considered. *[149]* examines the preferences of industry practitioners on the different trade corridors connecting China to Europe, developing a Fuzzy Multi-Criteria Decision Analysis (MCDA) model to rank the most appreciated alternatives on the ground of the data collected through survey. The model is built on a list of many evaluation criteria, which are clustered on the ground of different areas: technology, economics, environment, governance and commodity nature. This contribution allows to have a broader and more comprehensive view of the decisional drivers for the choice of the best transportation mode, by introducing innovative aspects such as product characteristics and environmental features. *[148]* exploits an optimization model in order to find the most cost-efficient solution able also to provide a predetermined service level, that is another driver to consider in the transportation routing problem formulation. *[30]* stresses the importance of the accessibility, which is a further logistics diver expressing the ease of reaching a specific node within the supply chain network, and therefore is related to the availability of proper infrastructures and transport routes. Examining a multimodal transport routing problem, that considers the possibility to integrate different transport modes within the same delivery, a time-spatial network is built, through which the best nodes for the B&R network design with respect to accessibility and transhipment are underlined. As verified by previous contributions, Manzhouli, Moscow and Warsaw are crucial hubs within the B&R network, while new suggestions are represented by Hamburg and Rotterdam.

2.2.3.2 World Trade and International Relations

The creation of the B&R is of course the result of economic and political considerations, which involve a huge number of countries that may be positively affected by the realization of the initiative in terms of trade volumes, infrastructure development and many more aspects. Indeed, according to the BRI official outline reported by ***[136]***, BRI aims to "promote the connectivity of Asian, European and African continents and their adjacent seas, establish and strengthen partnerships among the countries along the Belt and Road, set up all-dimensional, multi-tiered and composite connectivity networks, and realize diversified, independent, balanced and sustainable development in these countries". According to ***[91]***, the pursue of collaboration and connectivity between countries is crucial in the actual economic environment, where the globalization of markets requires transport and logistics infrastructure to move from single solutions to network solutions, in which a high number of terminals are placed in every partner country in order to enhance the speed and ease of goods' distribution.

The development of a widespread network opens new export opportunities for China. ***[67]*** evaluates the potential effect of the initiative on Chinese export by considering nine railway lines belonging to the B&R network and the countries connected by these infrastructures. Data shows that Chinese export performances are much higher with B&R partners, thanks to the positive impact of intercontinental railways. ***[157]*** deepens the analysis of the B&R consequences on trades between Europe and China, creating a model that evaluates the trade-off between transit time and transport cost of the different transport modes. Rail freight is proved to be 80% less expensive than air freight and 50% more beneficial in terms of transit time respect to sea freight.

"However, the BRI countries are very diverse in terms of their development status, political system, market size, consumption characteristics and transport infrastructure" ***[15]***. Therefore, for a successful export strategy, it's crucial for a country to select the most profitable foreign markets, on the ground of different parameters. ***[15]*** exploited a decision support model (DSM) to identify the best export opportunities for China in the BRI countries. Market selection is carried out considering countries' political and commercial risk, economic size and wealth, product characteristics and market accessibility, to come up with a list of the most profitable countries to export. Results show that, considering the number of products to sell abroad and the monetary value of the volume exported, the best country is represented by South Korea, followed by Austria and Poland.

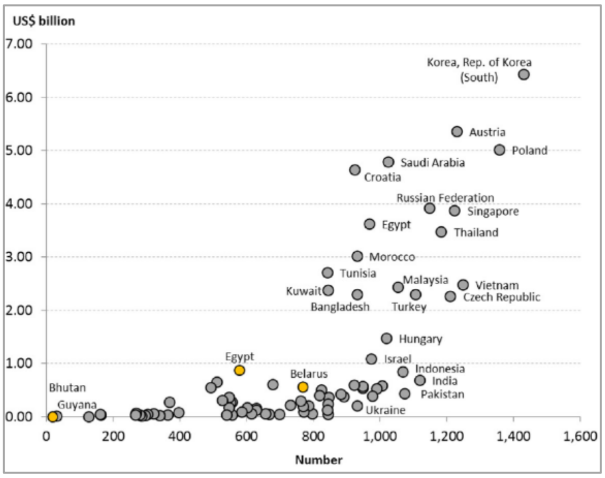


Figure 2.5: *BRI countries' export potential (Cameron et al., 2021).*

The B&R is not only beneficial for China in terms of export, but also for all the countries involved in the initiative. Indeed, as ***[10]*** notes, "the share of China's imports from these countries rose by 4.1 percentage-points (from 10.7% in 2001 to 14.9% in 2017)", that is clear evidence of the BRI positive impact on the B&R country partners. Focusing on European firms, ***[1]*** investigates the opportunities for small and medium-sized enterprises (SMEs) to export to Chinese markets. Frist, different trade barriers are discussed, such as transportation, warehousing and distribution operations, as well as marketing and communication activities. On the ground of these obstacles, the effects of BRI are reported, which show that the new logistics infrastructures notably lower the supply chain barriers and hence foster cooperation and international trade between European countries and China.

Obviously, BRI is not immune to its own share of criticism. The initiative seemed at first to be very limited in terms of volumes and value exported, respectively equal to 1% and 2% of the total trade activities between Europe and China in 2017. However, thanks to the positive trend registered in the latest years and the growing investments made by all the country involved, the initial skepticism has been overcome. The real extent to which the B&R can develop is represented by BRI partners diffidence of Chinese approach to the project. Indeed, as explained by ***[58]***, even if economic advantages are well visible, the way China promotes international cooperation is pretty frowned upon due to its lack of transparency and legal rules, since it is mostly based on informal institutions. "Chinese policy-making should adapt to the new reality of being a leader… China, if it does not realize that, despite being one of the biggest surprises in terms of dynamics of development in twentieth century, may become one of the biggest disappointments in twenty-first century" ***[58]***.

2.2.3.3 Innovation and Technology

The creation of such a complex project as the B&R requires the development and implementation of many technologies to support all the planned initiatives and to reshape the flow of goods and information within current business models ***[16]***. As noted by ***[64]***, China alone has already invested more than 900 billion USD in the BRI, covering various development areas.

Of course, logistic initiatives are characterized by the highest share within the BRI budget, due to its primary focus on international transportation enhancement. However, alongside the B&R network design, particular attention is paid to technologies able to support flow of goods' performance improvement. ***[156]*** introduces a mixed integer linear programming (MILP) model to optimize the problem of empty containers repositioning within the B&R network. As the authors explain "in this model, empty containers are repositioned from the inland of the original area, such as China, to other areas of B&R Initiative related countries and regions, such as European Union and Southeast Asia". The model allows to better allocate empty containers, optimize their routes and hence minimize transportation costs. However, as ***[21]*** notes, "to ensure the successful implementation of China's Belt and Road (B&R) Initiative, it is essential to enable the real-time monitoring of containers' locations, prevent theft during cargo delivery, ensure more efficient logistics management and reduce carbon emissions". This article presents a model for the development of an IoT-based container tracking system, which allows on one side to effectively control containers' routings across multiple countries in a cost-efficient way, and on the other side to simplify cross-border procedures.

Digital innovation is a crucial point within the B&R network, that became concrete in 2015 when the Digital Silk Road (DSR) was launched as a component of the BRI. This project aims at fostering digital connectivity between partner countries, and 79 billion USD has already been invested in several initiatives. On a macro perspective, data cables and storage centers, 5G networks and satellite navigation systems are the most widespread blueprints, while FinTech (financial technology), EdTech (education technologies) and e-commerce are crucial to promote linkages between local businesses and consumers. This latter, as explained by ***[142]*** has hugely fostered trade connections between countries, showing the potential of cross-border e-commerce (CBEC) and B&R network for export-oriented firms.

2.2.4 International Logistics

International logistics is defined by the Council of Logistics Management as "the management process of planning, implementing, and controlling the physical and information flows concerned with materials and final goods from the point of origin to the point of usage, when it involves crossing at least one international border". Of course, this is not a new topic in the research field, and indeed the selected articles cover a time frame of almost twenty years (2002-2020). Among them, 36% focuses on e-commerce, 33% on product types and characteristics, and 31% on international distribution.

2.2.4.1 International Distribution

The distribution of goods in foreign markets is one of the critical parts of the supply chain, and requires different strategies on the ground of the target country where products have to be exported. As explained by ***[48]***, China passed through a long transitional period, where the traditional distribution system, characterized by a strict control from the State and rigid vertical lines (manufacturers, wholesalers, retailers), has been replaced by the current one, in which the demarcation between each level of the distribution network have broken down. This means that nowadays manufacturers are allowed to sell directly to retailers without resorting to wholesalers, and hence the three tiers compete against each other.

From a foreign company perspective, Chinese logistic service providers have always been characterized by lower service level than in more developed countries, due to undeveloped logistics infrastructures. Indeed, as ***[155]*** shows, the booming economy and the consequent massive demand generated have not been supported by a proper logistic network, creating congestions in most of Chinese seaports and airports. Moreover, ***[30]*** notes that international logistics has to face unprecedent issues and risks, related to transportation, markets and environment. However, the development of the B&R and the improvement of the distribution network should encourage Chinese logistic service providers to move from cost to more service-based differentiation ***[106]***. Moreover, since new routes are now opened and old ones have been improved, Chinese logistics capacity has increased a lot and in now able to deal with huge volumes of goods to be transported. ***[61]*** investigates the best network of consolidation centers considering the Chinese railway express and national highways. By means of a TOPSIS model, Xi'an, Taiyuan, Zhengzhou, Wuhan, and Suzhou offer the best combination of consolidation center locations. Xi'an, Taiyuan, Zhengzhou, and Wuhan are found to be the best cities where to place a logistic hub in order to optimize the delivery of goods throughout China.

The development of an international distribution network allowed a new trend to rapidly evolved in the last decade, cross-border e-commerce (CBEC), which refers to overseas direct purchase made via internet. ***[20]*** examine how logistic aspects influence the success of CBEC, and notes that air delivery is nowadays more and more involved, since customers require fast and reliable deliveries, having also the possibility to track their order in real time. However, air freight industry is not able to meet the whole CBEC demand, and costs are still too high to meet customers' expectations. Therefore, the BRI and the new opportunity of train transportation may be the solution to overcome these barriers and foster the development of CBEC.

2.2.4.2 Cross-Border E-Commerce (CBEC)

The economic growth and the drastic socio-political changes that China has experienced over the past years had a huge impact on its national reality, but also on the global economy. The adoption of new technologies and the market digitalization boosted the development of e-commerce and encouraged consumers to shop online all around the world. Therefore, "as Chinese consumers are generally leaned towards buying international brands, entering this market while exploiting the rising trend of online and mobile commerce adoption might be an interesting opportunity for western companies" *[36]*. The combination of these two trends gives rise to the so-called Cross-Border E-Commerce (CBEC).

The success of a CBEC strategy lies on the logistics strategy adopted to support the distribution of goods in the foreign country. Indeed, as noted by *[69]*, the growth of CBEC has to be supported by an efficient and flexible distribution network, in order to fulfil consumers requirements. *[137]* presents three main CBEC logistic models:

- Third party logistics (3PL), which implies an outsourced provider who manages the logistic operations on behalf of the partner company.
- Overseas warehousing, which implies that the company places a warehouse in the target country where its products have to be sold.
- Logistics alliance, which aims at exploiting synergies between the resources of different companies by signing long-term contracts.

Focusing on the warehousing strategy, *[36]* developed a model that considers three different logistics solutions to apply within the apparel industry: distribution through warehouse placed in China, distribution through warehouse placed in the origin country or distribution through sorting hub placed in China, which differs from the previous ones in terms of operations, since sorting hubs can be defined as transit points which do not imply storage activities.

However, CBEC brings around some issues and challenges. *[37]* explains the main differences between CBEC and national e-commerce, stating that the first one is more complex and riskier, since it deals with multiple cultures and many factors. Moreover, it requires higher investments in order to better serve the destination market. Another issue is presented by *[153]*, who identifies "the mismatch between the traditional business supervision measures and the continuous innovative business models" as an obstacle in the development of China's CBEC.

2.2.4.3 Product Diversity

Logistics and Supply Chain Management have become more and more a complex topic as the market competition and the product variety increased. Therefore, product characteristics have become a crucial driver for the design of a proper network and to support the distribution of products into the market. *[33]* presents a first distinction between functional products, which are standard goods that require an efficient process, and innovative products, which require a more responsive process in order to meet varying customer requirements. On the ground of this diversification, efficient and responsible supply chains can be designed. *[23]* deepens this classification, identifying two different cluster of products on the ground of two main market winner features: service level and cost. The maximization of service level should be pursued by applying an Agile Supply Chain, characterized by high responsiveness and flexibility, while the minimization of costs can be achieved through a Lean Supply Chain, which exploits efficiency.

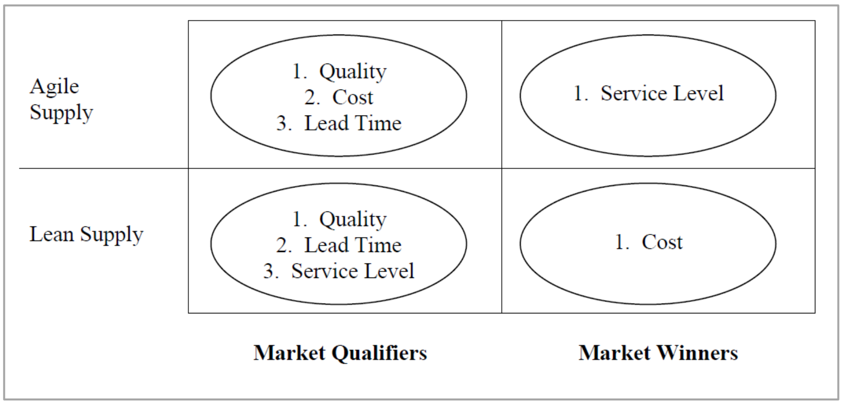


Figure 2.6: *Agile and Lean Supply Chain approaches (Christopher et al., 2002).*

Moreover, *[137]* highlighted also the importance of product lifecycle, while *[8]* expands the product characteristics to take into account when designing a supply chain, considering product shelf space, demand variability, product value, and lead time. The impact of product value on supply chain management has been analyzed by *[71]*, which develops a supply chain segmentation framework on the ground of different product characteristics, highlighting above all the importance of the so-called product value-density (PVD), defined as the ratio between product value and chargeable weight.

Among all product types, food industry is the one that arouses the highest interest and requires more attention due to its peculiar characteristics. *[80]* developed a supply chain optimization model for the transportation of fresh food products, with the objective of minimizing the total cost given a specific level of food quality to meet. Within the same context, *[76]* presented a framework to support food transport orders scheduling, considering both perishability constraints of food products and environmental constraints of the targeted market zones.

[5] investigates cold supply chain (CSC) distribution systems, highlighting their complexity due to the need of preserving food integrity and freshness. Moreover, the risk of food perishability increases CSC cost, especially related to the high fuel consumption od refrigerating equipment, which has a huge impact also on environmental sustainability because of significant emissions. Focusing on the "green" aspect, *[24]* questions the sustainability of food global distribution: "Inevitably, there is an environmental cost associated with the long-distance sourcing of these items. Transport and refrigeration rely on fossil fuels to power them, resulting in the emission of various gasses that have a detrimental effect on the environment".

2.3 Gap Analysis

From the presented review, it's possible to highlight the main lacks emerging in the analyzed academic literature, in order to understand the research area where this master thesis will be positioned.

The main consideration that clearly emerges from the articles cataloguing is that there is only a slight connection between the two main topics under inspection: B&R and international logistics. Indeed, even though this literature review presents plenty of articles dealing with international logistics, none of them translates any concept or finding into such a recent and interesting topic as the Belt and Road. On the other side, among all the articles dealing with the BRI, the ones approaching the problem of logistic network design and goods distribution are still limited to pure theoretical and qualitative reasoning, without providing successful models able to tackle these problems. Moreover, most of the research papers considers only economical and sociopolitical variables in the evaluation of specific opportunities and threats that the B&R may bring to Chinese and European companies, leaving apart other crucial aspects such as product characteristics and logistics features. However, in the latest years, these drivers have aroused the interest of many scholars and practitioners, who understood their importance for strategic managerial choices within the B&R environment. However, literature lacks of models that take into consideration all these decisional variables, because each article analyzes only one or few of them.

Another reflection regards the comparison between the different transportation modes that is possible to choose when dealing with the B&R. Indeed, many articles developed optimization models that evaluate different routes from the point of origin to the point of destination, considering the choice of the transportation mode as given. As BRI introduced train as a new transportation mean, and the New Silk Road and the 21st Century Maritime Silk Road as new routes, it would be interesting to compare all the possible transportation solutions, in order to choose the proper one on the ground of all the considered decisional variables.

Last, given the novelty of the topic, literature lacks of evidences on the efficacy and the coherence of the transportation solution adopted by companies respect to their requirements and managerial needs. Therefore, it would be interesting to investigate whether the possible transportation means are effectively exploited, especially railway network, to better understand also future developments and improvement areas.

To sum up, this master thesis aims to evaluate the different transportation modes of the B&R on the ground of all the relevant drivers that are possible to take into consideration, along with practical evidences of their exploitation by international companies.

3. Focus of the Thesis

The aim of this chapter is to clarify the main points on which the analysis of this thesis will focus. In particular, the following points will be clarified:

- Import and export flows between China and Europe;
- Main routes and logistical hubs used for trade flows;
- Classification of the product types used in the research.

3.1 Trade Flows between Europe and China

The USA, China and the EU have always been the world's three main superpowers, generating large amounts of trade and negotiations of all kinds over the years. For many years, the US has been the EU's leading trading partner, guaranteeing import and export flows of 232.6 mln and 384.4 mln respectively ***[108]***. In 2020, however, the hierarchies were reversed, with China becoming the European Union's top trading partner, thanks to rising numbers in both imports and exports. Imports grew by 5.6% year-on-year to EUR 383.5 billion, while exports grew by 2.2% to EUR 202.5 billion. At the same time, however, trade with the US saw exports fall by 8.2% (from EUR 384.4 billion to EUR 353 billion) and imports by 13.2% (from EUR 232.6 billion to EUR 202 billion).

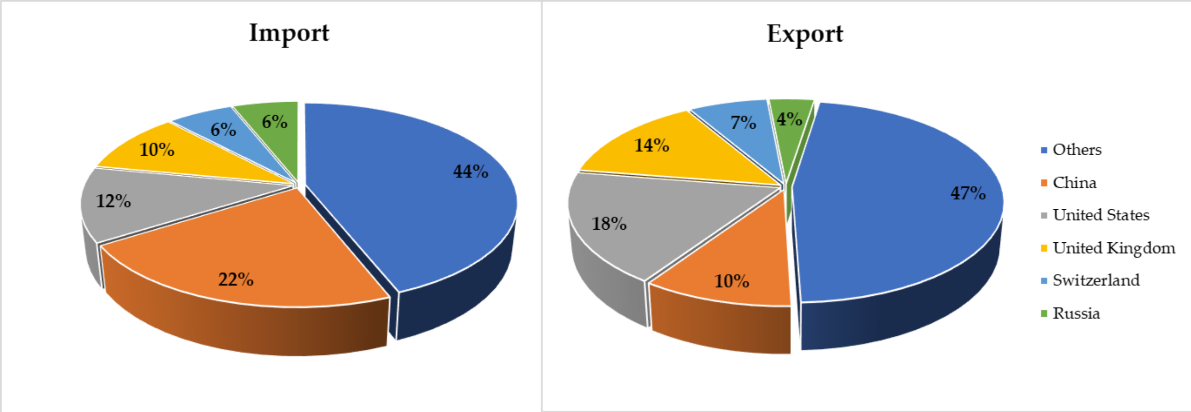


Figure 3.1: *EU Import and Export main partners (Eurostat, 2019).*

From Figure 3.1, it's possible to observe that China is the country from which the EU imports the most products, while on the export side, the United States remains the leading country in terms of export value. China's overtaking of the United States as the European Union's leading trading partner is due both to a powerful slowdown in US import-export trade flows and to a growth in European exports to China, but above all to even greater growth in European imports from China. Obviously, it should be stressed that the evolution of the data over the last two years is the result of a particular situation. In fact, the Covid-19 pandemic caused some imports from China to Europe to explode - emblematic, for example, is the case of masks. In addition, China reacted more quickly than Europe and the United States and this had a positive impact on trade flows. Finally, US data were affected both by the more closed policies of the end of Donald Trump's presidency and, of course, by Covid-19.

Having said this, our research will therefore focus on analyzing in detail the trade exchanges between the European Union and China. The initial idea with which the master thesis started was that of placing Italy at the center of the research, and then opting for a broadening of the focus by considering the most relevant states, in terms of importance and strategic position within the Belt & Road, within the European Union. This approach has been used in order to minimize research limitations, and then to be able to consider the different strategic drivers of the different European states that influence the choice of one means of transport rather than another.

3.2 *Routes selection*

This chapter aims to clarify the main routes that have been introduced by the B&R Initiative, and identify those that are useful for our research.

3.2.1 The New Silk Road Routes

The aim of the New Silk Road, also known as Belt & Road or One Belt One Road, is to promote economic cooperation and to connect China to South and Central Asia, Russia, Africa and Europe, opening new channels by land and sea, and to improve connectivity by building infrastructure, railways, ports. The two main elements of the OBOR are ***[114]***:

- The *"21st Maritime Silk Road"* or *"One Road"*, which runs along the whole of East and South Asia, reaching as far as the Mediterranean Sea through the Suez Canal, and therefore aims to create a link with Europe via the South China Sea and the Indian Ocean, and with the South Pacific via the China Sea.
- The *"Silk Road Economic Belt"* or *"One Belt"*, namely the Terrestrial Silk Road, which runs through the whole of Central Asia from China to Spain.

Looking at it in more detail, six corridors complete this Silk Road ***[113]***.

Figure 3.2: *Belt and Road Economic Corridors.*

1. The New Eurasia Land Bridge Economic Corridor (NELB). The New Eurasia Land Bridge, also known as the Second Eurasia Land Bridge, is an international railway line running from Lianyungang in China's Jiangsu province through Alashankou in Xinjiang to Rotterdam in Holland.
2. The China-Mongolia-Russia Economic Corridor (CMREC). Linked by land, China, Mongolia and Russia have long established various economic ties and cooperation by way of border-trade and cross-border cooperation.
3. China-Central Asia-West Asia Economic Corridor (CCWAEC). This Corridor runs from Xinjiang in China and exits the country via Alashankou to join the railway networks of Central Asia (Kazakhstan, Kyrgyzstan, Tajikistan, Uzbekistan, Turkmenistan) and West Asia (Iran, Turkey, etc.).
4. China-Indochina Peninsula Economic Corridor (CICPEC). The Corridor mainly covers the Greater Mekong Sub-region. In particular, Guangxi has opened an international rail line running from Nanning to Hanoi, as well as introduced air routes to several major Southeast Asian cities.

5. China-Pakistan Economic Corridor (CPEC). The objective of China-Pakistan Economic Corridor is to build an economic route running from Kashgar, Xinjiang, in the north, to Pakistan's Gwadar Port in the south.
6. Bangladesh-China-India-Myanmar Economic Corridor (BCIMEC). The B&R Initiative proposes developing the Bangladesh-China-India-Myanmar Economic Corridor and facilitate cooperation through building a closer relationship.

3.2.2 Belt and Road Main Logistics Hubs

Having presented the existing routes that make up the Belt & Road, the possible routes considered in the master thesis will now be defined. Given that the analysis that was subsequently carried out within the master thesis is aimed at 3 different product categories, as analyzed in more detail in the next chapter, where for each of them there is an optimal route and means of transport, it would have been limiting, to say the least, to focus on only one of the routes introduced by the B&R and only on one means of transport. Therefore, candidates focused on the choice of an all-encompassing solution, i.e., one that would consider all possible routes that could be used, including the air solution.

It is precisely the latter, which initially seems to take a back seat in the explanation of trade routes, is becoming increasingly relevant - and may eventually become important in global aviation even though unlikely will be a dominant feature in the BRI. In fact, it is notable how a growing number of Chinese mainland and Hong Kong investors are looking to Europe in particular for airport-related investments and while it is evident some are doing so with the spirit of the Silk Road at the forefront of their thinking ***[111]***.

Actually, China is the world's second largest aviation power after the US, but the international expansion planned under the BRI, with strategic cooperation and

M&As is expected to lead to a reshaping of the global industry. To show how air routes play at least an important role in the Belt & Road project nowadays, the following map shows the main routes of Hainan Airlines, one of the largest airlines in the Chinese country.

Figure 3.3: *Belt and Road air freight network.*

Furthermore, in Jan-2018, the South China Morning Post reported that investment company China Everbright and its one-third (32.3%) owned Hong Kong-listed aircraft leasing unit, China Aircraft Leasing, were planning to launch a Silk Road Fund that would "invest in aircraft leasing and related businesses".

As far as rail routes are concerned, for our research, analyzing the logistic of the BRI in Europe, of the six economic corridors outlined in the BRI initiative, the most relevant is the New Eurasian Land Bridge Economic Corridor, which trains link Chongqing to Duisburg, Chengdu to Lodz, Yiwu to Madrid, Wuhan to Hamburg, and Wuhan to Lyon, with the aim to increase the frequency of rail transportation between China and Europe.

As for the 21st Maritime Silk Road, which deals with shipping routes to European ports, the route followed, starting from China, pass through the Malacca Strait, follow Red Sea through the Suez Canal to the Mediterranean Sea, and visit ports in Greece, Italy, France, and Spain before returning to China. The most relevant case in this respect is the port of Piraeus in Greece, where COSCO shipping, currently the largest Chinese maritime transport company, holds approximately 70% of the port itself, thus contributing to the ongoing development of one of the world's most important container ports and confirming its centrality as a commercial hub. Another interesting case is that of the Italian port of Vado Ligure, one of the largest terminals of its kind in Europe, being the only one capable of hosting megaships among the ports of northern Italy. COSCO Shipping has acquired 40% of the issued share capital of Vado Holding, the company that owns the refrigerated terminals at the port of Vado Ligure. Among other port terminals in which Chinese companies have partly invested to acquire shares, it is worth naming: Valencia and Bilbao in Spain, Le Havre and Marseille in France, Zeebrugge and Antwerp in Belgium, Rotterdam in the Netherlands, Marsaxlokk in Malta and Kumport in Turkey. The Maritime Silk Road has also an important role in the connection between East Africa and the Mediterranean region through the Suez Canal.

Figure 3.4: *Sea and rail freight connections in the context of the B&R.*

3.2.3 Product type classification

One of the main focuses of our research, which will be further explored by explaining the mathematical model used, concerns the selection of the best means of transport and route according to the category of product being traded. Indeed, logistics and distributive strategies are strictly related to product characteristics, which affect both internal and external performances of the company. With this respect, the considered product categories have been classified by considering two main criteria: product flow and product value. The first one has been approached by taking the perspective of a European company trading goods with China, and hence flows have been distinguished between import and export, where the first one refers to the movement of goods from a Chinese point of origin to a European point of destination, while on the opposite the second one refers to the movement of products from a European point of origin to a Chinese point of destination. Product value is way more complex, and requires a deeper analysis. It is affected by product flow itself, due to the country-of-origin effect, which alter the value of a product with respect to the country where it has been produced. Moreover, absolute value is not a comparable unit of measure, and hence product value has been evaluated on a weight scale, assessing the value of one kilogram of the given product. This measure is called product value density (PVD), and allows to measure products' value per kilogram, allowing to make a fair and exact comparison between products based on their value. The whole process will be explained in details in the next chapters.

4. Research Questions

As emerged from the literature review, economic and socio-political factors represent the only drivers considered in the analysis of logistics problems throughout the Belt and Road within most of the research papers. Strategic factors, such as lead time and service level provided, as well as environmental issues, are largely considered by managers in the development of distribution strategies, and hence should be given higher attention within the academic research. With these premises, the objective of this master thesis is to provide a decision model able to apply an omni-comprehensive approach to logistics problems, considering and prioritizing economic, strategic and environmental drivers for the selection of the optimal freight solution in the context of the Belt and Road Initiative. The model has then a dual purpose: on a theoretical side, it aims at filling the highlighted literature gaps, while on a practical side, it is meant to provide a managerial tool to support logistics strategic decisions. Therefore, the first research question of this dissertation is:

> *RQ1. Which are the main decision drivers in the selection of the optimal freight mode for European companies trading goods with China throughout the Belt and Road?*

Managerial decisions are usually taken according to specific requirements, needs or benefits sought in the solution, with respect to the problem they aim to solve. Indeed, the importance that managers give to logistics drivers is function of a number of variables, which can be related to the external environment or company factors. However, product features usually are the one on which managers focus more, since they are strictly related to internal processes as well as customers. Therefore, the prioritization of decision drivers carried out by managers within the designed model is most likely to be influenced by some product characteristics, and hence the second research question is formulated as follows:

> *RQ2. How does the importance attributed by managers to freight mode decision drivers change with respect to specific product characteristics?*

The literature review highlighted also that logistics problems dealing with the Belt and Road are usually tackled by considering a single freight alternative as given, on which an optimization model is built. Therefore, in this case the pursue of the optimal solution regards the definition of the route, or the design of the logistics network including the choice of the main hubs to locate, but does not include the selection of the best freight mode through which cargos are transported from the origin to the destination point. Therefore, since the model is meant to evaluate the different transportation modes within the B&R on the ground of all the relevant drivers that are possible to take into consideration, the third research question is:

> *RQ3. Comparing the available freight alternatives to ship goods between Europe and China in the context of the Belt and Road Initiative, which is the optimal solution with respect to the importance attributed by managers to the decision drivers?*

As previously said, product characteristics influence managers' decision process and hence affects the way they perceive the importance of decision drivers. However, other parameters are crucial for the selection of the best freight mode, and hence a change in their status may modify the optimal solution. In this sense, this dissertation considers two global factors whose impact may alter the outcome of the model: the emergence of Covid-19 pandemics, and the increasing awareness of supply chain sustainability and environmental issues. On the ground of these two phenomena, two research questions are formulated:

RQ4.1. How does the optimal freight solution change when considering the impact of Covid-19 pandemics?

RQ4.2. How does the optimal freight solution change when considering the increasing awareness of environmental issues emerged in the last years?

5. Multi-Criteria Decision Model

5.1 Decision-Making

Decision making is the process through which an individual chooses the best option among all the alternatives that meet his specific needs ***[115]***. According to the time required to go through this process, decisions can be grouped into two different clusters:

- Programmed decisions, which occur frequently enough to make an individual able to develop an automated response to them, called decision rule.
- Non-programmed decisions, which are unique and require specific actions and careful considerations to come up with the best option.

Within a business context, decision-making process is applied by managers to determine the optimal set of actions for a specific initiative, whose implementation may lead to positive or negative results ***[116]***. Indeed, on average, half of the decisions made by managers in organizations fails, and hence it's crucial to maximize the effectiveness of decision-making process. From a managerial point of view, decisions can be classified into three categories, based on the organizational level they occur and their impact on the company:

- Strategic decisions, which are major choices of actions that set the course of the enterprise and directly impact on the achievement of its business goals.
- Tactical decisions, whose impact is limited to the implementation of strategic decisions, and generally involve a middle-term time horizon.
- Operational decisions, related to day-to-day operations of the company taken at the lower levels of the organization.

Historically, decisions were made by managers relying only on intuitions, considering the specific situation at hand. However, this approach is highly biased by individual's background and influences, that prevent decision makers from making the best choice. Therefore, data-driven decision-making processes are now the most popular among managers and executives, who use analytical techniques to optimize problems and design protocols applicable to similar situations they may face, in order to increase effectiveness as well as efficiency. Although different decision-making methods may be applied, they all share some steps in common ***[118]***:

1. *Business problem identification*. In order to make a choice, the decision maker must first identify the problem to solve or the question to answer. It is an immediate action, often driven by a specific need or goal, but it's crucial to set the starting point and at the same time the objective of the decision-making process.
2. *Information gathering*. Since a business problem usually involves many stakeholders, data collecting is a time-consuming activity, which requires internal and external sources. Moreover, it's not easy to identify only relevant information for the defined problem, and therefore the higher risk is to be stacked into this procedure.
3. *Identification and evaluation of alternatives*. Brainstorming and imagination, as well as data analysis and interpretation, are crucial activities for the generation of different options to choose. They are evaluated on the ground of both decision-making criteria previously defined and individual's experience.
4. *Selection and implementation of the best alternative*. From the evaluation of the potential solutions, the best one is chosen and is converted into an action plan to make it tangible and achievable.
5. *Feedback analysis*. Evaluating the outcome of the implemented decision is crucial in order to check whether or not it has solved the initial business

problem. If results are not the desired ones, corrective actions may be put in place, which are also a way to learn from mistakes and improve decision-making skills.

Of course, the most critical and controversial activity is the identification and evaluation of alternatives, because of the coexistence of both data-driven and intuitive approaches. Indeed, it's quite hard to balance the results coming from the use of analytics tools and managers' opinions and intuitions. Moreover, a further challenge is represented by the maximization of stakeholders' commitment within the business decision, which is possible to be achieved through an effective communication strategy.

5.2 Decision Models

A decision model is a system or process that can be followed or imitated to make the best choice among different alternatives ***[117]***. A model allows to simplify the decision-making process by providing guidelines to help teams or individuals identify benefits and drawbacks of the various options, in order to reach a beneficial conclusion. Moreover, decision models make the process visible and easily communicable for everyone involved, in order to foster collaboration between team members.

Decision models and decision support systems (DSS) are one of the key elements of decision management, which is defined as a set of processes that aims to improve the precision, consistency and agility of decision-making. Along with decision-making models, decision management exploits other tools such as Business Intelligence (BI), Artificial Intelligence (AI), Predictive Analytics and Mathematical Programming, which leverage technology to meet modern needs and operational requirements.

Given the focus of this dissertation, the main decision-making models will be discussed in the following sections. Since enterprise decision management (EDM) deals with a wide range of problems in different functional areas, various models have been developed over the years. Therefore, picking the right decision model for each specific situation is crucial in order to find the best solution. The most applied models follow four different approaches, and hence can be grouped into four clusters ***[121]***:

- *Rational decision model;*
- *Intuitive decision model;*
- *Recognition-primed decision model;*
- *Creative decision model.*

After a general discussion about the different decision-making models, the analysis will concentrate on the rational approach, deepening a particular branch called Multi-Criteria Decision Making (MCDM).

5.2.1 Rational Decision Model

Rational decision-making is the most classical approach, as well as the most popular. It is logical and sequential methodology, which implies a series of steps to be considered when making a decision that should lead to the best choice. These models are highly applicable when dealing with well-defined problems and quantifiable options.

Rational decision models imply eight main sequential steps:

1. *Identify the problem*. The first step requires to define the goal or obstacle to achieve or overcome, which is crucial in order to clearly understand the desired outcome that the solution should produce.
2. *Establish decision criteria*. The evaluation of the alternatives will be based on specific factors that the decision-maker has to define, that are chosen considering in which terms the different options can be judged.

3. *Weight decision criteria*. Usually, decision-makers assign a specific importance level to each decisional driver, on the ground of their potential relevance respect to the nature of the considered problem. however, if each factor is equally important, this step is not required.
4. *Generate alternatives*. Using available data and brainstorming sessions, a list of potential options for solutions has to be created. Each alternative should be supported by evidence, to show how and why it would solve the problem.
5. *Evaluate the alternatives*. On the ground of the relevant information gathered before, each alternative has to be evaluated against the criteria chosen in step 2. At the end of this activity, all the options should be listed and ranked respect to the value assigned for each weighted decisional criterion.
6. *Choose the best alternative*. With respect to the ranking and the corresponding overall value generated in the previous step, the best alternative is selected.
7. *Implement the decision*. The selected alternative is converted into an action plan, which has to be followed in order to put the solution into practice.
8. *Evaluate the decision*. The outcome of the solution must be analysed in order to evaluate whether it meets expectations. If not, some assumptions should be relaxed and a new process starts.

Thanks to this logical approach, rational decision models prevent decision-makers from being biased in the evaluation of alternatives, since decisional criteria are previously defined on the ground of the characteristics of the problem and the goal to be achieved. Moreover, the generation of a large number of alternatives and the consideration of many drivers allow to cover a wide range of possibilities and hence to make a more effective decision.

However, the analysis of such a high volume of information, as well as the evaluation of all the alternatives according to the established decisional criteria, may be time consuming and conflicting with time constraints that decision-makers must respect. Moreover, optimal decisions are not the only acceptable solutions: due to human "bounded rationality", decision-makers usually don't pursue the optimal solution, but tend to accept the first alternative that meets minimum criteria defined at the first step.

5.2.2 Intuitive Decision Model

Enterprise decision management (EDM) is characterized by challenging constraints, such as time pressure, uncertainty or risk, that prevent decision-makers from rigorously applying all the sequential steps of the rational decision model explained before. Therefore, they may follow feelings and instinct to make quick decisions, based on their knowledge and experience. The following steps summarize the process:

1. *Identify the problem*. As the previous model, the first activity implies to define the desired outcome, which can be a goal or obstacle to achieve or overcome.
2. *Identify patterns*. Through a scan of the environment, decision-makers look for similarities with problems encountered in the past, in order to define a potential solution based on their prior experience.
3. *Determine a usable solution*. On the ground of the highlighted patterns, as well as inner knowledge and experience, a usable solution is developed.
4. *Finalize the decision and take action*. Once a usable solution is determined, it is put into motion.

With this approach, the key point is that only one choice is considered at a time. Moreover, intuition lies on experience, and therefore novices may not be able to make effective decisions.

5.2.3 Recognition-Primed Decision Model

The recognition-primed decision model was introduced in 1998 by Gary A. Klein, American research psychologist and famous pioneer of naturalistic decision making. In his book Sources of Power: How People Make Decisions (1998), Klein proposed a decision-making model which considers people's prior experience and rational approach as crucial elements for the process, since they allow to use a combination of intuition and analysis to make decisions. Therefore, this approach is particularly useful for managers who have to make important decisions, which require a high level of analysis, subject to time constraints.

Recognition-primed decision model is constituted by 6 steps:

1. *Identify the problem*. As usual, the definition of the objectives is the first milestone for the development of the model.
2. *Consider relevant information and similar situations*. Combining the research steps of the two previous models, both data and patterns between actual and past situations are investigated.
3. *Create a potential solution*. Prior experience and additional knowledge from the analysis of the problem are merged to come up with a potential solution. At first, it can be generic and become more and more detailed as the decision-maker thinks through it.
4. *Consider if the solution works*. The solution is investigated on the ground of its capability to achieve the goals or to overcome the obstacles previously defined.
5. *Redesign the solution*. If the potential option does not solve all the required challenges, or does not produce the best possible outcome, it can be modified by adding new actions, make it more detailed or change it in whole or in part.
6. *Finalize the decision and take action*. Once the solution is defined, in can be formalized and converted into practice.

Recognition-primed decision approach is highly relevant in fast-paced environments, such as fire fighters, search and rescue units, police, and other emergency services. Alternative options are considered only if the original plan does not produce the expected outcome, and the success rate of this model is linked to decision-maker's knowledge and experience.

5.2.4 Creative Decision Model

Creativity is defined as the ability to produce or use original and unusual ideas. The increasing competition between companies and incessant consumers' demand for new products drive organizations and managers to be creative in decision-making, ranging from cost saving to new business development. Therefore, in addition to the rational, intuitive and recognition-primed approaches, the creative decision model is a crucial tool to be an effective decision-maker. The key point in the creative process regards the design of an innovative solution without referencing to similar previous or actual situations. To do so, a decision-makers should pass through five stages:

1. *Problem recognition*. As all the previous models, it's crucial to make the need for problem solving visible, otherwise it's impossible to solve it.
2. *Immersion*. The problem has to be analyzed consciously and information gathered, resorting also to expertise in the area under inspection.
3. *Incubation*. The decision-maker should set the problem aside for a while, letting his brain working on it unconsciously.
4. *Illumination*. The solution of the problem appears to the individual in a spontaneous way, usually when it is least expected.
5. *Verification and Application*. The feasibility of the solution has to be verified, before proceeding with its implementation.

This model is often used for situations never experienced before, like new projects or production issues, and clearly requires flexible thinking to create innovative and successful solutions. However, creativity is only one side of the innovation process, which involves also realistic planning and feedback analysis.

5.3 Multi Criteria Decision Model

Referring to the definition reported by *[27]*, Multicriteria Decision Making (MCDM) constitutes an advanced field of operations research that is devoted to the development and implementation of decision support tools and methodologies to confront complex decision problems involving multiple criteria, goals, or objectives of conflicting nature. As explained by *[107]*, this approach applies numeric techniques to help decision makers choose among a discrete set of alternative decisions, on the ground of the impact of the alternatives on certain criteria and thereby on the overall utility of the decision maker(s).

MCDM models are the most popular among the rational ones, and are characterized by a wide range of applications. *[144]* enhances the comprehension of supply chain sustainability by providing a multi-attribute method to assess performances as well as to deal with uncertain managerial environments. *[68]* deals with uncertainty in manufacturing systems 4.0 through a multi-criteria evaluation of potential benefits and risks. *[3]* develops a multi-criteria decision model to find the optimal plant layout design on the ground of expected qualitative performances. *[25]* proposes a firm export performance measurement model, which categorizes the most significant decision criteria for export activities in order to enable both scholars and practitioners to evaluate firm's international trade activities. *[139]* applies MCDM to enhance supplier evaluation and selection, on the ground of specific drivers determined through the SCOR model.

Although MCDM models may be widely diverse, all of them have seven main components:

- A goal (or a set of goals), which represents the objective that the decision maker wants to achieve.
- A decision maker (or a group of decision makers), who is the subject interested in the multi-criteria evaluation. He is characterized by a basket of preferences respect of a number of criteria on which the different alternatives are evaluated.
- A set of evaluation criteria, on which the decision maker evaluates the alternatives.
- A group of attributes, which is specific for each decision criterium. An attribute can be defined as a numerical variable which allows to measure in a quantitative or qualitative way the related criterium.
- A preferences vector, which associates a relative weight to each attribute of the ground of the decision maker's preferences.
- A set of decision alternatives, which represent the objectives of the evaluation.
- A set of outcomes, which express the score of each alternative respect to each attribute, and constitute the elements of the evaluation matrix.

The interconnections between these components are represented by Figure 5.1.

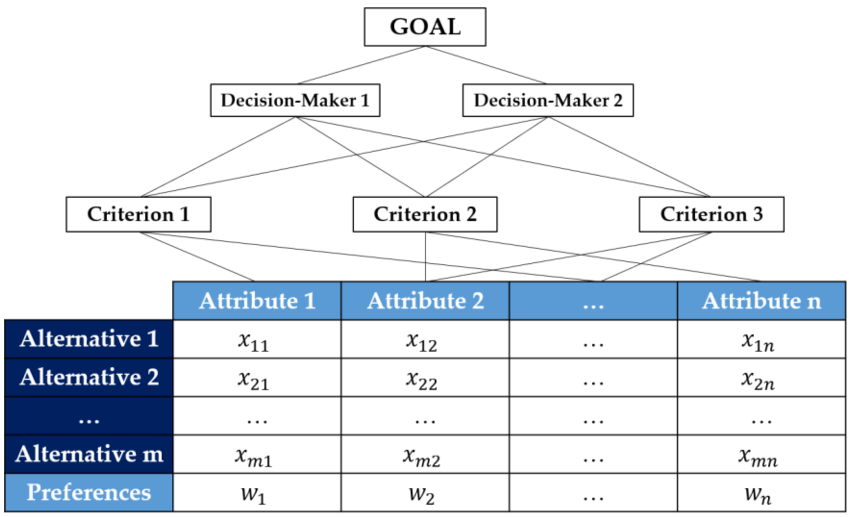


Figure 5.1: *Multi-Criteria Decision Model Structure.*

Multi-criteria decision models can be classified according to their specific decisional rule: optimizing models aim to rank alternatives and hence find the best one respect to a set of drivers, while satisficing models pursue an alternative which is able to meet specific requirements. Focusing on the first category, the main objective is to determine the optimal alternative, which is the one characterized by the highest overall performance score respect to the attributes related to the selected decisional criteria. Therefore, MCDM problems can be formulated as follow:

$$Max\ F(x) = [f^1(x), \dots, f_{\mathrm{k}}(x)]^T \qquad (5.1)$$
$$s.t. \qquad x \in \mathrm{X} \subseteq R^{\mathrm{n}}$$

Where:

X is the set of decision alternatives.

$F(x)$ is the set of attributes.

On the ground of the nature of the set of alternatives X, it's possible to distinguish MCDM models into:

- Multi-attribute decision-making (MADM) models, when X is discrete.
- Multi-objective decision-making (MODM) models, when X is continuous.

In case of MADM, the discrete set of alternatives is defined as $X = \{F(x): x \in \mathrm{X}\}$ and $f_j(x)$ represents the performance score of the alternative x for the j-th attribute. On the other side, MODM implies a continuous set of alternatives, whose performances are defined by a function for each criterium, called objective, which individuates a point on the space of the decision-making variable.

MCDM models can be further classified according to the number of decision-makers involved in the problem, distinguishing between single decision-maker methods and group decision-maker methods. Notice that, in order to be considered as a group method, decision-makers must have different preferences or pursue different goals.

Another way of classifying MCDM methods is according to the environment in which the decision is taken, that directly affect the type of data used. It's possible to discern:

- Deterministic MCDM models, which are designed within conditions of certainty and hence their output is fully determined by the initial status and the relationships between the decisional variables of the problem.
- Stochastic MCDM models, which are characterized by randomness that requires to associate a probability of occurrence to each potential outcome.
- Fuzzy MCDM models, which manage information uncertainty through fuzzy numbers.

However, there may be situations which involve combinations of all the above (such as stochastic and fuzzy data) data types.

In the next paragraphs, following the contribution of ***[81]***, the main MCDM methods will be presented.

5.4 Multi-Objective Decision Model (MODM)

A MODM problem involves the design of a solution among a continuous set of alternatives, in order to optimize the various objectives of the decision-maker. It can be designed as a Vector Optimization Problem (VOP), which aims to optimize a vector-valued objective functions with respect to a partial ordering given by the importance of each criterium.

Therefore, MODM problems are formulated as follows:

$$Max\ F(x) = [f^1(x), \dots, f_k(x)]^T \qquad (5.2)$$
$$s.t. \qquad x \in X \subseteq R^n$$

Where:

X is the continuous set of alternatives.

$F(.)$ is the set of objectives.

The resolution of a VOP consists in the implementation of a scalar optimization approach, which allows to find the set of efficient solutions X^*. Its main model is the so-called weights scalarization, which implies that, given:

$$W = \left\{ w : w \in R^k, w_j \geq 0, \sum_{j=1}^{k} w_j = 1 \right\} \tag{5.3}$$

The solution can be found by solving the following optimization problem:

$$Max\ P(\overline{w}, x) = \sum_{j=1}^{k} w_j f_j(x) \tag{5.4}$$

Defined for a given vector of weights $\overline{w}$ related to each objective function. An efficient solution can be defined if x^* is the sole acceptable alternative, or if exists a $\overline{w} \in$ W such that $P(\overline{w}, x^*)$ is maximized.

On the ground of the preference information on the objectives provided by the decision-maker, MODM methods can be classified into four clusters:

- Methods for absence of preference information.
- Methods for a priori preference information.
- Iterative methods for progressive preference information.
- Methods for retrospective preference of information

For each group, the main models are discussed below.

5.4.1 Methods for Absence of Preference Information

5.4.1.1 Global Criterion Method

Global Criterion Method belongs to the cluster of MODM methods used in absence of preference information from the decision-maker. It aims to minimize a function called global criterion, which is defined as the sum of the distances between the values of each objective function with respect to the optimal solution and a given alternative. Therefore, this approach allows to measure the proximity between the decision-maker's choice and the ideal solution. The global criteria can be formulated as follows:

$$F_p = \sum_{j=1}^{k} \left[\frac{f_j(x_j^*) - f_j(x)}{f(x_j^*)} \right]^p \quad (5.5)$$

Where:

x is the selected alternative.

$f_j(x)$ is the value of the j-th objective for the selected alternative.

x_j^* is the optimal solution for the j-th objective, which is determined by maximizing the j-th objective function under certain constraints:

$$\begin{aligned} &Max\ f_j(x) \\ s.t.\quad &g_i(x) \leq 0\ \forall\ i = 1, \dots, m \end{aligned} \quad (5.6)$$

$f_j(x_j^*)$ is the value of the j-th objective for the optimal solution.

p is a fixed integer exponent that reflects the importance of the objective functions. The higher p, the higher F_p because the larger the deviation between the optimal value and the selected one.

Therefore, the optimal solution is defined by solving the following problem:

$$\begin{aligned} &Min\ F_p \\ s.t.\quad &g_i(x) \leq 0\ \forall\ i = 1, \dots, m \end{aligned} \quad (5.7)$$

5.4.2 Methods for A Priori Preference Information

5.4.2.1 Lexicographic Method

This approach belongs to the cluster of ordinal information introduced by ***[17]***, and implies the decision-maker to rank the objectives in terms of importance level, in order to determine the solution by optimizing the objective functions one by one, starting from the one with the highest priority.

Therefore, once defined $P = (\pi_1, \dots, \pi_k)$ as the vector of objectives' priorities, for which $\pi_i \geq \pi_{i+1}$, the objective with the highest importance is the first to be optimized:

$$\begin{gathered} Max\ f_{\pi_1}(x) \\ s.t. \quad g_i(x) \leq 0\ \forall\ i = 1, \dots, m \end{gathered} \tag{5.8}$$

If only one solution is determined, it is the optimal one. Otherwise, the potential solutions ${X_1}^*$ are evaluated to the optimal respect to the second most important objective:

$$\begin{gathered} Max\ f_{\pi_2}(x) \\ s.t. \quad g_i(x) \leq 0\ \forall i = 1, \dots, m \\ f_1(x) = f_1({x_1}^*) \end{gathered} \tag{5.9}$$

This procedure is iterated till the j-th objective, or stopped if ${x_k}^*$ results as the sole solution. However, it's possible to consider a variant of this model, which allows to relax the objectives by a tolerance threshold δ_k applied step by step. Therefore, the model results as:

$$\begin{gathered} Max\ f_{\pi_j}(x) \\ s.t. \quad g_i(x) \leq 0\ \forall\ i = 1, \dots, m \\ f_k(x) \geq f_k({x_k}^*) - \delta_k\ \forall k = 1, \dots, j-1 \end{gathered} \tag{5.10}$$

5.4.2.2 Goal programming

This method lies on the principle of acceptability, and aims to find a compromising solution between the goals of the decision-maker for each objective. Therefore, once defined the goals $y_j{}^* \forall j = 1, \ldots, k$, two deviational variables are determined:

Over-achievement: $$d_j{}^+ = \begin{cases} y_j - y_j{}^* & if\ y_j > y_j{}^* \\ 0 & otherwise \end{cases} \tag{5.11.a}$$

Under-achievement: $$d_j{}^- = \begin{cases} y_j{}^* - y_j & if\ y_j < y_j{}^* \\ 0 & otherwise \end{cases} \tag{5.11.b}$$

The compromising solution is possible to be determined by solving:

$$Min \sum_j w_j \left| y_j{}^* - f_j(x) \right|^p \tag{5.12}$$

$$s.t. \quad g_i(x) \leq 0 \ \forall\ i$$

Since $f_j(x) = y_j$, the previous problem can be formulated by explicating the deviational variables:

$$Min \sum_j w_j (d_j{}^- + d_j{}^+)^p \tag{5.13}$$

$$\begin{aligned} s.t. \qquad & g_i(x) \leq 0 \ \forall\ i \\ & y_j{}^* - f_j(x) = d_j{}^- - d_j{}^+ \quad \forall j \\ & d_j{}^- * d_j{}^+ = 0 \quad \forall j \\ & d_j{}^\mp \geq 0 \quad \forall j \end{aligned}$$

These types of problems can be solved by using Mixed Integer Linear Programming (MILP) and Mixed Integer Non-Linear Programming (MINLP) methods. According to the definition of ***[60]***, MILP models optimize problems with a linear objective function subject to linear constraints, while MINLP optimization problems contain both discrete and continuous variables, as well as nonlinear functions in the objective function and constraints.

5.4.3 Iterative Methods for Progressive Preference Information

Iterative methods are widely used when no a priori information on decision-maker's preferences is available, because they allow him to provide it progressively as the different alternatives are evaluated. Indeed, preference information correspond to local trade-off with respect to the analyzed alternative, and are crucial in order to determine a new potential solution. Therefore, the decision-maker plays an active role within the process, since he is able to improve the solution step by step by exploiting the so-called "learning by doing" approach.

Two groups of methods are possible to be distinguished, on the ground of the type of preference information provided by the decision-maker:

- Methods for explicit trade-off information.
- Methods for implicit trade-off information.

For the first cluster, the most used model is the Zionts-Wallenius, while the STEM method is widely applied among the ones belonging to the second group.

5.4.3.1 Zionts-Wallenius Method

This is an interactive method developed by Professors Stanley Zionts and Jyrki Wallenius in 1976, which aims at solving linear programming problems characterized by more than one linear objective. It is particularly used for MCDM problems with progressive explicit preference information, since it requires the decision-makers to choose between different available alternatives, and to provide suggestions for improving the selected option in each iteration.

Without deepening the mathematical formulation of the model, the underlying principle implies to determine the problem weights on the ground of the preferences that the decision-maker is required to provide progressively, and to determine the optimal solution among the efficient ones that characterize the linear value function of the objectives.

5.4.3.2 STEM Method

This method differs from the previous one in the nature of information provided by the decision-maker, who expresses implicit preferences. Indeed, trade-offs between objectives are indirectly specified through local acceptability levels with respect to each alternative, which are translated into deviations between the value of each alternative and the ideal value, weighted respect to their relative importance.

Therefore, the problem is modelled as follows:

$$Min\ F_w = w_j[f_j(x_j^*) - f_j(x)] \qquad (5.14)$$

Once a first solution is defined, the decision-maker evaluates for which objectives the deviation is not acceptable, and which values can be worsened to improve the first ones. Therefore, different tolerance levels Δf_j are provided, which represents for each objective the maximum increase in deviation with respect to the ideal value. Then, a new iteration is carried out, looking for a new solution able to meet the expressed preferences. The process ends when the selected solution satisfies the decision-maker, or if none does it.

5.4.4 Methods for Retrospective Preference Information

5.4.4.1 Parametric Method

It is a combination between the scalarization method and the retrospective approach. In this case, the VOP is solved by determining the set of non-dominated solutions from an unknown utility function, which are then evaluated by the decision-maker in order to come up with the preferred one. The process follows four main steps:

1. Determine for each objective the vector of weights $W_j = \{w_j{}^1, \ldots, w_j{}^k : w_j \epsilon [0,1]\}$
2. Generate the set of k-th $W_1 x W_2 x \ldots x W_k$.
3. Solve the problem $P(\overline{w})$ for each w_j.
4. Verify if the obtained solutions are non-dominated.

These group of methods are not commonly used, since the set of solutions to select may be very large and hence the decision process results as complex and time consuming. However, they are often involved in other models.

5.5 Multi-Attribute Decision Model (MADM)

As previously presented, MADM can be defined by a decision matrix:

$$D = [x_{ij}, i = 1, \ldots, m;\ j = 1, \ldots, n] \tag{5.15}$$

Where:

$A_i, i = 1, \ldots, m$ is the set of alternatives.

$x_j, j = 1, \ldots, n$ is the set of attributes.

x_{ij} represents the value of the j-th attribute with respect to the i-th alternative.

Attributes can be quantitative or qualitative. In case of second ones, it's necessary to apply a scalarization, in order to convert them into numeric values which allow to measure and rank them. On the ground of the problem's assumptions, the scalarization involves different approaches:

- A nominal scale is used for deterministic environments, in which a unique value is assigned to each attribute.
- A probability scale is used for environments characterized by randomness, in which a set of probabilities of occurrence is assigned to each potential value of every attribute.

- An interval scale is used for uncertain environments, in which fuzzy numbers are used to convert qualitative values.

An important concept in MADM problems is the notion of compensation between attributes, which regards the possibility to balance the negative outcome of one attribute with the positive value of another one. Therefore, in case of compensation, a trade-off function is developed on the ground of the decision-maker's preferences respect to the different attributes. In these terms, MADM can be classified as:

- Non compensatory models, which don't allow to define trade-offs between attributes.
- Compensatory models, which allow to evaluate globally the alternative, by defining an overall score (scoring models), measuring the proximity respect to the ideal value (compromising models) or comparing it with the decision-maker's preferences.

An additional categorization of MADM models is based on the type of preference information on the attributes provided by the decision-maker. ***[17]*** distinguishes between absence and presence of information, and within the second cluster individuates standard level, ordinal and cardinal information. In the following paragraphs, the main methods are discussed.

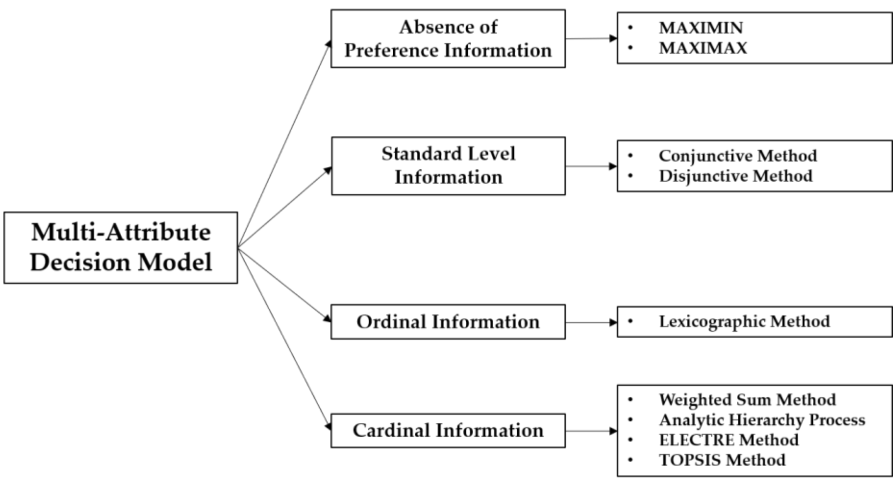


Figure 5.2: *Multi-Attribute Decision Models (Chen et al., 1991).*

5.5.1 Methods for Absence of Preference Information

5.5.1.1 MAXIMIN and MAXIMAX

In these models, each alternative is represented respectively by its worst or best attribute, and the solution is selected by considering the alternative with the best value. Therefore, the problem is designed as follows:

MAXIMIN: $$A^* = \left\{A_i : i = \underset{i}{argmax}\left[\underset{j}{min}\, x_{ij}\right], i = 1,\dots,m;\ j = 1,\dots,n\right\} \quad (5.16.a)$$

MAXIMAX: $$A^* = \left\{A_i : i = \underset{i}{argmax}\left[\underset{j}{max}\, x_{ij}\right], i = 1,\dots,m;\ j = 1,\dots,n\right\} \quad (5.16.b)$$

These methods require the attributes to be measurable respect to a common scale. Moreover, compensation is not possible to be exploited.

In order to find a compromise between these two procedures, the Hurwicz model can be applied, which allows the decision-maker to assign a weight α to the pessimistic approach of MAXIMIN and in turn a weight $1-\alpha$ to the optimistic approach of MAXIMAX:

$$A^* = \left\{A_i : i = \underset{i}{argmax}\left[\alpha * \underset{j}{min}\, x_{ij} + (1-\alpha) * \underset{j}{max}\, x_{ij}\right], i = 1,\dots,m;\ j = 1,\dots,n\right\} \quad (5.17)$$

5.5.2 Methods for Standard Level Information

5.5.2.1 Conjunctive and Disjunctive Method

With these two models, the decision-maker is asked to provide a set of acceptability levels for the attributes.

The first approach, also called satisfying method, stands that the i-th alternative A_i is acceptable if and only if the values of all the attributes for the given alternative respect the minimum requirements (standard levels) expressed by the decision-maker:

$$A_i \; is \; acceptable \; \leftrightarrow \; x_{ij} \geq {x_j}^0 \; \forall j = 1, \ldots, n$$

Where:

${x_j}^0$ is the set of standard levels expressed by the decision-maker.

The second model implies that the i-th alternative A_i is acceptable if and only if at least one attribute respects the related standard level expressed by the decision-maker:

$$A_i \; is \; acceptable \; \leftrightarrow \; \exists j = 1, \ldots, n: x_{ij} \geq {x_j}^0$$

5.5.3 Methods for Ordinal Information

5.5.3.1 Lexicographic Method

In this model, the decision-maker expresses the relative importance of the attributes through a qualitative information, and hence a scalarization process is applied to convert the qualitative preferences into numeric values. Then, starting from the most important attribute, the method looks for the alternatives that maximize its value:

$$A^1 = \left\{ A_i : i = \underset{i}{argmax}[x_{i1}] \right\} \tag{5.18}$$

A_1 is the set of alternatives for which the value of the most important attribute is maximized. If A_1 contains only one solution, it is the optimal one. Otherwise, the second most important attribute is considered. The process ends at the least important attribute.

5.5.4 Methods for Cardinal Information

5.5.4.1 Weighted Sum Model (WSM)

This is one of the most commonly used approach, and lies on the so-called additive utility assumption. This principle implies that the overall value of each alternative is equal to the sum of the values of the weighted attributes for the given alternative. Therefore, the problem is formulated as follows:

$$A^* = \left\{ A_i : \max_i \sum_{j=1}^{n} w_j x_{ij} \ \ \forall i = 1, \dots, m \right\} \tag{5.19}$$

Where:

A^* is the optimal solutions.

A_i is the set of alternatives.

w_j is the weight of the j-th attribute.

x_{ij} is the value of the j-th attribute with respect to the i-th alternative.

Problems with this model arise when it is applied to multi-dimensional problems, in which different unit of measure are used to assign a value to each attribute. In this case, the additive utility assumption is violated and the result is no more acceptable.

5.5.4.2 Analytic Hierarchy Process (AHP)

AHP was developed by Thomas Saaty in 1970s, and implies to decompose the MADM problem into a system of hierarchies to build the classic decision matrix. In particular, the global value of each alternative is determined, like the WSM, as the sum of the weighted performances of the given alternative respect to all the attributes. However, each value of the matrix is scaled on the ground of the relative importance of the alternative's performance respect to each criterion, according to a pairwise comparison technique. Therefore, similar to the previous model:

$$A^* = \left\{ A_i : \max_i \sum_{j=1}^{n} w_j a_{ij} \ \ \forall i = 1, \dots, m \right\} \tag{5.20}$$

Where:

$a_{ij} = \frac{x_{ij}}{\sum_j x_{ij}}$ is the scaled value of the j-the attribute with respect to the i-th alternative.

Notice that, for each column of the decision matrix, related to a specific attribute:

$$\sum_j a_{ij} = 1 \tag{5.21}$$

The high flexibility and intuitiveness of this method make it one of the most used in the decision-making area. However, by decomposing the problem, the time required to solve it increases, arising an issue of time consuming.

5.5.4.3 ELECTRE Method

The Elimination and Choice Translating Reality (ELECTRE) method was formulated by ***[7]*** and further improved by ***[93]***. It is based on the concept of outranking relations: given two efficient alternatives A_k and A_l, an outranking relation $A_k \rightarrow A_l$ defines A_k at least no worse than A_l, on the ground of decision-maker's preferences. The model implies to compare alternatives in pairs, to create an outranking binary system. The process follows seven steps:

1. Normalize the decision matrix:

$$R = [r_{ij}] \quad \textit{where}: \ r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} {x_{ij}}^2}} \tag{5.22}$$

2. Weigh the decision matrix:

$$V = RW \quad \text{where: } W = [w_{ij}] \tag{5.23}$$

3. Determine the concordance and discordance sets.

   The concordance set C_{kl} of two alternatives A_k and A_l is defined as the set of all attributes for which $A_k \rightarrow A_l$:

$$C_{kl} = \{j: x_{kj} \geq x_{lj}, j = 1, \dots, n\} \tag{5.24}$$

The discordance set $D_{lk}$is the complementary of the previous one, and is defined as:

$$D_{lk} = \{j: x_{kj} < x_{lj}, j = 1, \dots, n\} \tag{5.25}$$

4. Construct the concordance and discordance matrices.

   The elements of the concordance matrix are calculated as the sum of the weights associated with the attributes of the concordance set:

$$c_{kl} = \sum_{j \epsilon C_{kl}} w_j \tag{5.26}$$

   The elements of the discordance matrix are related to the deviation of the worse alternative A_k respect to the better A_l for each attribute, scaled by the maximum distance between the values of the given attribute for the two alternatives:

$$d_{kl} = \frac{\max\limits_{j \epsilon D_{kl}} |y_{kj} - y_{lj}|}{\max\limits_{j} |y_{kj} - y_{lj}|} \tag{5.27}$$

5. Determine the concordance and discordance dominance matrices.

   The concordance dominance matrix is defined as:

$$F = [f_{kl}] \quad \text{where: } f_{kl} = \begin{cases} 1 & if\ c_{kl} \geq c_0 \\ 0 & otherwise \end{cases} \quad \text{and } c_0 = \frac{1}{m(m-1)} \sum_{k=1}^{m} \sum_{l=1}^{m} c_{kl}$$

(5.28.a)

   The discordance dominance matrix is defined as:

$$G = [g_{kl}] \quad \text{where: } g_{kl} = \begin{cases} 1 & if\ d_{kl} \geq d_0 \\ 0 & otherwise \end{cases} \quad \text{and } d_0 = avg(d_{kl})$$

(5.28.b)

6. Determine the aggregate dominance matrix:

$$E = [e_{kl}] \qquad \text{where: } e_{kl} = f_{kl} * g_{kl} \tag{5.29}$$

7. Eliminate the less favorable alternatives, which are the dominated ones, for which $e_{kl} = 1$.

5.5.4.4 TOPSIS Method

The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) lies on the concept of proximity between alternatives. Indeed, the principle behind this method is that the selected alternative should be characterized by the shortest Euclidean distance from the optimal solution, and the longest from the negative ideal one. Positive and negative ideal solutions are hypothetical alternatives for which all attributes' values correspond respectively to the maximum and minimum values among the potential outcomes. Therefore, TOPSIS gives a solution that is not only closest to the hypothetically best, that is also the farthest from the hypothetically worst (Venkat Rao, 2007).

5.6 Model Selection

In order to choose a proper model for the problem that this dissertation investigates, different decisional drivers are analyzed on the ground of the presented MCDM taxonomy:

- Nature of the problem
- Number of alternatives
- Nature of problem variables
- Decision environment

Nature of the problem

The problem under analysis regards the selection of the best transportation mode among different alternatives with respect to a set of decisional criteria for different product categories. It is clearly a well-defined dilemma, which requires a logical and sequential process in order to evaluate and choose the best option among the available ones. Therefore, a rational approach is selected. Moreover, given the structure of the problem, a Multi-Criteria Decision Model (MCDM) can be used to solve it.

Number of alternatives

Since the decision regarding the best transportation modes involves three different potential solutions (sea transportation, rail transportation and air transportation), the problem is characterized by a discrete set of alternatives. Therefore, a Multi-Attribute Decision Model is selected.

Nature of problem variables

Decision-makers provide a set of ordinal information, and hence the lexicographic method is applied in order to convert the qualitative preferences into numeric values. Since individual opinions are highly subjective, the translation from qualitative to quantitative values is not deterministic, but rather uncertain. Therefore, a fuzzy approach is used in the scalarization process. However, once ordinal information is converted into cardinal ones, AHP model is used to build the decision matrix.

Decision environment

As described before, decision-makers' opinions are characterized by uncertainty, and hence their conversion into ordinal values is done by involving fuzzy numbers. However, the evaluation of transportation modes performances with respect to the selected attributes is done by considering a deterministic environment. Therefore, for each combination of alternative and attribute, only one outcome is defined.

6. Model Development

Taking into account the considerations made in the previous chapter, a fuzzy multi-attribute decision model has been developed in order to support the selection of the optimal international freight solution on the ground of pre-determined decision-maker's preferences. As anticipated in detail in the previous chapter, multi-criteria decision models may differ on the basis of many aspects, but they all present the same components:

- A set of decision alternatives under evaluation.
- A set of evaluation criteria to judge the alternatives.
- A group of attributes, which quantitatively or qualitatively measure the related criteria.
- A decision maker, who is interested in the evaluation and aims at optimizing the problem.
- A vector of preference, which assigns a weight to each attribute on the basis of the preferences of the decision maker.
- A decision matrix, which is constituted by a performance score for each combination of alternative-attribute.
- An objective function to optimize.

Each component will be analyzed in detail within this chapter.

6.1 Set of Decision Alternatives

Following the extensive discussion carried out in chapter 3, this chapter attempts to summarize all the possible routes and methods through which trade between China and Europe is performed, in order to come up with potential alternatives for the defined problem.

The set of decision alternatives is composed of:

- *Sea transportation.*
- *Air transportation.*
- *Rail transportation.*

As far as sea transportation is concerned, the main focus will be on the "21st Maritime silk road" (i.e., the maritime route of the Belt & Road), which starts in China and goes through the Suez Canal to the main European ports.

The air freight alternative is more difficult to map, as there is no single route for Europe-China trade, but airports of origin and destination are located in most regions of China. However, according to estimates by "Airports Council International", the five largest China cargo airports in terms of size and quantity of daily cargo handled are Hong Kong International, Shanghai Pudong International, Beijing Capital International, Guangzhou Baiyun International, Shenzhen International. Among the main European cargo airports, classified according to the volume of airfreight processed, we can mention Frankfurt, Paris Charles De Gaulle, Amsterdam Schipol, Istanbul Ataturk and London Heathrow.

Last, rail transportation takes into account the New Eurasian Land Bridge Economic Corridor, which is the only one route among the six economic corridors making up the Belt & Road that links Europe to China.

6.2 Set of Evaluation Criteria

The set of decision alternatives just explained are evaluated according to specific criteria, defined by the decision maker in order to assess the different options. As emerged in the literature review, research papers dealing with international distribution focus on evaluating different freight transport systems according to only one or few features at time, which results in a lack of overview and global understanding of both the problem and the potential solutions. For this reason, having identified as a gap in the literature the absence of an all-inclusive analysis (i.e., one that considers several criteria for the choice of an optimal solution), it was decided to consider three main decision criteria in the multi-criteria analysis:

- *Economic criterion.*
- *Strategic criterion.*
- *Environmental criterion.*

Therefore, these three criteria seek to combine the main evaluation drivers that can significantly influence a decision-maker's choice of one alternative over another into a single model. Each of them is then broken down into a group of attributes, which are needed to assign a numerical value to the defined alternatives.

6.3 *Group of Attributes*

The attributes that were chosen for analysis, related to the three decisional criteria previously introduced, represent variables that allow qualitative or quantitative measurements of the criterion to which they refer. Specifically, in this chapter, each attribute will be explained in detail, in particular the criterion to which it refers, the definition of the specific attribute and the unit of measurement, if any, or the way in which they have been evaluated and with which they will be measured in the construction phase of the model. The objective is to find, in light of the calculations, considerations and assumptions explained in the chapter, a relative performance score, i.e., a score related to the three alternatives, which will then be inserted in the decision matrix, needed later for the optimization of the vector product with the preference vector.

6.3.1 Attributes Referring to the Economic Criterion

Relating the economic criterion to a matter of cost analysis, the related group of attributes includes transportation cost and the inventory carrying cost:

1. *Transportation cost*. It is the cost internally assumed by the service provider for the transportation of goods from a point of origin to a point of destination. It depends on various conditions related to geography, infrastructure, administrative barriers, energy, and transport mode, and is measured through monetary terms. In particular, within this model, transportation cost is expressed in US Dollars per kilogram ($\$/kg$), since it takes into account the cost to move one kilogram of goods between two locations for each solution. Pre-pandemic and post-pandemic situations are taken into account in order to define costs, and a weighted average is applied to come up with the final value for each alternative, with the post-pandemic scenario being weighted more heavily, as it is assumed that prices would remain around that level in the medium to short term.

2. *Inventory Carrying cost*. Inventory carrying cost, or carrying costs, is an accounting term that identifies all business expenses related to holding and storing unsold goods. Also in this case, the attribute is expressed in US Dollars per kilogram ($\$/kg$), and values are identified according to both case studies within the literature and experts' opinions.

6.3.2 Attributes Referring to the Strategic Criterion

The group of attributes relating to the strategic criterion is the most numerous, mainly due to the number of literary references to strategic decision drivers from which candidates have drawn inspiration. The following attributes belong to this first group:

3. *Maximum load capacity*. It defines, as the name suggests, the maximum weight (expressed in tons) that a transport system is able to move. Therefore, to assess the performance of each alternative for this attribute, the main vehicles are analyzed, in order to define their total load capacities. However, for a better and broader comprehension of this attribute, the unit load capacity is also considered.

4. *Lead time*. Lead time, also called transport time, is the amount of time needed to move a cargo from an origin point to a destination point, and represents one of the most important measures in inventory control. Performances related to this attribute are calculated by considering three trade routes that all alternatives have in common, in order to be able to compare their values in a consistent way. Since lead time is a stochastic variable, a statistic approach is applied to come up with a specific outcome, expressed in days of travel.

5. *Lead Time Variability*. As said in point 4, transport time is subject to variability, which reflects the degree of lead time variation for a trip that is repeated in similar conditions over several days. Lead time variability highly affects supply chain management, since it carries around risk of delay or advance, that negatively impact on inventory and distribution. As per lead time, lead time variability of each alternative is calculated through statistical considerations as the dispersion range of lead time, measured in days.

6. *Accessibility*. This attribute expresses the availability of proper infrastructure close to the point of origin or destination. In the logistics industry accessibility is an important location factor because better accessibility translates into lower transportation costs and shorter time to markets. In order to calculate the relative performance of the alternatives respect to this attribute, they have

been evaluated according to their capability to reach specific Chinese locations, weighted on the ground of their importance, on the ground of mathematical models searched within the literature.

7. *Damage risk*. It refers to the probability of damage that a product incurs while being transported from an origin to a destination. The relative performance scores of alternatives consider both the percentages of units damaged and the percentage of good units in transit and of units not damaged in transit, whose weighted average represents the outcome for each alternative.

8. *Theft risk*. Theft risk is defined as the risk that products being transported from a point of origin to a point of destination may be stolen. Again, a weighted average between the performance values derived respectively from the percentage of stolen cargo and the percentage of safe cargo is calculated to assess the final relative performance scores.

6.3.3 Attributes Referring to the Environmental Criterion

Due to the ever more insistent climate change on our planet, the environmental component is becoming an increasingly important decision driver for international trade managers. Moreover, the transport sector is estimated to be the main source of pollution on the planet, contributing about 30% of total GHG emissions. Therefore, it was decided to include an environmental attribute related to emissions as well:

9. *Emissions*. Greenhouse gases' volumes are extrapolated from reports and articles, in order to assess the degree of sustainability and eco-friendliness of each alternative, on which their relative performance score is calculated.

6.4 Decision-Maker

A multi-criteria decision model requires one or more decision-maker to evaluate the different criteria selected. As already explained, this model is developed for a single decision-maker, who expresses its preferences related to the defined attributes and attempts to find the optimal solution on the ground of his personal requirements and experience. Preference information are provided through lexical variables which the decision-maker is required to select for each attribute, that are converted into numerical values thanks to a scalarization process. This quantification allows to mix information preferences from decision-maker and alternatives' performance scores, to come up with the optimal solution for the specific problem.

6.5 Preference Vector

As explained in the previous chapter, the preference vector associates a relative weight to each attribute on the ground of the decision maker's preferences, which are based on the importance that he assigns to each specific attribute. In this model, given the nature of personal opinions, which are highly subjective and uncertain in their quantification, preference information is defined as linguistic variable, and modeled by a fuzzy set to assign them a numeric value.

With the aim of representing vagueness and imprecise information, fuzzy logic considers the principle of partial truth, for which the truth value of variables may be any real number between 0 and 1, which correspond to the concept of completely true and completely false. A fuzzy set $\tilde{A}$ is defined with its membership function $\mu_{\tilde{A}}(x)$, which signifies the truth degree of variable x in $\tilde{A}$ ***[22]***. Therefore, given:

$$\tilde{A} = (a, b, c, d) \quad \text{where } a \leq b \leq c \leq d$$

The membership function of the trapezoidal fuzzy set $\tilde{A}$ is defined as:

$$\mu_{\tilde{A}}(x) = \begin{cases} \frac{(x-a)}{(b-a)} & a \leq x \leq b, \\ 1 & b \leq x \leq c, \\ \frac{(x-d)}{(c-d)} & c \leq x \leq d, \\ 0 & otherwise \end{cases} \quad \text{where } a,b,c,d \in R \tag{6.1}$$

And the related trapezoidal fuzzy number can be denoted by the fuzzy set (a, b, c, d), as represented in figure x.

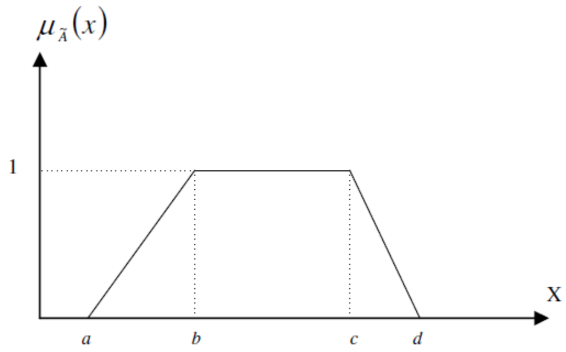


Figure 6.1: *Trapezoidal fuzzy number representation.*

For the development of this model, given two trapezoidal fuzzy numbers $\tilde{A} = (a, b, c, d)$ and $\tilde{B} = (e, f, g, h)$, the following operations are defined:

- Addition of two trapezoidal fuzzy numbers

$$\tilde{A} \oplus \tilde{B} = (a + e, b + f, c + g, d + h) \tag{6.2}$$

- Multiplication of any real number k and a trapezoidal fuzzy number

$$k \otimes \tilde{A} = (ka, kb, kc, kd) \tag{6.3}$$

According to *[17]*, eight conversion scales are the most used when applying linguistic variables and converting them into fuzzy numbers. In this dissertation, following the contribution of *[22]* and *[72]*, the following scale is used:

Linguistic Variable	Fuzzy Numbers
Very Low	(0,0,0,3)
Low	(0,3,3,5)
Medium	(2,5,5,8)
High	(5,7,7,10)
Very High	(7,10,10,10)

Table 6.1: *Linguistic variables and related fuzzy set (Chou et al., 2008).*

Therefore, once the decision-maker has selected one linguistic variable for each criterium among the available ones in the table above, the scalarization process allows to define the fuzzy preference vector as:

$$\widetilde{W} = (\widetilde{w_1}, \dots, \widetilde{w_n}) \qquad (6.4)$$

Where $\widetilde{w_j} = (a_j, b_j, c_j, d_j)$ denotes the fuzzy weight of the j-th attribute.

The following step implies to defuzzify each $\widetilde{w_j}$. To do so, the signed distance is adopted:

$$d(\widetilde{w_j}) = \frac{1}{4}(a_j + b_j + c_j + d_j), \quad j = 1, \dots, n \qquad (6.5)$$

Last, the crisp value (real value) of the normalized weight for each attribute is computed:

$$w_j = \frac{d(\widetilde{w_j})}{\sum_j d(\widetilde{w_j})} \qquad (6.6)$$

Where w_j is the crisp weight of the j-th attribute.

Therefore, the preference vector is defined as:

$$W = (w_1, \dots, w_n) \qquad (6.7)$$

6.6 Decision Matrix

In this chapter, the decision alternatives are evaluated respect to the different attributes, in order to create a decision matrix which will be crucial to select the best solution respect to the preference vector previously defined. In particular, for each combination of alternative-attribute, a relative performance score is assigned, which constitutes the basic element of the matrix and is calculated as a value between 0 and 10 respect to the performance of the best alternative for the same attribute. This procedure allows on one side to compare different attributes, characterized by incompatible units of measure, and on the other side to highlight the real impact of the given alternatives on the selected decisional criteria.

The design process of the decision matrix is the following one:

- *Performance identification*. For each attribute, relevant information and data have to be searched, in order to assign a value to the alternatives according to the specific unit of measure. This step is mainly based on data gathering, and therefore different information sources are evaluated, such as academic articles, journals, books and websites.
- *Performance rationalization*. Since attributes are characterized by different unit of measures, and hence it's not possible to compare them, performance scores are rationalized respect to the best alternative's outcome. In particular, it's possible to identify two types of attributes on the ground of their performances:
    - Attributes for which the best performance is the one characterized by the lowest value (i.e., transportation cost, lead time, …). In this case, the highest relative performance score (10,00) is assigned to the alternative characterized by the lowest performance value, and the others are defined respect to the best alternative. Therefore, for a given attribute $\bar{J}$, the following formula is applied:

$$x_{i\bar{j}} = \frac{10 * \min_i p_{i\bar{j}}}{p_{i\bar{j}}} \tag{6.8}$$

Where:

$p_{i\bar{j}}$ represents the performance value of the i-th alternative respect to the attribute $\bar{j}$.

$x_{i\bar{j}}$ represents the relative performance score of the i-th alternative respect to the attribute $\bar{j}$.

- Attributes for which the best performance is the one characterized by the highest value (i.e., maximum load capacity, accessibility). For this cluster of attributes, the alternative with the highest performance value is the one characterized by the highest relative performance score (10,00), and is taken as reference for the calculation of the other. Therefore, the used formula is the following:

$$x_{i\bar{j}} = \frac{10 * p_{i\bar{j}}}{\max_i p_{i\bar{j}}} \tag{6.9}$$

Where:

$p_{i\bar{j}}$ represents the performance value of the i-th alternative respect to the attribute $\bar{j}$.

$x_{i\bar{j}}$ represents the relative performance score of the i-th alternative respect to the attribute $\bar{j}$.

The next chapters will present the procedure previously explained for each attribute, showing the performance values for the given alternatives and the related relative performance score.

6.6.1 Transportation Cost

One of the most used approaches to investigate supply chain issues is the Total Landed Cost (TLC), which is a quantitative cost analysis that evaluates the total end-to-end supply chain cost starting from origin to destination for a given service level. With the objective to understand the real cost of bringing products from a point of origin to a destination point located in different countries, this approach allows to decompose the total expense into its main components, which include transportation cost and, as discussed below, inventory carrying cost.

Transportation cost implies three main phases:

- *Pre-carriage*. The inland transportation from the origin point to the port/airport/railway station of origin.
- *Linehaul*. The intercontinental movement between the port/airport/railway station origin and destination.
- *On-carriage*. The inland transportation from the destination port/airport/railway station to the point of destination

For the aim of this dissertation, which focuses on international transportation, only linehaul and its related cost have been considered.

The evaluation of the performance value of each alternative for the attribute under analysis required first some considerations:

1. In order to be able to make a comparison between alternatives, the performances must be expressed in the same unit of measure. Since air freight fare is usually reported as USD per kilogram transported, also sea freight and rail freight will follow the same logic. Unlike air freight, the latter ones' fares consider the unit load selected for the transportation, which are explained in detail in the chapter dealing with maximum load capacity attribute. Therefore,

to calculate the performance value for sea and rail freight, the following formula is applied:

$$p_{i1} = \frac{fare_i}{weight\ capacity_i} \qquad (6.10)$$

Where:

p_{i1} represents the performance value of the i-th alternative respect to transportation cost.

$fare_i$ [$] represents the freight cost of one unit load.

$weight\ capacity_i\ [kg]$ represents the maximum weight capacity of one unit load.

2. Transportation cost is one of the many logistics factors that suffered the huge impact of Covid-19. The rising of freight fares originates from different causes related to the pandemic, and highly affected companies' businesses and the logics of supply chain management. This dissertation takes into account both pre- and post-covid realities, in order to consider the actual environment in which decision-makers have to operate, and the previous one, which has faced such a huge disruption. In particular, the performance of each alternative is calculated on the ground of the cost in the present reality. However, due to the massive impact of pandemics, which according to many scholars has brought our world into a "new reality" totally different from the previous one, a sensitivity analysis has been carried out in the following chapters, in order to analyze how Covid-19 has modified logistics solutions and how companies have reacted to these changes.

In order to define the fares for the different alternatives, an average of the freight cost for the main routes between Europe and China has been considered. Moreover, since the actual environment is characterized by high uncertainty and variability, the post-covid costs have been calculated considering an average increase respect to the pre-covid fares, which were more structured and less volatile.

Following the data reported by Assarmatori, the average composite index for the sea freight cost of a 40HQ container was 1.770 USD in the last five years, while it suffered an average increase of 289% in the last year due to pandemics ***[122]***. This trend is globally confirmed by looking at other main international routes involving Chinese harbors: in 2018, the cost to ship a 40HQ container from Los Angeles to Shanghai was 1.580 USD, while in 2020 it reached 2.760 USD, with an increase of "only" 175%. Within the Europe-China sea freight, the highest trend has been reported by the Rotterdam-Shanghai route, whose cost has more than tripled (+335%).

As explained in the previous chapters, rail freight between Europe and China has heavily grown in the last years, thanks to the BRI and the various investments made by the partner countries. The tariffs to ship a 40HQ container are higher than sea freight, with an average pre-covid cost of 3.200 USD ***[123]***. However, the impact of pandemics, although still huge, is lower than sea transportation, with a medium increase of 227% in the last year.

For what concern air freight, tariffs are much higher than the previous two solutions, which is counterbalanced by a superior service level, defined in terms of lead time. It's possible to distinguish between two types of air shipments ***[124]***: express freight and air freight. The first one is typically handled by one logistics service provider that is in charge of the entire shipment lifecycle (door-to-door), while the second one includes only linehaul transportation. Moreover, express freight is usually used for small and lightweight shipments, while international air freight shipments can be significantly larger. Therefore, in this analysis, the second option is considered. International air cargo average rate is defined as 4,5 USD/kg in the pre-covid context, while currently it reached 12 USD/kg, with an increase of 267%.

Therefore, performance values and the relative performance scores are calculated. Table 6.2 shows the results:

	TRANSPORTATION COST	
	Performance Value [USD/kg]	Relative Performance Score
Sea Freight	0,19	10,00
Rail Freight	0,27	7,06
Air Freight	12,00	0,16

Table 6.2: *Transportation Cost performances.*

6.6.2 Inventory Carrying Cost

Following the same approach applied in the previous chapter, the Total Landed Cost will be used as guideline to define and calculate the inventory carrying cost for the different freight solutions. According to this method, inventory carrying cost must take into account three different components:

- Cycle stocks, which are inventories dealing with the different operative rhythm of two following stages in the supply chain.
- Safety stocks, which are inventories dealing with the uncertainty of both the demand and the replenishment lead times.
- In transit stocks, which are in transit inventories between stocking or production points.

The cost of these three elements is function of lead time, lead time variability and inventory management policy applied, which are directly related to the transportation solution adopted and the nature of product moved. Therefore, inventory carrying cost has been evaluated by considering the combination of freight alternative-product nature, distinguished between high-value and low-value products. Taking as reference various case studies within the literature, among which *[95, 87, 103]*, two relative performance scores are defined, whose average represents the final relative performance score for each alternative. The procedure is depicted in Table 6.3:

	HIGH-VALUE PRODUCT		LOW-VALUE PRODUCT		TOTAL
	Performance Value [USD/kg]	Relative Performance Score	Performance Value [USD/kg]	Relative Performance Score	Relative Performance Score
Sea Freight	22,30	3,26	0,73	3,29	3,27
Rail Freight	16,10	4,51	0,37	6,49	5,50
Air Freight	7,26	10,00	0,24	10,00	10,00

Table 6.3: *Inventory Carrying Cost performances.*

6.6.3 Maximum Load Capacity

In order to assess the maximum load capacity respect to each alternative, a general analysis on the common freight vehicles is required, in order to determine the maximum weight of goods that a freight vehicle can transport.

Sea freight implies the exploitation of cargo ships, which are defined as merchant ships that carry cargo, goods and materials from one port to another ***[125]***. Cargo ships can be divided into several clusters, according to the characteristics of cargo moved:

- Tankers, which are designed to transport liquids or gases.
- Bulk carriers, which are specialized in the movement of bulk cargo, such as grains, coal, ore etc.
- Container ships, which carry the whole load in intermodal containers.

Since the latter are the common means of international sea trade and transport most of the seagoing non-bulk cargo, they are taken as reference for this analysis. Within this cluster, it’s possible to distinguish between two types of container ships:

- Feeder vessels, which are medium-size freight ships designed to collect shipping containers from different ports and transport them to central container terminals, where they are leaded into bigger vessels for the intercontinental transport (Hub-and-Spoke strategy)
- Container vessels, which are large-size freight ships designed to perform intercontinental transports and carry containers from one hub port to another one.

Given the focus of this dissertation, only container vessels are considered. In order to assess the maximum load capacity of a generic container vessel, different models have been evaluated, and the maximum load capacity is calculated as the average of the load capacity of the container ships analyzed, as shown in Table 6.4.

Container ship	Load Capacity [tons]
MSC Zoe	150.853,00
Thalassa Tyhi	148.667,00
NYK Hermes	144.179,00
COSCO Development	141.716,00
CMA CGM Aquila	131.332,00
Maximum load capacity (AVG)	**143.350,00**

Table 6.4: *Main container vessels and related load capacity.*

For what concern air freight, the same procedure has been applied, starting with the analysis of the main aircrafts. However, since Boing 747-8F is widely used, it has been taken as reference for the definition of air freight maximum load capacity.

Aircraft	Load Capacity [tons]
Airbus A300-600F	48,00
Airbus A330-200F	70,00
Airbus A380	68,00
Boeing 737-700C	18,20
Boeing 757-200F	39,78
Boeing 747-8F	**134,20**
Boeing 747 LCF	83,33
Boeing 777F	103,00

Table 6.5: *Main aircrafts and related load capacity.*

Rail freight capacity varies on the ground of the type and the number of containers carried by each car. Within the last years, thanks to the infrastructure development and the initiatives launched by the BRI partner countries, the amount of goods that is possible to ship via train between Europe and China has incessantly increased. Due to this constant growth, data regarding rail freight capacity are quite blurred and subject to variability. However, taking as reference latest shipping, it's possible to assess the maximum load capacity as the average between the recent rail cargos delivered from Europe to China. For instance, the route Xi'an-Melzo (Milan) allows to carry a number of 50 containers for a total capacity of 1.330 tons, while the new connection between Wuwei and Duisburg launched in May 2021 is able to move up to 80 containers from Europe to China, with an overall capacity of 2.128 tons ***[128]***.

However, while assessing the performance value of each alternative respect to the maximum load capacity, considering only the total weight that a vehicle can handle may limit the analysis. Indeed, another crucial aspect is the capacity of the single unit load used, defined as the basic transport unit. Sea and rail freight share the same type of unit load, represented by the container, characterized by a wide range of models. Since the most used is the Forty-foot Equivalent Unit (FEU) container, it is taken as reference for the maximum unit load capacity of both sea and rail freight, with a value of 23 tons *[129]*. With the same reasoning, the most common unit load for air freight is the air pallet, which is characterized by a weight capacity of 6,7 tons *[130]*.

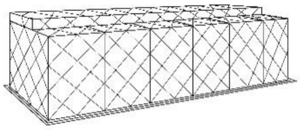
	TRANSPORT UNIT LOAD			
	Description	Image	Dimensions	Net Capacity [tons]
Sea Freight / **Rail Freight**	Forty-foot Equivalent Unit (FEU)		12,04 x 2,35 x 2,39 m	23,00
Air Freight	Air Pallet 6P6 (PMC)		2,44 x 3,18 x 2,9 m	6,70

Table 6.6: *Transport unit load capacity.*

Therefore, the final relative performance score is calculated as the average of the scores related to the maximum total load capacity and the maximum unit load capacity. Performance values and relative performance scores are shown Table 6.7.

	TOTAL LOAD CAPACITY		UNIT LOAD CAPACITY		TOTAL
	Performance Value [tons]	Relative Performance Score	Performance Value [tons]	Relative Performance Score	Relative Performance Score
Sea Freight	143350	10,00	23,00	10,00	10,00
Rail Freight	2128,00	1,86	23,00	10,00	5,93
Air Freight	134,20	0,10	6,70	2,56	1,28

Table 6.7: *Maximum Load Capacity performances.*

6.6.4 Lead Time and Lead Time Variability

As per transportation cost, the evaluation of lead time and lead time variability performances takes into account only intercontinental transportation. In order to be able to compare lead times of different alternatives, three main routes connecting Europe and China have been selected, which are possible to be travelled by sea, rail or air. The routes under inspection are the following:

- Milan – Xi'an
- Zhengzhou – Milan
- Duisburg – Wuwei

Of course, for these routes, sea freight implies an intermodal strategy. However, only sea transportation has been considered.

In this analysis, lead time is considered as a stochastic variable, whose values depend on outcomes of an aleatory phenomenon. This is reasonable considering the range of drivers that affect lead time, not least the impact of pandemics faced in the last two years. Therefore, defining a symmetric normal distribution $N(\mu, \sigma^2)$, the lead time of each alternative for a specific route is represented by the mean value μ, while lead time variability is expressed in terms of dispersion range (2σ).

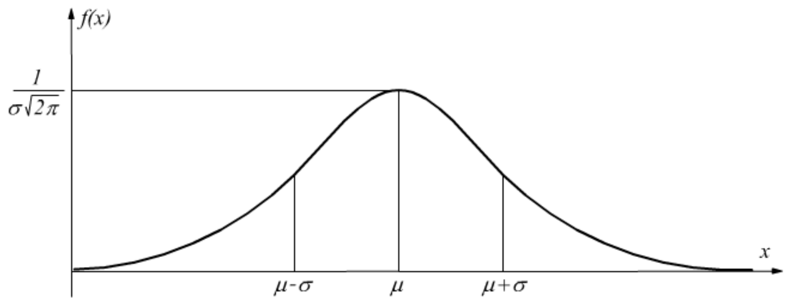


Figure 6.2: *Normal distribution.*

In order to assign a concrete value for each combination of route-alternative, different websites of logistics service providers have been consulted. The estimation of lead time is provided through a time window, which reports a potential upper and lower bound in terms of travel days.

Therefore, from the hypothesis of symmetric normal distribution of lead time, the following formulas are applied:

$$\mu = \frac{(\mu + \sigma) + (\mu - \sigma)}{2} = \frac{LT^{upper\ bound} + LT^{lower\ bound}}{2} \quad (6.11.a)$$

$$2\sigma = (\mu + \sigma) - (\mu - \sigma) = LT^{upper\ bound} - LT^{lower\ bound} \quad (6.11.b)$$

Notice that lead time variability has been defined as dispersion range (2σ) instead of standard deviation (σ) because running behind schedule is as damaging as being late, and hence both sides must be considered.

Therefore, data gathered and relative performance scores are reported below.

Routes	Value approach	Sea freight [gg]	Rail Freight [gg]	Airfreight [gg]
Milan - Xi'an	$\mu - \sigma$	36,00	15,00	3,00
Milan - Xi'an	$\mu + \sigma$	45,00	17,00	5,00
Milan - Xi'an	μ	40,50	16,00	4,00
Milan - Xi'an	2σ	9,00	2,00	2,00
Zhengzhou - Milan	$\mu - \sigma$	33,00	17,00	4,00
Zhengzhou - Milan	$\mu + \sigma$	43,00	20,00	5,00
Zhengzhou - Milan	μ	38,00	18,50	4,50
Zhengzhou - Milan	2σ	10,00	3,00	1,00
Duisburg-Wuwei	$\mu - \sigma$	35,00	18,00	3,00
Duisburg-Wuwei	$\mu + \sigma$	47,00	21,00	5,00
Duisburg-Wuwei	μ	41,00	19,50	4,00
Duisburg-Wuwei	2σ	12,00	3,00	2,00
AVG LEAD TIME		**39,83**	**18,00**	**4,17**
AVG LEAD TIME VARIABILITY		**10,33**	**2,67**	**1,67**

Table 6.8: *Lead Time and Lead Time Variability.*

	LEAD TIME	
	Performance Value [gg]	Relative Performance Score
Sea Freight	39,83	1,05
Rail Freight	18,00	2,31
Air Freight	4,17	10,00

Table 6.9: *Lead Time performances.*

	LEAD TIME VARIABILITY	
	Performance Value [gg]	Relative Performance Score
Sea Freight	10,33	1,61
Rail Freight	2,67	6,25
Air Freight	1,67	10,00

Table 6.10: *Lead Time Variability performances.*

6.6.5 Accessibility

Accessibility has always been a logistics feature that only qualitative reasonings attempted to assess. According to Dr. Jean-Paul Rodrigue, accessibility is the measure of the capacity of a location to be reached from, or to be reached by, different locations ***[126]***. ***[104]*** introduces a formula which takes into account both the importance of the specific locations and the ease of reaching them, either in terms of cost, time, or distance:

$$A_i = \sum_j w_j * f_{ij} \tag{6.12}$$

Where:

A_i represents the accessibility of the i-th location.

w_j represents the attractiveness of the j-th location.

f_{ij} represents the ease function of reaching the j-th location from the i-th location.

However, within this dissertation, this concept assumes a slightly different meaning, taking as reference ***[79]***, which defines accessibility as the ease with which locations can be reached from a certain place and with a certain system of transport. In this case, the system of transport assumes a central role, leading accessibility to be thought as the ease of a certain transport system to connect two different locations. Therefore, in order to assess the accessibility performance of each alternative, two steps are followed:

1. Verify whether each alternative is able to connect European hubs with the most important Chinese locations.
2. Verify for the remaining Chinese districts the degree of accessibility of each alternative.

Chinese locations with the highest level of attractiveness are defined to be all the Chinese Free Trade Zones (FTZ), which assume a crucial role in the global trade. A FTZ is an area usually placed closed to major seaports, international airports and cross-border railways, where goods may be landed, handled, manufactured or reconfigures, and re-exported without the intervention of the customs authorities ***[131]***. They assume a particular relevance due to the trade advantages they provide to foreign companies, such as tax benefits, easier license acquisitions, access to subsidies and faster import of goods and bank accounts. Therefore, alternatives are first evaluated on their capability to reach the Chinese FTZ, which in turn is determined by the presence of harbors, airports or railways dedicated to international trade activities. Therefore, for each alternative, the performance value is calculated as:

$$p_{i6} = \frac{\sum_J FTZ_{ij}}{\sum_j FTZ_J} \tag{6.13}$$

Where:

p_{i6} represents the performance value of the i-th alternative respect to accessibility.

$\sum_J FTZ_{ij}$ represents the number of Chinese FTZ connected to Europe by the i-th transport system.

$\sum_j FTZ_J$ represents the total number of FTZ.

Notice that, within this analysis, only international terminals have been considered, which are those characterized by intercontinental flows of goods between Europe and China. The following table sum up the results, showing the accessible transport solutions for each FTZ, and the performance values of the alternatives.

FTZ	Port	Railway Station	Airport
Shanghai	YES	YES	YES
Guangdong	YES	YES	YES
Tianjin	YES	YES	YES
Fujian	YES	YES	NO
Liaoning	YES	YES	NO
Zhejiang	YES	YES	NO
Henan	YES	YES	YES
Hubei	YES	YES	NO
Chongqing	NO	YES	YES
Sichuan	NO	YES	NO
Shaanxi	NO	YES	YES
Hainan	YES	NO	NO
Accessibility FTZ	**0,75**	**0,92**	**0,50**

Table 6.11: *Accessibility of Chinese Free Trade Zones.*

In addition, in order to have a broader analysis, qualitative reasonings have been carried out, based on the remaining Chinese areas that are not considered in the previous list. Most of these are inland locations, where sea freight is unlike to be applicable, while thanks to the Chinese widespread network of airports, air freight is the one having the highest accessibility. The development of railway infrastructures, fostered by BRI, allows rail freight to be characterize by a good accessibility level even in Chinese hinterland, positioning itself right below air transportation.

Therefore, a total performance value is obtained through a weighted sum of the two previous approaches, giving more importance to FTZ accessibility, as expressed by the following formula:

$$p_{i6} = 0{,}6 * p_{i6}^{FTZ} + 0{,}4 * p_{i6}^{inland\ locations} \tag{6.14}$$

In the end, the relative performance score for each alternative is calculated, as shown in Table 6.12.

	FREE TRADE ZONES		INLAND LOCATIONS		TOTAL
	Performance Value [%]	Relative Performance Score	Performance Value [%]	Relative Performance Score	Relative Performance Score
Sea Freight	0,75	8,18	3,00	3,16	6,90
Rail Freight	0,92	10,00	7,00	7,37	10,00
Air Freight	0,50	5,45	9,50	10,00	8,13

Table 6.12: *Accessibility performances.*

6.6.6 Damage Risk and Theft Risk

Product safety is a crucial driver for the choice of international transportation mode, and can be evaluated according to two different concepts: damage risk and theft risk.

Product damage during transportation is a common fact, and there is no transport system able to eliminate it *[132]*. However, technology is always improving, and minimizing damage risk leads to efficiency increase and cost reduction. From a qualitative perspective, air freight is the transportation mode that ensures the highest level of safety, due to shorter lead time and advanced technologies. On the other side, sea cargos are subject to lots of environmental stimuli, such as heavy impacts, vibrations, moisture, humidity and thermal shock, which determine sea freight damage risk as the highest one. Rail transportation assumes an intermediate position, since it suffers from the same issues of sea freight, but their impact is lower thanks to the shorter lead time and the infrastructures developed especially in the last years thanks to the BRI.

In order to provide a more quantitative analysis, different case studies have been searched. Among them, *[96, 35]* have been selected as reference, with the objective to extrapolate relevant data useful for a comparison between the different transport modes. The assessment has been carried out considering an average percentage of both damaged units and good units, which are merged together in order to have a broader perspective.

	DAMAGED UNITS		GOOD UNITS		TOTAL
	Performance Value [%]	Relative Performance Score	Performance Value [%]	Relative Performance Score	Relative Performance Score
Sea Freight	2,40	5,00	97,60	9,88	8,41
Rail Freight	1,58	7,59	98,42	9,96	9,25
Air Freight	1,20	10,00	98,80	10,00	10,00

Table 6.13: *Damage Risk performances.*

With the same approach used for product damage risk, theft risk is assessed by considering the percentages of cargo thefts and safe cargos. Of course, air transportation is almost free from theft risk, while sea and rail freight are subject to theft risk, which is function of the specific transport system and the route followed *[133, 134]*. Considering the data from BSI and TT Club Cargo Theft Report 2021 *[127]*, performance values and relative performance scores are calculated for the different alternatives.

	CARGO THEFTS		SAFE CARGOS		TOTAL
	Performance Value [%]	Relative Performance Score	Performance Value [%]	Relative Performance Score	Relative Performance Score
Sea Freight	0,98	0,10	99,02	9,90	8,92
Rail Freight	0,05	2,00	99,95	10,00	9,20
Air Freight	0,01	10,00	99,99	10,00	10,00

Table 6.14: *Theft Risk performances.*

6.6.7 Emissions

In the last years, the concept of supply chain sustainability has acquired attention among both scholars and practitioners, especially in relation to the management of environmental impact. According to OECD, air pollution and greenhouse gas emissions are the main causes of environmental issues, whose main contributors include also freight transportation industry. Indeed, each year, transportation industry is responsible for 28% of total greenhouse gas emissions, having a significant impact on the environment we are living in. To compare the different alternatives, the main pollutants' volumes generated by each freight transport solution have been considered, in order to provide an average value of air pollution emission, on which the relative performance scores can be calculated. From OECD data ***[135]***, sea and rail freight keep the emission at a very low level, which is only few grams of greenhouse gases per ton-kilometer, while air transportation is by far the most polluting solution.

	EMISSIONS	
	Performance Value [grams/ton*km]	Relative Performance Score
Sea Freight	0,19	10,00
Rail Freight	0,27	7,01
Air Freight	4,90	0,38

Table 6.15: *Emissions performances.*

Moreover, in order to deepen this topic, which has gained more and more importance in the last years, a sensitivity analysis has been conducted in chapter 8. In particular, the different alternatives are evaluated considering a pre-determined preference level for the environmental criteria, in order to assess whether sustainability concern has significant impacts on supply chain management.

6.7 *Set of Outcomes*

On the ground of the considerations made before, a decision matrix is built by merging the relative performance vectors of all the alternatives for each specific attribute. The matrix, through a vectorial product with the preference vector, is then used to assess the optimal solution. On the ground of the outcomes shown in the previous paragraphs, the decision matrix is structured as shown in the following page.

	ECONOMIC CRITERION		STRATEGIC CRITERION						ENVIRONMENTAL CRITERION
	Transportation Cost	Inventory Carrying Cost	Maximum Load Capacity	Lead Time	Lead Time Variability	Accessibility	Damage Risk	Theft Risk	Emissions
Sea Freight	10,00	3,27	10,00	1,05	1,61	6,90	8,41	8,92	10,00
Rail Freight	7,06	5,50	5,93	2,31	6,25	10,00	9,25	9,20	7,01
Air Freight	0,16	10,00	1,28	10,00	10,00	8,13	10,00	10,00	0,38

Table 6.16: *Decision Matrix performances.*

6.8 *Objective Function*

In order to come up with the best alternative respect to the preference information provided by the decision-maker, the Weighted Sum Model (WSM) is applied. This method, based on the additive utility approach, implies that the overall value of each alternative is equal to the vector product of the defuzzyfied preference vector and the relative performance scores of the given alternative. Therefore, the optimal solution is the one characterized by the highest overall value, calculated as stated before. The mathematical formulation is the following one:

$$A^* = \left\{ A_i : \max_i W \otimes A_i \stackrel{\text{def}}{=} \max_i \sum_{j=1}^{n} d(\widetilde{w}_j) x_{ij} \;\; \forall i = 1, \ldots, m \right\} \qquad (6.15)$$

Where:

A^* is the optimal solution.

A_i is the set of alternatives.

$\widetilde{d(w_j)}$ is the defuzzyfied value of the j-th attribute.

x_{ij} is the relative performance score of the j-th attribute with respect to the i-th alternative.

7. Model Implementation

After a deep analysis and modelling of all the considered variables carried out in the previous pages, this chapter presents a model implementation, provided with computations and statistical analysis in order to come up with relevant results and considerations, useful to answer the research questions defined in chapter 4.

In order to test the model, the following steps have been followed:

1. *Definition of the preference vector*. In order to calculate the weight of each attribute, and hence build the preference vector, a survey has been constructed, which is useful to collect relevant data of the decision maker and his preference information respect to the attributes. A group of European managers was asked then to fill the survey, whose answers contributed to assess the attributes' weights. According to the data collected from the survey, managers have been divided into four clusters, on the ground of the type of product that they import or export, and hence four preference vectors have been defined.
2. *Computation of alternative's global score*. Once the four preference vectors have been defined, the values of the alternatives have been calculated for each one. This is assessed through the vector product of each preference vector and the relative performance scores of each alternative.
3. *Selection of the optimal* solution. On the ground of the calculated global score, the optimal solution has been defined for each preference vector, and a ranking of the alternatives respect to their score has been provided.

The whole process is deeply described hereafter.

7.1 Definition of Preference Vector

In this chapter, the development of the survey, as well as the categorization of decision maker's answers and the creation of different preference vectors are descripted.

7.1.1 Survey

As widely explained in the previous chapters, the assessment of the performance weights that compose the preference vectors requires decision-maker's opinions to be collected through linguistic variables and transformed into numeric variables. To do so, a survey has been structured on the ground of the needed data, which are related to company information, product information and decision-maker information and opinions.

Company information are required to understand the environment in which managers operate. Indeed, decision-making is highly affected by external factors, which may influence the outcome of the process. Within this survey, two main company features have been considered:

- *Company location*. Geographical origin matters when considering the factors influencing a decision-making process. Indeed, as supported by the Hofstede model, cultural dimensions and hence territorial roots significantly affect the way problems are analyzed and tackled, and therefore, with respect to this dissertation, they are strictly related to the preferences expressed by managers on the defined attributes. Moreover, focusing on the topic of this thesis, country-specific characteristics, such as the level of infrastructure development or the political legislation, are crucial drivers for the definition of logistics and distribution strategies within companies, which may follow different plans on the ground of the country in which they operate.

Therefore, managers were asked to indicate the country where the company in which they work is placed.

- *Company size*. The bulk of a company is not only an important indicator of its success, but also an influencing factor for its management. Indeed, company size affects the development of business decision-making process, which is tailored to different needs. Indeed, large companies excel at problem analysis and decision implementation, while smaller companies are better at quick, flexible and innovative decisions. In order to define the company size, the number of employees has been considered as the determinant, since it influences companies' decision-making process much more than other economic or financial indicators. Therefore, managers had to choose between the following options[1]:
    - *Micro-Enterprise* (employees < 10).
    - *Small-Enterprise* (10 < employees < 50).
    - *Medium-Enterprise* (50 < employees < 250).
    - *Large-Enterprise* (250 < employees).

Product information are crucial in the choice of the transportation mode, in order to select the system able to match cargo's characteristics as much as possible. Indeed, distribution strategies are tailored to product features, which require specific practices for given needs, as well as to product flows, for which different logistics networks should be planned. Therefore, the survey presents two aspects of the product(s) considered by the decision-maker:

[1] https://ec.europa.eu/growth/smes/sme-definition_it

- *Product type*. As already anticipated, product characteristics influence the choice of transportation system, because different needs emerge and are required to be fulfilled. In this regard, different needs are translated into different preference information on attributes that managers express, which directly affect the calculation of the global score of each alternative and hence the selection of the optimal solution. Therefore, managers were asked to select the product category to consider for the application of the model among nine clusters:
    1) *Textile products, apparel and footwear.*
    2) *Chemical products, rubber and plastic articles.*
    3) *Pharmaceutical products and medical devices.*
    4) *Computers, electronic and optical products, watches.*
    5) *Houseware products.*
    6) *Vehicles and other means of transport.*
    7) *Furnitures.*
    8) *Machinery and mechanical appliances.*
    9) *Base metals and articles of base metals.*

Product categories have been defined by agglomerating product groups defined by the International Trade Centre (ITC), which is a multilateral agency that collaborates with the World Trade Organization (WTO) in the provision of trade technical assistance to companies all over the world. The clusterization has been carried out by taking as reference the Harmonized System (HS), which is a global product classification method used by customs authorities around the world to identify products[2]. It should be noticed that food products are not considered in this analysis, since they are characterized by peculiar features that prevent them to be included within the defined categories.

- *Product flow*. This aspect involves the physical movement of goods from a supplier to a customer. Since this dissertation focuses on the transportation of products between European countries and China, bilateral trade activities have been considered. Moreover, the developed survey takes the perspective of European companies, allowing decision-makers' to choose between two types of product flows:
  - *Import flow*: it implies to define a Chinese location as origin point, from which goods are moved to a European location, defined as destination point.
  - *Export flow*: in this case, goods are moved from a European origin to a Chinese destination.

Product type and product flow are crucial features for the definition of the Product Value Density (PVD), which has been considered as the main driver to categorize managers' answers. The whole process is described is the next chapter.

Manager's data are asked to have a broader understanding of the decision-maker, and hence questions have been structured on the ground of job title and experience.

- *Job title*. Referring to managerial roles dealing with the problem analyzed in this master thesis, the following job descriptions are defined:

[2] https://www.trade.gov/harmonized-system-hs-codes

  - *Export/Sales Manager.*
  - *Operations/Logistics/Supply Chain Manager.*
  - *Purchase/Procurement Manager.*
  - *Other*

- *Managerial experience*. This aspect considers the years of work spent in managing people or projects. Managers are required to choose between the following options:
  - *Years < 5*
  - *5 < Years < 10*
  - *10 < Years*

Regarding preference information on attributes, managers must express their preference opinions by matching one specific linguistic variable among the available ones presented in the previous chapter with each attribute. Moreover, in order to be able to compare the theoretical results that the developed model provides with the decisions taken by managers, these latter are asked to indicate the freight solutions they exploit to move the product type considered.

7.1.2 Data Collection

Once designed the survey, LinkedIn has been used as the principal mean to spread it among managers. In particular, given the focus of this master thesis, managers have been searched by considering only European countries as locations of the respective companies. Moreover, in order to find adequate professional figures, a filter was applied by means of keywords, taken from the job titles previously defined. However, also word of mouth and personal network of contacts have been exploited in order to reach as much potential decision-makers as possible.

Answers have been collected into an Excel spreadsheet and processed according to the steps explained in chapter 6.5, in order to convert the linguistic variables associated by managers to the attributes into numeric variables. Overall, the cluster of surveyed managers counts 96 answers, characterized by a considerable level of multinationality. Indeed, although Italy accounts for the highest number of answers (25), as it was trivial to predict given the nationality of the two candidates, also Germany (15), Netherlands (13), France (12), Spain (11), Poland (10) and Austria (10) contributed to this dissertation and hence can be included in the analysis. Moreover, respondents show heterogeneity also in terms of company size and job experience. Regarding the first one, medium enterprises accounts for 45% of the total answers, followed by large enterprises (28%), small enterprises (22%) and micro enterprises (5%). This latter percentage was expectable, since only few micro enterprises are able to exploit suitable logistics capabilities to perform trade activities with China, which is known to be a complicated market under many managerial aspects. With respect to job experience, the largest share (48%) belongs to the most expert managers, followed by the second and third clusters in descendent order of experience, with respective shares of 34% and 14%.

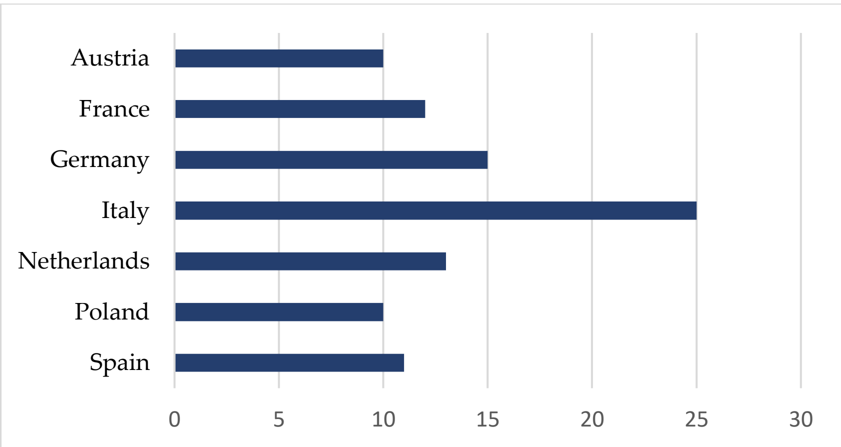


Figure 7.1: *Surveyed managers' nationalities.*

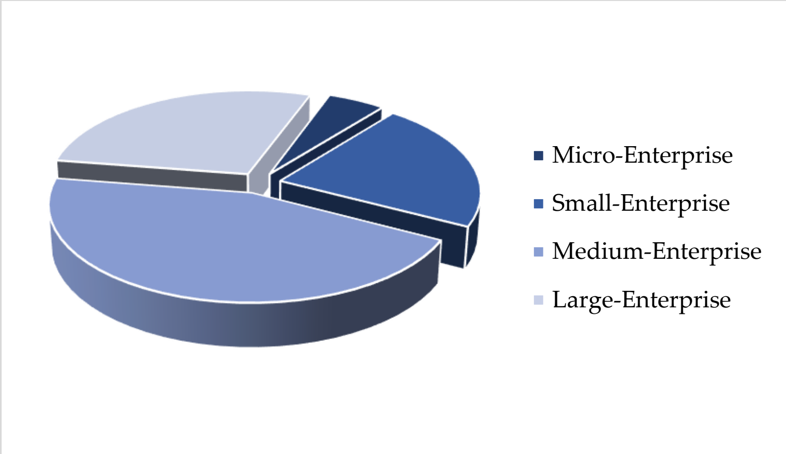


Figure 7.2: *Surveyed managers' company size.*

The following table shows the distribution of the answers provided by managers respect to product categories and related flows. Overall, 52 answers deal with the movement of goods from China to Europe, while 44 answers are related to the opposite flow. Within the first cluster, houseware products (5) accounts for the highest share of answers, followed by computers, electronic, watches and optical products (4), chemical products, rubber and plastic articles (2), and all the others. On the other side, related to the export of goods from Europe to China, the largest set of answers is related to textile products, apparel and footwear (1), followed by machinery and mechanical appliances (8) and the remaining ones.

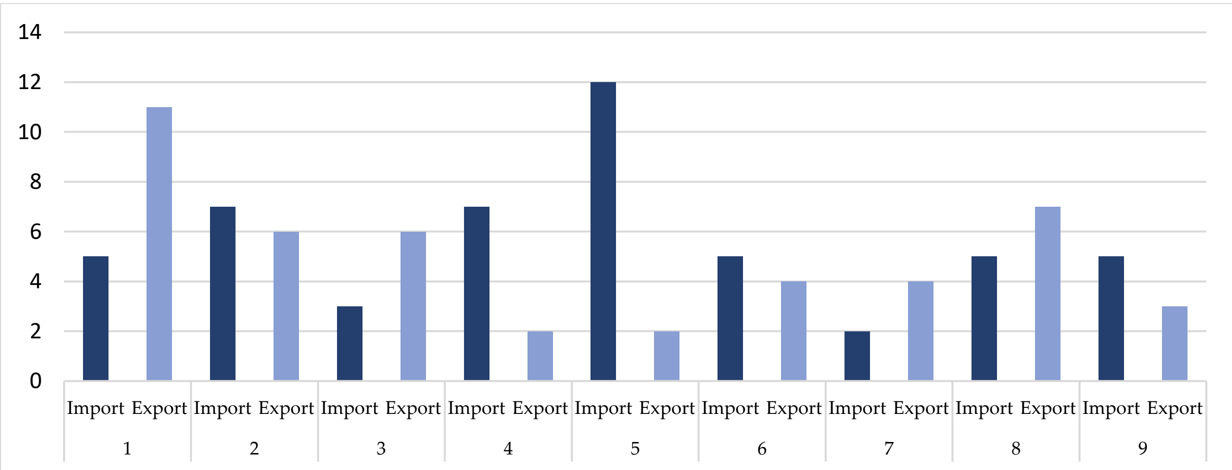


Figure 7.3: *Surveyed managers' product category and product flow.*

7.1.3 Data Categorization: Product Value Density

In order to provide a better representation of managers' answers in terms of preference information on the attributes considered within the decision model, different perspectives have been evaluated. Indeed, logistics and distribution management are influenced by many aspects, which may be exogenous or endogenous variables, such as demand variability or service level to provide. However, product features usually capture the attention of managers, since they are directly related to both business efficiency and effectiveness. Within this dissertation, product value and product weight are considered as the main drivers to categorize managers' preference information, and in particular their ratio, called product value density (PVD), has been used as reference measure for the distinction.

Product value density (PVD) is defined as the ratio between the product value and the chargeable weight, expressed in kilogram:

$$Product\ value\ density\ (PVD) = \frac{Product\ value}{Chargeable\ weight} \tag{7.1}$$

Product value includes all the activities performed until transportation from the point of origin (pre-carriage) is performed, and hence corresponds exactly to the product price of an Ex-Works transaction (EXW), which implies the seller to make the good at disposal of the buyer at the point of origin. Product value does not include also packaging, which is usually performed before the international transportation to reduce the risk of damage, insurances and royalties or license fees related to the goods. On the other side, chargeable weight refers to the highest value between the actual cargo weight and the volumetric cargo weight, obtained by using a cubic meter to weight conversion factor. Therefore, PVD expresses the value per kilogram embedded by a specific product. Although this concept is widely recognized as a crucial factor for business decisions, only few contributions in the academic literature take a specific focus on it. ***[137]*** relates product value density with the level of manufacturing centralization, stating that product characterized by high-value density are the ones to be produced in few large-scale plants. *[87]* focuses on the centralization of inventories with respect to PVD, proving that higher levels of product value density are associated with higher degrees of inventory centralization. Within this dissertation, PVD is considered as a main driver for the definition of freight transport strategies, as it influences the importance given by managers to the considered decisional criteria.

In order to define the product value density for each product category previously defined, the International Trade Centre (ITC) database has been used as source to gather values and quantities of goods traded between European Union and China. Figure 7.4 shows these data for the year 2020, with product value and product quantity relatively expressed in USD thousand and tons. Moreover, table 7.1 groups these values and reports the product value density by product category and product flow.

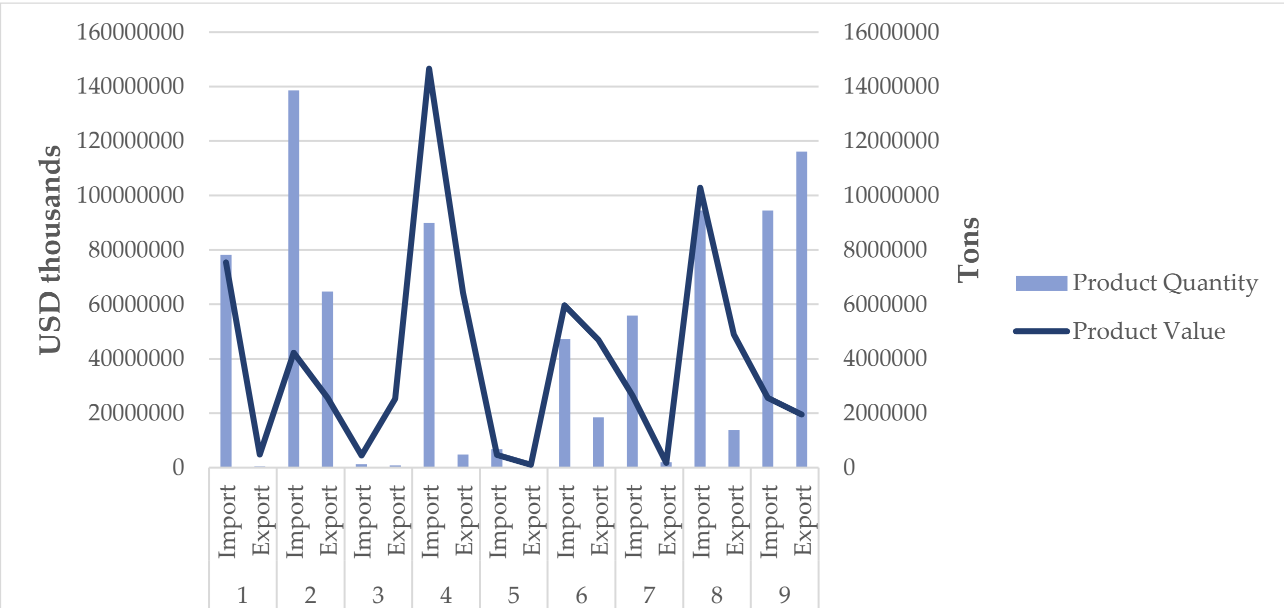


Figure 7.4: *Products traded between China and EU by quantities and values.*

Product Code	Product Label	Product Flow	Sum of Quantity	Sum of Value	PVD
1	Textile products, apparel and footwear	Import	7818469,00	$ 75.398.681,00	9,64
		Export	47946,00	$ 4.787.250,00	99,85
2	Chemical products, rubber and plastic articles	Import	13860066,00	$ 42.276.737,00	3,05
		Export	6476246,00	$ 25.625.546,00	3,96
3	Pharmaceutical products and medical devices	Import	126186,00	$ 4.463.905,00	35,38
		Export	80469,00	$ 25.290.548,00	314,29
4	Computers, electronic and optical products, watches	Import	8986193,00	$ 146.583.614,00	16,31
		Export	477956,00	$ 64.246.653,00	134,42
5	Houseware products	Import	686438,00	$ 4.668.246,00	6,80
		Export	20128,00	$ 1.049.957,00	52,16
6	Vehicles and other means of transport	Import	4713631,00	$ 59.668.105,00	12,66
		Export	1843749,00	$ 46.897.234,00	25,44
7	Furnitures	Import	5594022,00	$ 26.549.178,00	4,75
		Export	199887,00	$ 1.700.190,00	8,51
8	Machinery and mechanical appliances	Import	9448363,00	$ 102.790.297,00	10,88
		Export	1391451,00	$ 48.941.190,00	35,17
9	Base metals and articles of base metals	Import	9448363,00	$ 25.666.572,00	2,64
		Export	11615408,00	$ 19.530.654,00	1,68

Table 7.1: *Products traded between China and EU by quantities, values and PVD.*

Once PVD for each product category has been calculated, the distinction between high and low PVD has been carried out by taking as reference *[157]*. In this contribution, cargo is considered as high-value whenever its PVD is above 12 USD/Kg, following the guidelines of US Chamber of Commerce (2006). Therefore, as shown by Figure 7.5, product value densities for each combination of product category and product flow are mapped within a grid, along with a straight line which defines the limit between the two categories (PVD = 12 USD/Kg). Then, the points above the line are defined as high PVD, while the points beyond the line are defined as low PVD. Table 7.2 reports the results of this analysis.

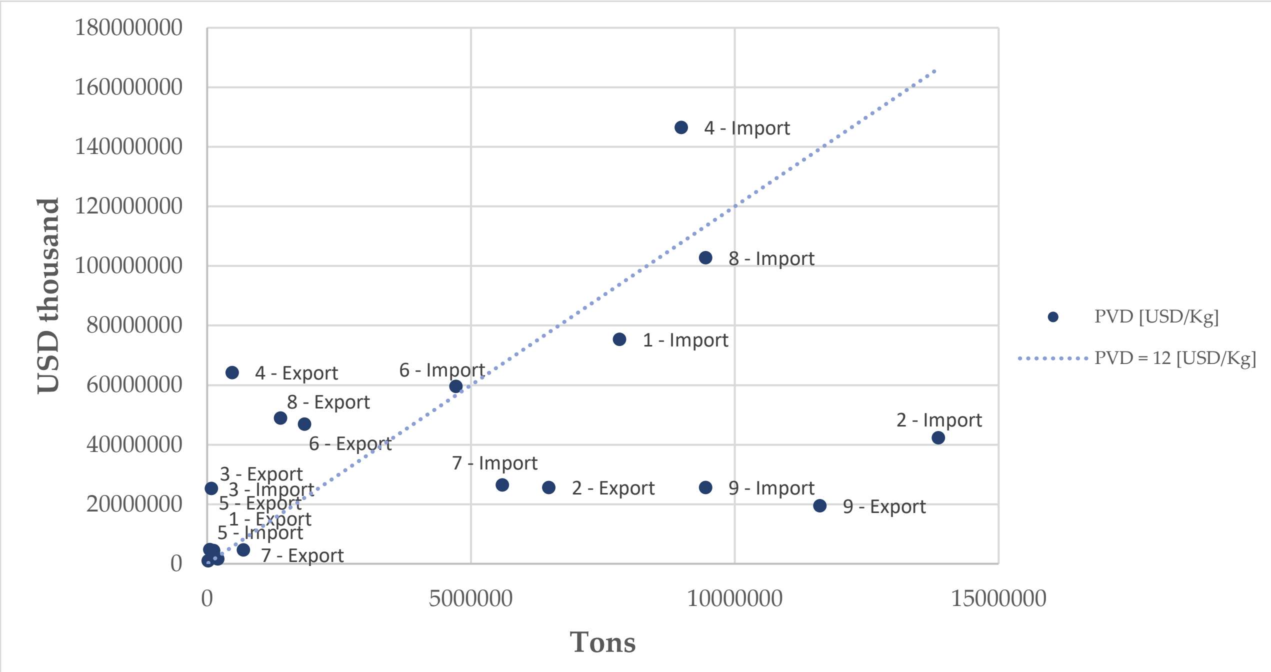


Figure 7.5: *Product Value Densities.*

Product Category Code	Product Category Label	Product Flow	PVD
1	Textile products, apparel and footwear	Import	Low
		Export	High
2	Chemical products, rubber and plastic articles	Import	Low
		Export	Low
3	Pharmaceutical products and medical devices	Import	High
		Export	High
4	Computers, electronic and optical products, watches	Import	High
		Export	High
5	Houseware products	Import	Low
		Export	High
6	Vehicles and other means of transport	Import	High
		Export	High
7	Furnitures	Import	Low
		Export	Low
8	Machinery and mechanical appliances	Import	Low
		Export	High
9	Base metals and articles of base metals	Import	Low
		Export	Low

Table 7.2: *High/Low Product Value Densities.*

7.1.4 Preference Vectors

Following the categorization explained before, preference opinions have been grouped according to the product value density of the product category and the product flow selected by managers. Therefore, four different preference vectors are created:

- *Import/High-PVD*
- *Import/Low-PVD*
- *Export/High-PVD*
- *Export/Low-PVD*

The following tables show the preference vectors presented above, composed by the defuzzyfied and normalized weights of each attribute, calculated by following the steps reported in chapter 6.5. It is to be noted that attributes are reported in a descendent order with respect to their score related to preference information provided by managers.

IMPORT/HIGH-PVD		
Decisional Criteria	Defuzzyfied Vector	Normalized Vector
Damage Risk	7,97	0,14
Transportation Cost	7,19	0,13
Lead Time Variability	6,92	0,12
Lead Time	6,77	0,12
Inventory Carrying Cost	6,25	0,11
Theft Risk	6,08	0,11
Accessibility	5,97	0,11
Maximum Load Capacity	5,17	0,09
Emissions	4,31	0,08

Table 7.3: *Import/High-PVD preference vector.*

IMPORT/LOW-PVD		
Decisional Criteria	Defuzzyfied Vector	Normalized Vector
Transportation Cost	9,03	0,19
Lead Time Variability	7,02	0,15
Lead Time	6,37	0,13
Maximum Load Capacity	5,53	0,11
Accessibility	5,19	0,11
Emissions	4,40	0,09
Damage Risk	4,57	0,09
Inventory Carrying Cost	3,13	0,06
Theft Risk	2,94	0,06

Table 7.4: *Import/Low-PVD preference vector.*

EXPORT/HIGH-PVD		
Decisional Criteria	Defuzzyfied Vector	Normalized Vector
Damage Risk	8,25	0,14
Lead Time	7,35	0,12
Lead Time Variability	7,12	0,12
Transportation Cost	7,01	0,12
Inventory Carrying Cost	6,56	0,11
Theft Risk	6,39	0,11
Maximum Load Capacity	5,71	0,10
Accessibility	5,44	0,09
Emissions	5,15	0,09

Table 7.5: *Export/High-PVD preference vector.*

EXPORT/LOW-PVD		
Decisional Criteria	Defuzzyfied Vector	Normalized Vector
Transportation Cost	9,10	0,17
Lead Time Variability	6,88	0,13
Maximum Load Capacity	6,87	0,13
Lead Time	6,19	0,11
Accessibility	6,19	0,11
Emissions	5,52	0,10
Damage Risk	5,31	0,10
Inventory Carrying Cost	4,17	0,08
Theft Risk	4,02	0,07

Table 7.6: *Export/Low-PVD preference vector.*

Looking at these preference vectors, some considerations may emerge. First, under a global perspective, it's possible to observe that, on equal PVD, the sum of attributes' weights is higher for export flows than import flows, suggesting that exporters give a higher importance to attributes compared to importers. This outcome may be the result of the type of incoterm that each couple of exporter-importer signs within a trade activity. Incoterm rules are an internationally recognized standard used worldwide in international and domestic contracts for the sale of goods, that define respective responsibilities and risks of buyers (importers) and sellers (exporters) in international transactions, and identify the implications to both parties in terms of logistics responsibility, risk and cost. Therefore, incoterms define the time and place where the "actual ownership" of goods shipped moves from the exporter to the importer, as well as the obligations and charges. According to this perspective, incoterms are possible to be grouped into two clusters:

- *Freight Collect terms*. This category includes all the incoterms which imply a shift of goods' ownership from the seller to the buyer before the linehaul is performed:

- *Ex Works (EXW)*. The exporter makes the goods at disposal of the importer at his premises (point of origin), and hence this term places the maximum obligation on the importer and minimum obligations on the exporter.
- *Free Carrier (FCA)*. The exporter delivers the goods to a place owned by the importer within the exporting country, dealing with packaging, loading of goods, pre-carriage and custom clearance operations.
- *Free Alongside Ship (FAS)*. The exporter delivers the goods alongside the vessel in the designed port (used only for sea freight).
- *Free on Board (FOB)*. The exporter delivers the goods on board the vessel nominated by the buyer at the named port of shipment, and hence is responsible also for the loading of containers on carriage (used only for sea freight).

- *Freight Prepaid Terms*. In this cluster, all the incoterms characterized by a shift of goods' ownership from the seller to the buyer after the linehaul are grouped:
  - *Cost and Freight (CFR).* The exporter is in charge of all the activities performed till the port of destination, bearing their costs but not the risk associated to the linehaul, for which the importer is responsible (used only for sea freight).
  - *Cost, Insurance and Freight (CIF).* The exporter is in charge of all the activities performed till the port of destination, bearing their cost plus the insurance cost to cover the linehaul risk sustained by the importer.
  - *Carriage Paid To (CPT).* The exporter delivers the goods to a place owned by the importer within the importing country, dealing with all the activities from packaging to the linehaul and on-carriage.
  - *Carriage and Insurance Paid To (CIP)*. The exporter delivers the goods to a place owned by the importer within the importing country, dealing

with all the activities from packaging to the linehaul and on-carriage, plus a cover insurance for any issues occurred during the transportation.

- *Delivered at Place (DAP)*. The exporter delivers the goods to the destination point, where their ownership is moved to the importer, who is in charge of unloading the goods and paying import duties, taxes and custom clearance operations.
- *Delivered at Place Unloaded (DPU)*. The exporter bears all risks involved in bringing the goods to and unloading them.
- *Delivered Duty Paid (DDP)*. The exporter is in charge of all the activities but the unloading of goods.

Therefore, the first cluster is characterized by a larger set of duties and costs allocated to the importer, while the second one assigns more duties and costs to the exporter. Considering the higher overall score related to export flow compared to import flow on equal PVD, a possible reason may be the higher percentage of Freight Prepaid Terms signed by managers. Indeed, as incoterms belonging to this latter cluster allocate a larger set of cost and responsibilities to exporters than importers, managers dealing with export flows may be more sensitive to the defined attributes compared to those managing import flows, assigning higher values. To mention but a few examples, transportation cost scores for export and import flows in case of low PVD, which are the highest values of the related vector, are equal respectively to 9,10 and 9,03. With respect to high PVD, although damage risk is the most weighted attribute for both export and import flows, it assumes values respectively of 8,25 and 7,97.

Deepening the analysis of attributes' weights assigned by managers with respect to product value density and product flows, it's possible to highlight that transportation cost, lead time and lead time variability remains on the top four positions for all the preference vectors, suggesting their absolute relevance regardless any product characteristics. Indeed, transportation cost is the main and most immediate freight entry impacting on product cost, and hence plays a crucial role in the choice of transport solution. Lead time and lead time variability are directly related to features which are visible to the customer, such as speed and reliability, that highly affect the service provided and hence the effectiveness of the business.

High PVD vectors report a primary importance given by managers to the damage risk, which is reasonable considering the impact that a damage could have on high value products. On the other side, theft risk does not show the same level of relevance, probably because of the low incidence of occurrence and the latest security measures implemented by service providers. Moreover, inventory carrying cost is way more taken into consideration within high PVD vectors compared to low PVD vectors, since it is a cost item whose value (and hence whose impact on the whole product cost) proportionally increase with product value. The opposite outcome is valid for the maximum load capacity: since the higher it is, the more transportation cost can be spread among the shipped goods, low value products benefit more from this effect, because the impact of freight cost is higher compared to high value products. Therefore, low PVD vectors show higher scores for this attribute compared to high PVD vectors. This reasoning is applicable also for accessibility, since the ease of reaching a specific point of destination by means of a given freight system is inversely proportionate to the cost of the service. Therefore, as stated for maximum load capacity, since transportation cost impacts more on low value products, accessibility is provided with higher importance within low PVD vectors. Last, emissions attribute does not show a specific distribution pattern, suggesting that the environmental awareness is highly related to managers' and companies' values rather than product or logistics reasons. However, its importance seems to be marginal within preference vectors, and way far from the top attributes voted by managers. Within the next chapter, a sensitivity analysis on the environmental criteria is reported, which inspects the potential variation of the optimal freight solution with respect to each preference vector as a result of an increase of the importance given to the attribute "emissions".

7.2 Computation of Alternatives Global Scores

As previously explained, the global score of a given alternative for a specific preference vector is calculated as the sum of the products between the defuzzyfied value of an attribute and the relative performance score of the alternative with respect to the attribute. To do so, the following formula is applied:

$$W \otimes A_i \stackrel{\text{def}}{=} \sum_{j=1}^{n} d(\widetilde{w}_j) x_{ij} \tag{7.2}$$

Where:

$d(\widetilde{w_j})$ is the defuzzyfied value of the j-th attribute.

x_{ij} is the relative performance score of the j-th attribute with respect to the i-th alternative.

Therefore, by using the formula defined before, a global score for each combination of freight alternative and preference vector is calculated. Results are shown in the graphs above.

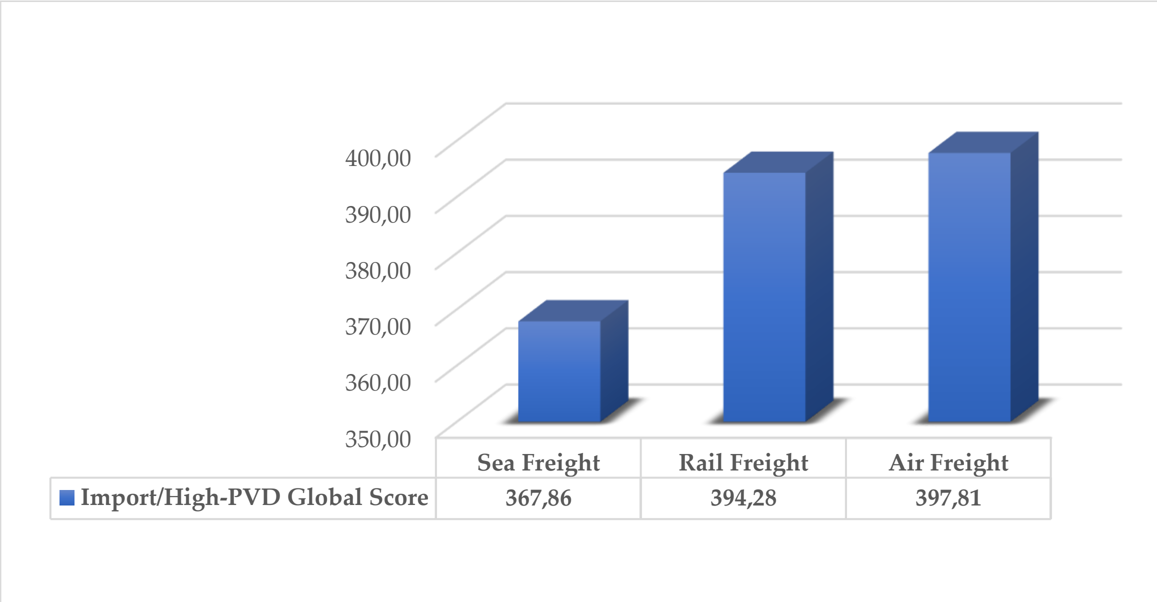


Figure 7.6: *Import/High-PVD alternatives' global score.*

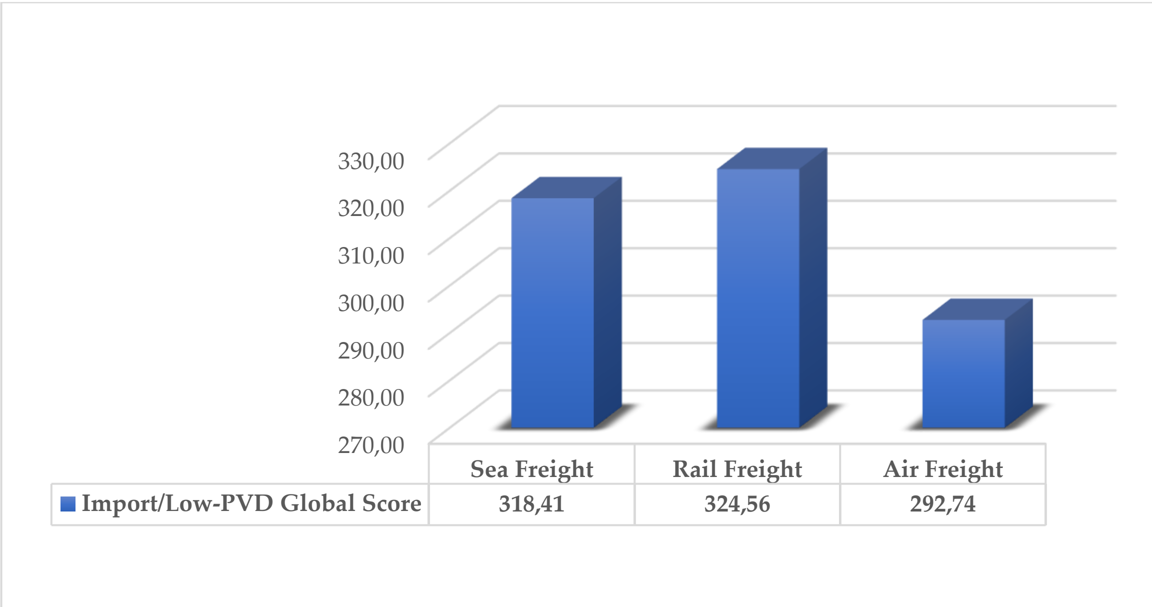


Figure 7.7: *Import/Low-PVD alternatives' global score.*

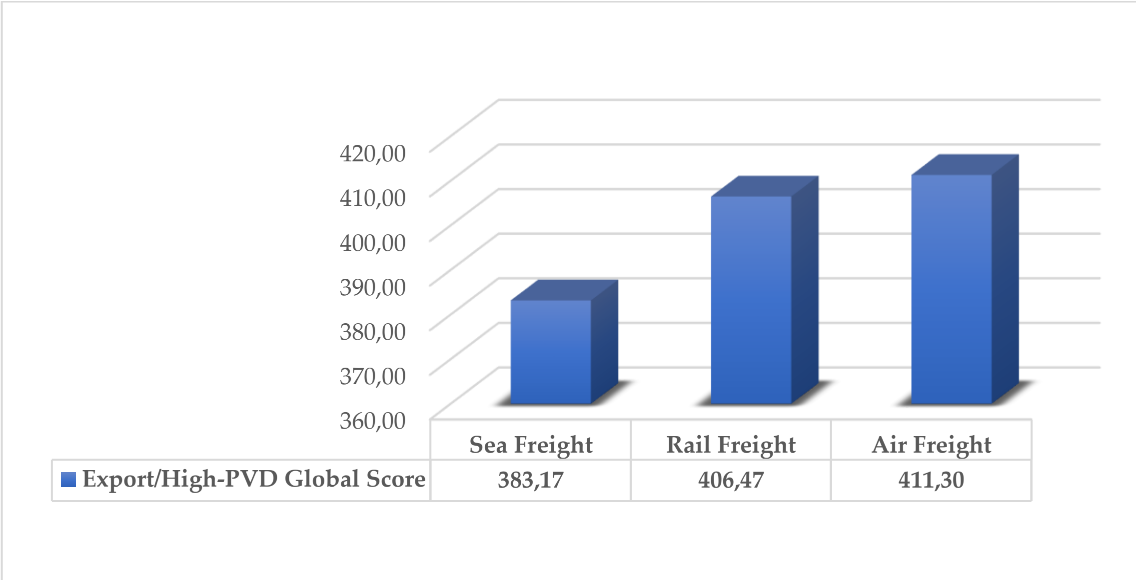


Figure 7.8: *Export/High-PVD alternatives' global score.*

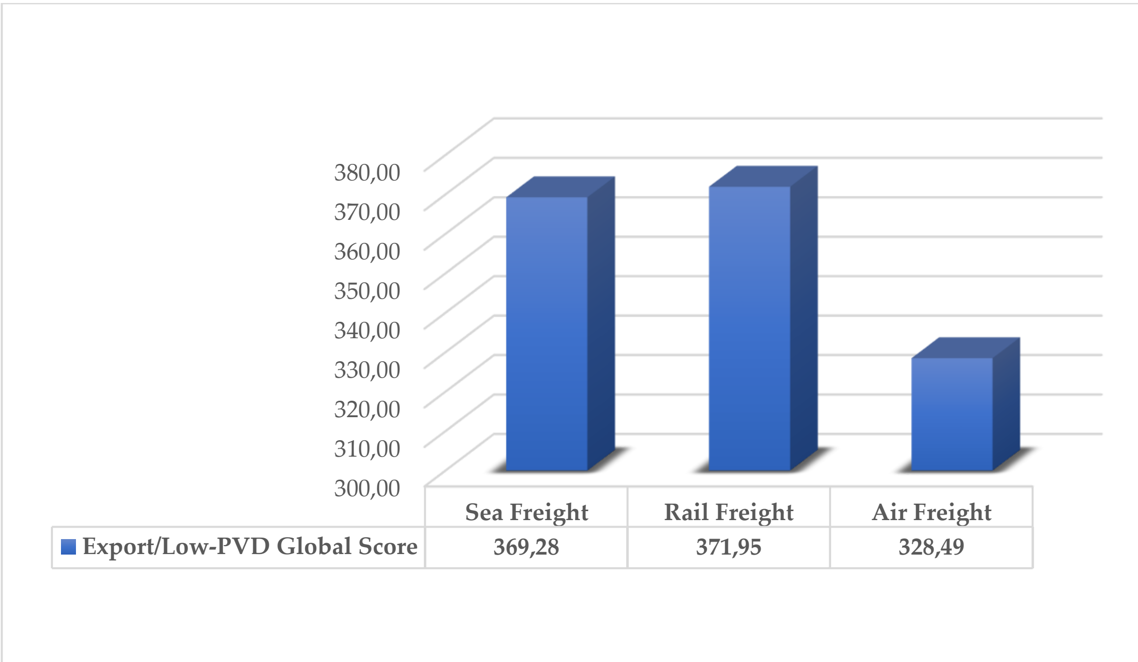


Figure 7.9: *Export/Low-PVD alternatives' global score.*

7.3 Selection of the Optimal Solution

Once assessed the global scores of the alternatives, the optimal solution related to each specific vector is the one characterized by the highest score, according to the following formulation:

$$A^* = \left\{ A_i : \max_i W \otimes A_i \stackrel{\text{def}}{=} \max_i \sum_{j=1}^{n} d(\widetilde{w}_j) x_{ij} \;\; \forall i = 1, \dots, m \right\} \qquad (7.3)$$

Where:

A^* is the optimal solution.

A_i is the set of alternatives.

$\widetilde{d(w_j)}$ is the defuzzyfied value of the j-th attribute.

x_{ij} is the relative performance score of the j-th attribute with respect to the i-th alternative.

The following tables sum up the results, by reporting for each preference vector the ranking of the alternatives in a descendent order respect to the global score. Therefore, the optimal solution is the one highlighted in green, which is related to the highest global score.

IMPORT/HIGH-PVD	
Freight Solution	Global Score
Air Freight	**397,81**
Rail Freight	**394,28**
Sea Freight	**367,86**

Table 7.7: *Import/High-PVD alternatives' ranking and optimal solution.*

IMPORT/LOW-PVD	
Freight Solution	Global Score
Rail Freight	**324,56**
Sea Freight	**318,41**
Air Freight	**292,74**

Table 7.8: *Import/Low-PVD alternatives' ranking and optimal solution.*

EXPORT/HIGH-PVD	
Freight Solution	Global Score
Air Freight	**411,30**
Rail Freight	**406,47**
Sea Freight	**383,17**

Table 7.9: *Export/High-PVD alternatives' ranking and optimal solution.*

EXPORT/LOW-PVD	
Freight Solution	Global Score
Rail Freight	**371,95**
Sea Freight	**369,28**
Air Freight	**328,49**

Table 7.10: *Export/Low-PVD alternatives' ranking and optimal solution.*

Looking at the global scores of the alternatives, it's possible to come up with some considerations for each preference vector. Air freight results as the best option for products characterized by high value density in both import and export flows. This outcome was expectable, considering that the related preference vectors are characterized by three of the four top attributes in terms of importance for which air freight shows the highest relative performance scores compared to the other alternatives. Within the same rankings, sea freight shows the worst global scores and the larger distance from the optimal solution, which is reasonable as high product value densities make managers to prefer attributes such as damage risk or lead time, whose relative performance scores related to sea freight are the lowest. Last, analyzing rail freight for vectors related to high product value density, its global scores are right below the air freight, showing a tiny distance from the optimal solution. This is due to the shortened transport time and the high quality in terms of damage and theft risk of the Belt and Road network, which has been able to attract high value goods and to move away from tradition, that shows rail freight being used only to transport lower value and bulk cargoes in the past.

Focusing on the vectors related to low product value density, rail freight results as the best solution for both import and export flows. Of course, low PVD has specific requirements such as low transportation cost and other related attributes as maximum load capacity and accessibility, in which air freight performs as the worst. Moreover, even though sea freight is the best option in terms of transportation cost, which is by far the most important attribute for low value products, rail freight is able to globally perform better, considering further strategic attributes like lead time, lead time variability and accessibility. However, this outcome is also the consequence of market disruptions occurred in the last two years due to Covid-19. Indeed, as deeply explained in chapter 6.6.1, the rise of transport fares had a major impact on sea freight, which suffered a higher increase compared to rail freight and became less competitive. This reasoning is further developed in the next chapter, where a sensitivity analysis in performed considering the transportation cost related to a pre- and post-pandemics situation.

8. Sensitivity Analysis

The results just presented show that air freight is the best solution for the import or export of high-value density products, while rail freight is the preferred solution for the import or export of low-value density products.

At this stage, a sensitivity analysis was performed, in order to quantify the effects induced by a change in the parameters with which the decision matrix and the vector of preferences were calculated.

In particular, two sensitivity analyses have been pointed out:

- The first considers an increase in transportation costs in a post-pandemic scenario, compared to costs before the Covid-19 pandemic;
- The second concerns a realistic and conceivable future trend, in which the environmental aspect will have a greater influence on the choices made by company managers.

8.1 Impact of Covid-19

As mentioned in the previous chapter, some outcomes were strongly influenced by the market disruption that Covid-19 brought with it. One of the most evident consequences has been a considerable increase in prices, in all sectors, although international transport has been one of those most affected.

With this aim, Table 8.1 attempts to summarize the parameters explained in chapter 6.6, relating to the price per kilogram of goods transported through the different alternatives considered in a pre-covid and post-covid situations. As can be seen, prices of all the considered alternatives increased in absolute terms, although for some alternatives the percentage increase was smaller than for others. Indeed, rail freight is the alternative with the smallest percentage increase compared to sea and air freight, and hence its relative performance with respect to transportation cost increased the most compared to air freight, while sea freight continued to be the alternative characterized by the lowest transportation cost, and hence the best relative performance.

	PRE-COVID		POST-COVID		COST VARIATION	
	Performance Value [USD/kg]	Relative Performance Score	Performance Value [USD/kg]	Relative Performance Score	Absolute Value [USD/kg]	Relative Value
Sea Freight	0,07	10,00	0,19	10,00	+0,12	+171%
Rail Freight	0,12	5,53	0,27	7,06	+0,15	+125%
Air Freight	4,50	0,15	12,00	0,16	+7,5	+167%

Table 8.1: *Pre- and post-Covid freight fares.*

At this point, vector product has been run between the preference vectors, which remained unchanged, and the decision matrix, in which the relative performance of the transportation cost has been modified according to the new transportation costs, to understand what impact would have had on the optimal choices. The outcomes of this analysis are shown in the following figures.

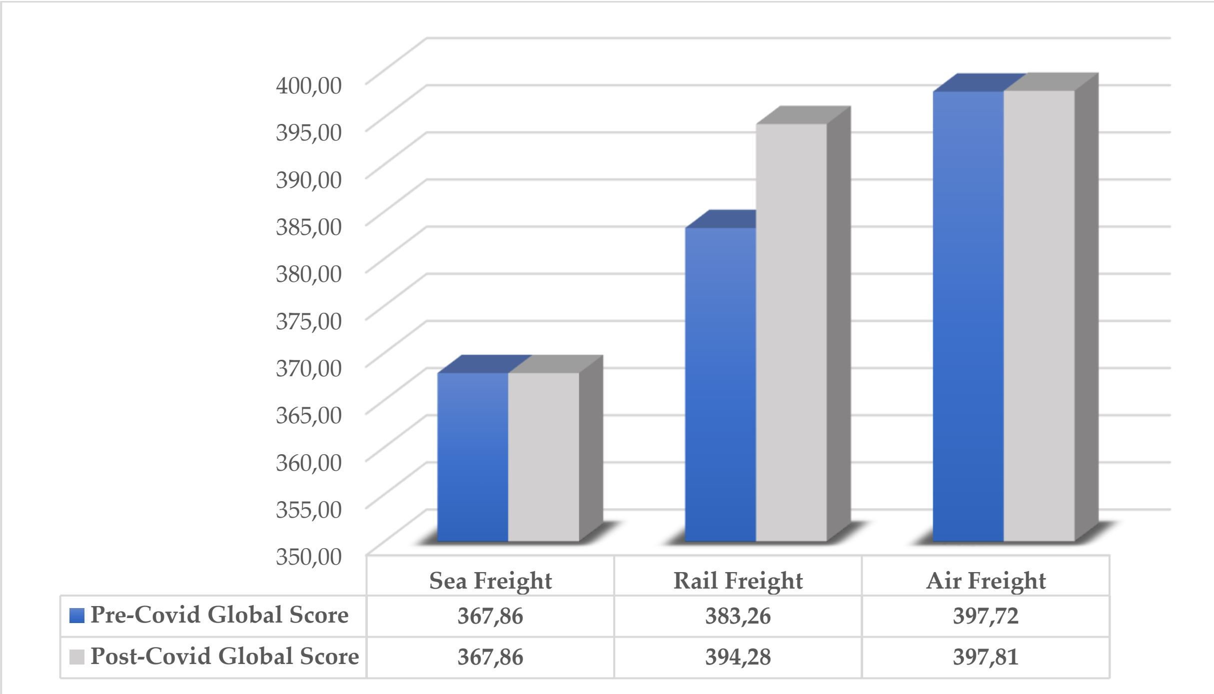


Figure 8.1: *Import/High-PVD alternatives' global score in pre- and post-Covid context.*

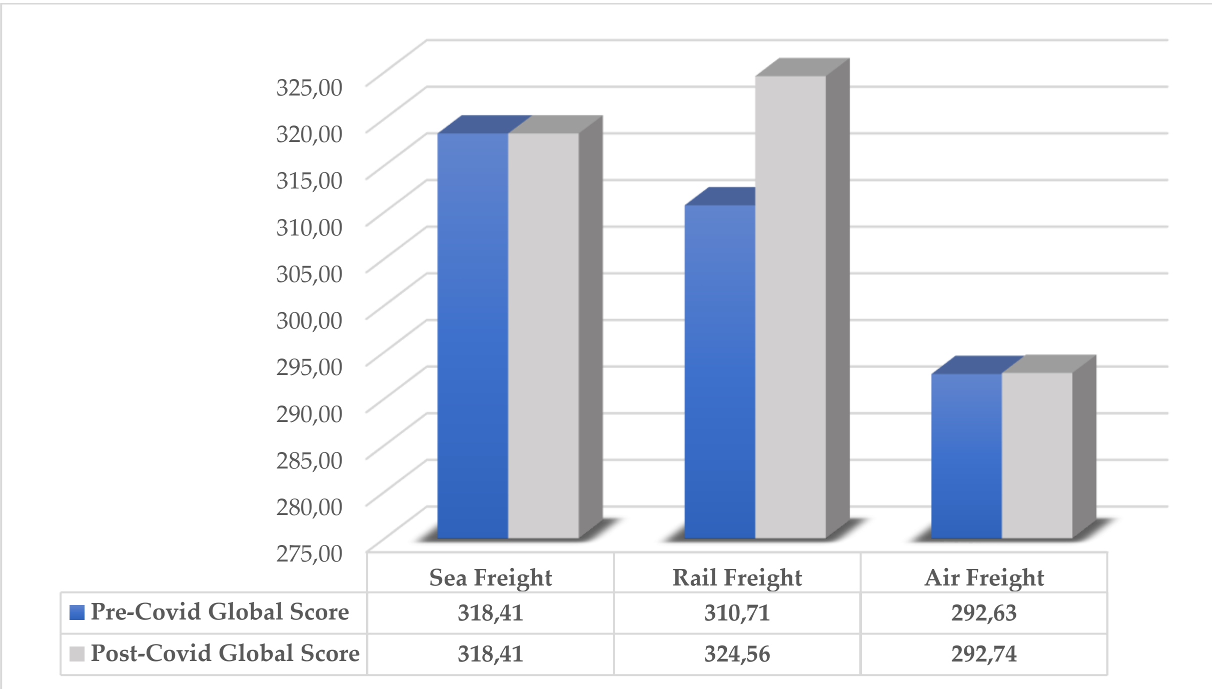


Figure 8.2: *Import/Low-PVD alternatives' global score in pre- and post-Covid context.*

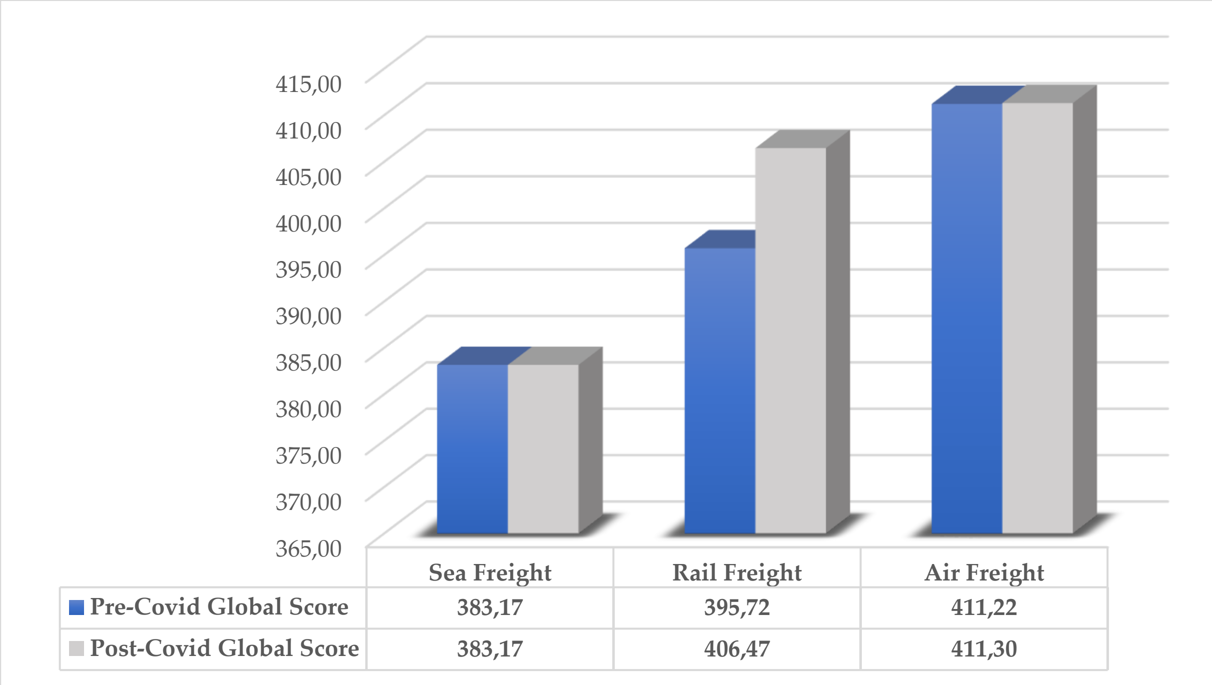


Figure 8.3: *Export/High-PVD alternatives' global score in pre- and post-Covid context.*

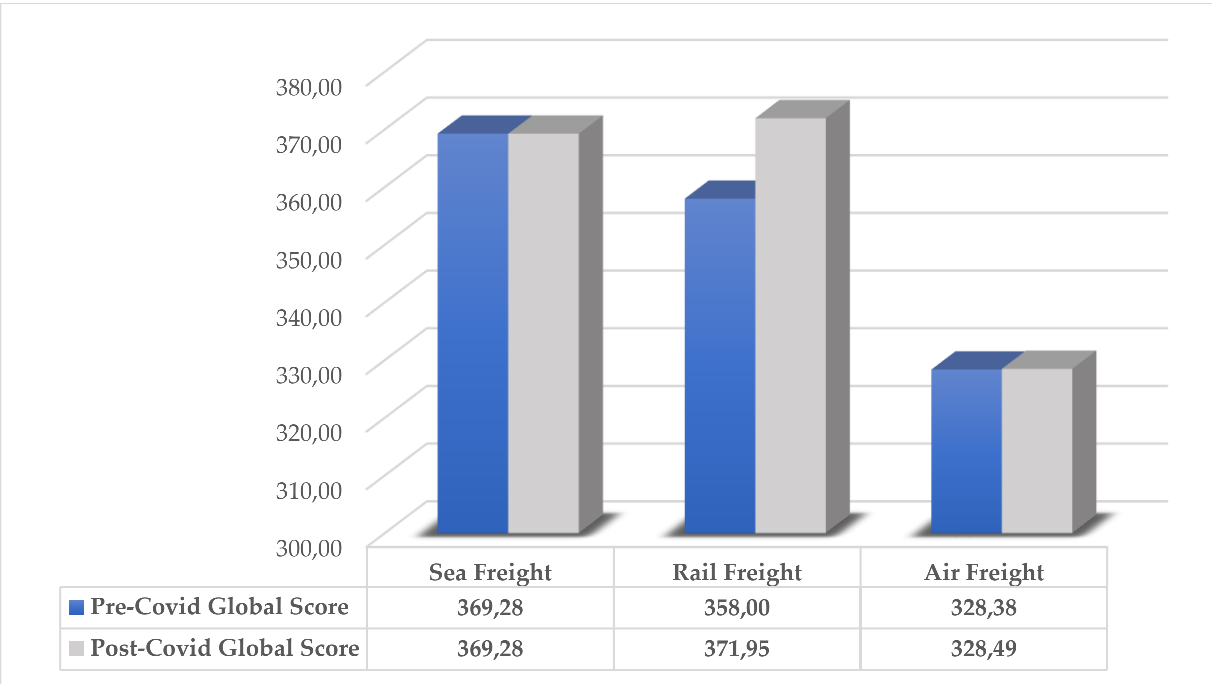


Figure 8.4: *Export/Low-PVD alternatives' global score in pre- and post-Covid context.*

Results show that, in a pre-pandemic situation, the optimal solutions were air freight for high-value density products and sea freight for low-value density products. Since the advent of covid, and looking at the current situation, we see how the hierarchies have changed. First of all, it must be noted that sea freight global score remains unchanged switching from pre-pandemic to post-pandemic situation. This is because in both cases sea freight is characterized by the lowest transportation cost, and hence it continues to be the alternative with the best relative performance score, which is 10 and does not change. For rail freight and air freight, their relative performance scores increase on two different paces, as their relative performance in the decision matrix changes.

Against this consideration, it can be seen that for high-value dense products the optimal solution remains unchanged from the starting situation. Although rail freight comes considerably closer to the air freight, the latter remains preferable mainly because of the importance of attributes such as "damage risk", "lead time variability" and "lead time", in which it performs best.

For low-value density products, however, the situation is different. For this type of product, the transportation costs attribute is the most important, and given the significant increase in the relative performance of the train and the fact that the results of the ship have not changed, the former is the new optimal transport solution for low value density products.

8.1.1 Theory vs Reality

At this point it is interesting to investigate how the changes of the optimal choices in the results matrix are reflected in the actual choices of the company managers. This means verifying whether the answers given by company managers in the questionnaires regarding the mode of transport they use to import or export the products really correspond to the optimal solution derived from the model that has been developed.

Table 8.2 summarizes the following information: for each European country we have compared the responses relating to the means of transport used first with the pre-covid results matrix and then with the post covid results matrix. To facilitate the analysis, it is assumed that the responses given by company managers remained the same. Then, it has been evaluated whether optimal choices in a post-pandemic situation had improved or worsened compared to a pre-pandemic situation.

Country	Pre-Covid optimal decisions [%]	Post-Covid optimal decisions [%]	(+/-)
Poland	40%	70%	30%
Germany	60%	73%	13%
Austria	40%	50%	10%
Netherlands	69%	62%	-8%
France	67%	42%	-25%
Italy	76%	36%	-40%
Spain	82%	27%	-55%

Table 8.2: *Shares of optimal managers' decisions in pre- and post-Covid context.*

Now, it is interesting to make some considerations about the results that can be observed in the table. Countries such as Poland and Germany play a major role in international rail transport. Duisburg station in Germany, already considered the largest inland port in the world, thanks to the Belt & Road initiative infrastructure project is fast becoming Europe's central logistics hub. Poland, on the other hand, thanks to its favorable logistical position in the center of Europe, is a fundamental hub with its Lodz station. This is to underline how, with the importance of rail in the post-covid situation, these two countries see an improvement in the number of optimal choices compared to the pre-covid situation.

For countries such as the Netherlands, Italy, France and Spain, the situation is slightly different. For these countries the trend is negative, i.e., the correspondence between optimal solutions in a post-pandemic situation and the solutions chosen by managers is lower than in the pre-pandemic situation. These results can be deduced from a number of reflections. The trend in the Netherlands is only slightly negative: this is due to the fact that it relies heavily on maritime transport, having the port of Rotterdam, Europe's largest freight port, but on the other hand it has a good rail infrastructure that ensures it can use the rail freight solution when necessary.

As far as Italy, France and Spain are concerned, the reasons for the negative trend in optimal solutions are comparable: all three countries have nearly a marginal role in the context of the Belt & Road Initiative's rail infrastructure, with most business managers preferring to rely on other solutions such as air freight and sea freight with respect to rail freight. In addition, all three countries have some of the busiest freight ports in Europe: Valencia, Algeciras, and Barcelona in Spain, Trieste and Genoa in Italy, and Marseille in France.

8.2 Environmental Sustainability

Analyzing the value of the environmental criterion within the preference vector, it was found that, at present, the attribute concerning emissions was given a relatively low value compared to the other attributes, in all product categories. This is due to the fact that company managers currently attach much more importance to cost or time decision drivers than to environmental factors. However, it is reasonable to think that already in the immediate future, thanks to initiatives at European and world level aimed at safeguarding the environment, this parameter will have more and more strategic relevance and therefore, in the context of the model constructed, will assume an increasingly high score within the vector of preferences attributed by company managers. Therefore, the importance attributed to the environmental parameter has been considered as fast growing among companies and managers, and hence the four preference vectors has been modified, giving to the attribute *emissions* a medium-high relevance. This was possible by considering the fuzzy numbers relative to the linguistic variables *medium* (2, 5, 8) and *high* (5, 7, 10) between which an average was then made (3.5, 6, 9) and the resulting vector was then defuzzyfied, giving a value of 6.13. This value was then substituted for the previous values for the environmental parameter in each preference vector. At this point, the vector product between the performance matrix, which remained unchanged, and the preference vectors was computed again, with the changes made to the environmental criterion. The following figures show the outcomes of this second sensitivity analysis.

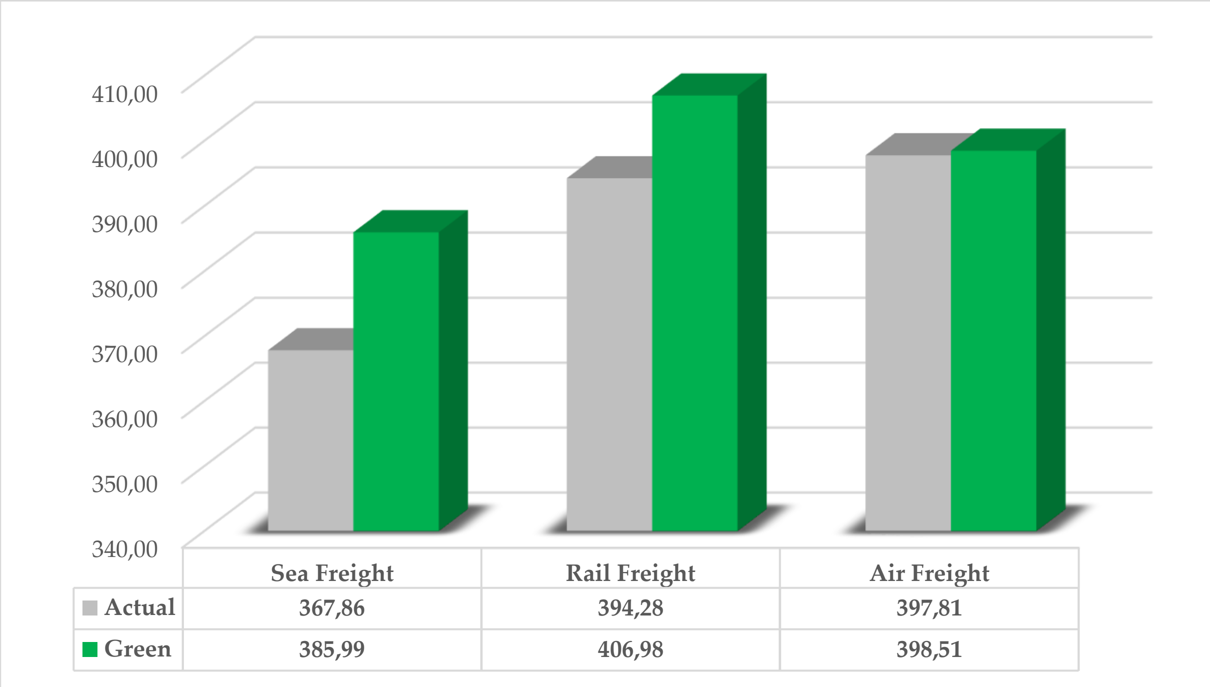


Figure 8.5: *Import/High-PVD alternatives' global score considering actual and potential future environmental awareness.*

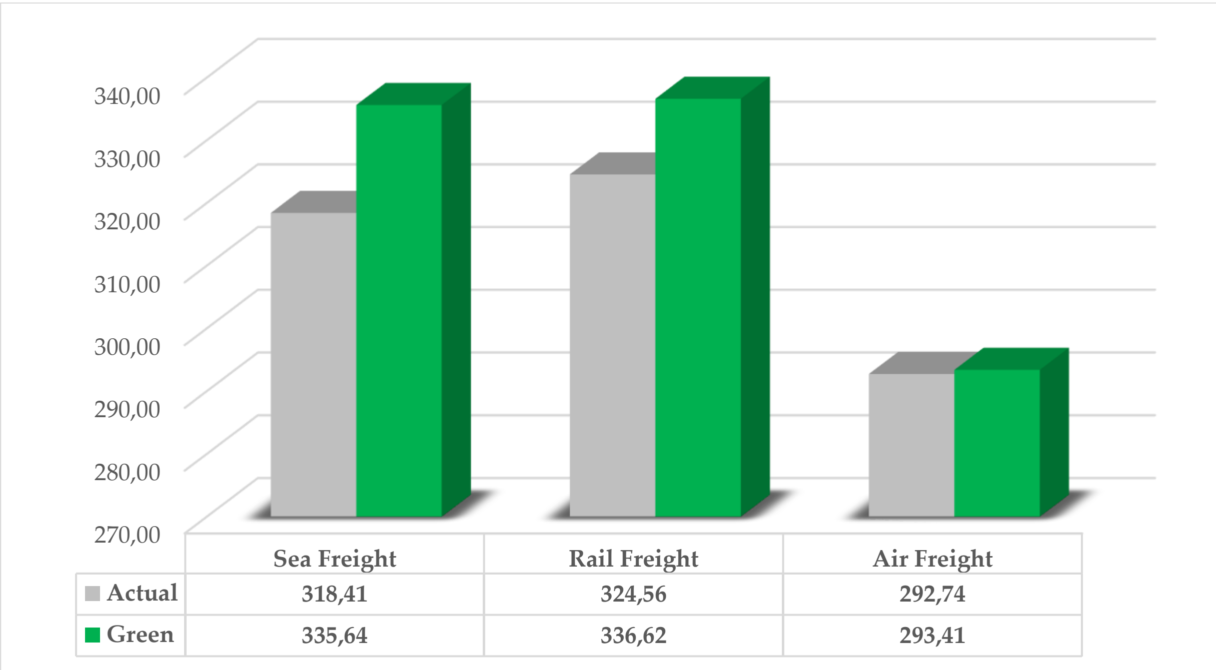


Figure 8.6: *Import/Low-PVD alternatives' global score considering actual and potential future environmental awareness.*

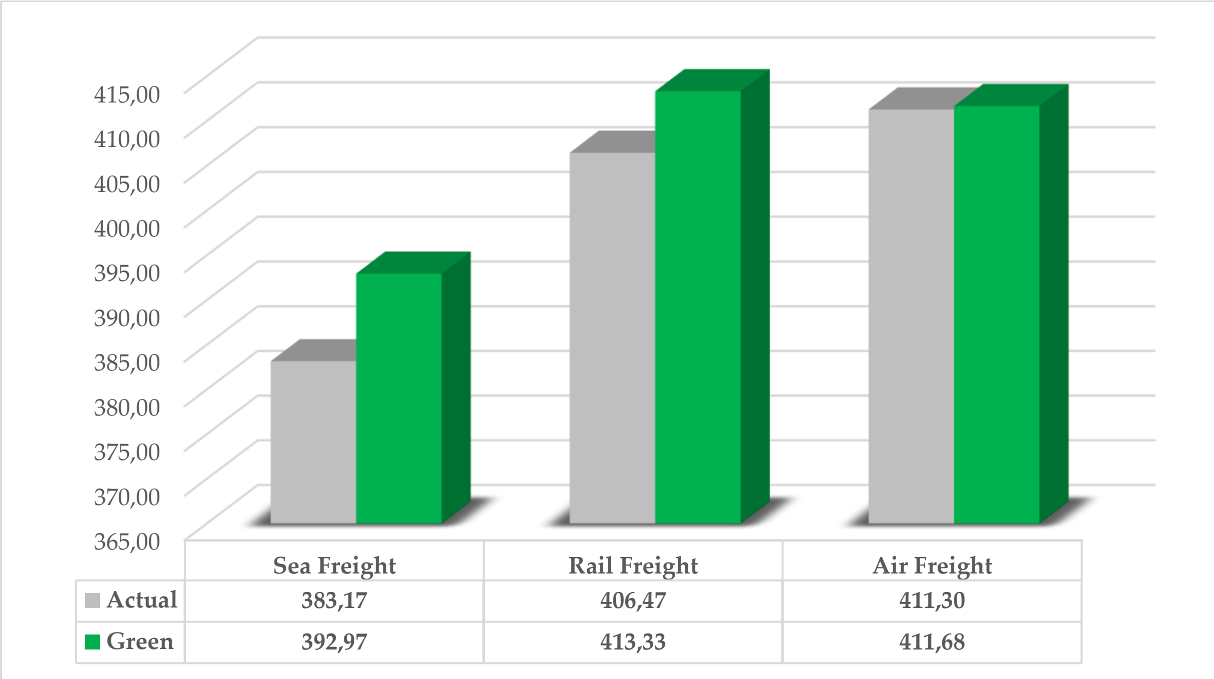


Figure 8.7: *Export/High-PVD alternatives' global score considering actual and potential future environmental awareness.*

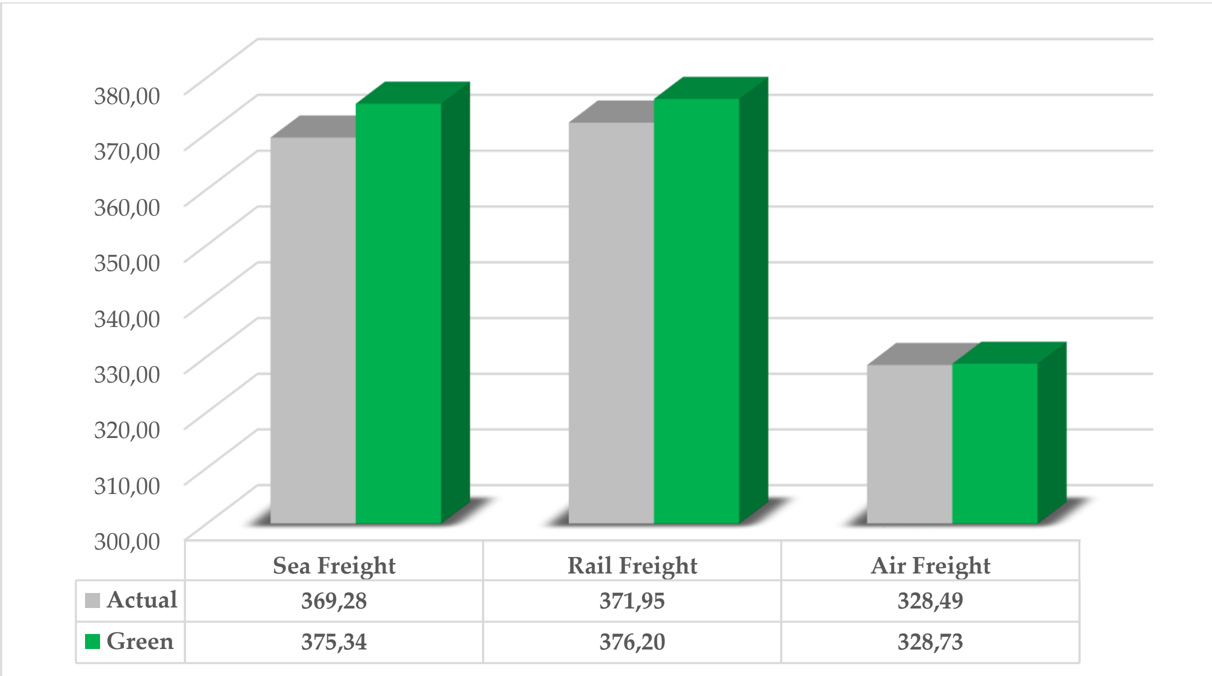


Figure 8.7: *Export/Low-PVD alternatives' global score considering actual and potential future environmental awareness.*

At this point, some considerations are necessary. For the same load, ship's emissions were considered the lowest, train's intermediate, and the aircraft's the highest. Therefore, in terms of performance, sea freight has the highest score, air freight the lowest, while rail freight is an intermediate solution. Once the vector product between the preference vector and the performance matrix has been performed, the impact of increasing the score of the attribute *emissions* will be minimal for the aircraft alternative and maximal for the ship alternative. This impact is reflected in the variation of the values within the final matrix, where the values of the air freight alternative have a minimum delta with respect to the starting situation, while the values of the air freight and train alternatives show a greater variation.

This makes the optimal solution for high-value density imported products, which in the baseline situation appeared to be air freight, become rail freight. This change is mainly due to the fact that the train was already slightly inferior to the airplane alternative in the baseline situation. This is compounded by the fact that, since train performs significantly better than airplane in terms of emissions - 7.01 for the train versus 0.38 for the airplane – assigning greater importance to the environmental criterion shifts the optimal choice from the air to rail freight.

In the case of low-value-density products, however, the argument is different. In this case, the optimal alternative in the starting situation was rail freight. Here, too, a change to the alternative with a better emissions performance would have been expectable, as was the case of high-value density products, shifting the optimal solution from rail to sea freight. However, even after changing the values of the attribute *emissions*, it can be seen that the optimal solution remains rail freight. This happens because for important attributes such as lead time variability, lead time, accessibility to which high values have been attributed by company managers, they have a better performance in rail freight, to such an extent that they manage to balance a lower performance in the environmental criterion.

8.3 Final Considerations

Thanks to the first sensitivity analysis, it's possible to observe that, from a pre-pandemic situation in which the optimal solutions involved air freight for high-value products and sea freight for low-value products, we pass to a current post-pandemic situation in which the use of sea freight for low-value products is abandoned in favor of rail freight and for high-value products the situation remains unchanged. This, as already mentioned in the previous chapter, is due to a reduction in transport costs, which made the relative performance of the train compared to the ship improve with the advent of the pandemic and made it preferred in optimal solutions.

The second sensitivity analysis examined, starting from a current post-pandemic scenario, how the situation might evolve in the near future: that is, with the environmental factor becoming increasingly important in strategic choices, how the optimal solutions would change if managers gave a higher value to the environmental parameter. Results show an interesting result: rail freight would become the optimal alternative for each product category, even replacing air freight for the transport of high-value dense products.

This gives us an idea of the direction in which the international trasport sector might go in the future, in which the Belt & Road initiative will become increasingly important, and in which rail transport will assume a leading role, becoming almost entirely preferable to air and sea transport.

9. Conclusions and Future Developments

The present master thesis ground its basis on the impact that the Belt and Road Initiative has and will have in the future on the international trade between Europe and China. In particular, considering rail freight as a new opportunity opened up by the BRI, the main theme tackled is represented by the selection of the best distributive strategy to move goods between Europe and China. This aim can be broken up into two main purposes: the first one is that of filling the gaps in literature, since BRI has been widely analyzed under economic and geopolitical perspectives, but lacks of researches in transport fields. The other one in that of providing European companies with a helpful tool that can be used in the definition of the best transport solution to import/export goods from/to China.

The defined purposes have been then translated into five main research questions, which all refer to a more general problem, related to the choice of the optimal freight solution for European companies to trade goods between Europe and China. In particular, the first question investigates the main factors which are taken into account by European companies while designing the best freight strategy to apply when trading with China. Three main criteria have been selected, which are further broken up into nine decisional drivers:

- Economic criterium
    - Transportation cost
    - Inventory carrying cost
- Strategic criterium
    - Maximum load capacity

    - Lead time
    - Lead time variability
    - Accessibility
    - Damage risk
    - Theft risk
- Environmental criterium
    - Emissions

These attributes are weighted by managers differently according to some factors, which are usually related to product characteristics due to their importance both for internal and external company's performances. In order to answer the second question, which explores the product features impacting on the prioritization of decision drivers in the choice of the best freight solution for trade activities between Europe and China, two product characteristics have been considered: product value, which in turn is function of product flow, and product weight. These two factors represent the components of the so-called product value density (PVD), which has been considered, along with product flow, as the main feature when assigning a weight to decision drivers for the problem under inspection. Therefore, taking the perspective of European companies, four different situations have been considered:

- Import flow characterized by high PVD
- Import flow characterized by low PVD
- Export flow characterized by high PVD
- Export flow characterized by low PVD

In order to be able to come up with the best transport solution for the analyzed problem, a Multi-Criteria Decision Model has been defined, which evaluates the performance of the available freight alternatives with respect to the defined attributes. The freight alternatives considered to perform the international transport of goods between Europe and China are the following ones:

1. Sea freight
2. Rail freight
3. Air freight

Sea and air freight are traditional solutions already used by companies to ship goods between European countries and China, while rail freight is a new logistics opportunity opened by thanks to the Belt and Road Initiative. Therefore, once assessed the performances of the alternatives with respect to the decision drivers, the optimal solution is determined by maximizing the global score associated to each solution, which is calculated as the vector product of the freight alternative's performances and the weights attributed to each attribute by the manager.

The model has been tested on a cluster of 96 European managers, who were required to fill a survey by indicating (among other data) the importance attributed to each decision driver, the category of product and the trade flow they dealt with. On the ground of the gathered answers, some considerations arose:

- On average, export flows are characterized by higher weights assigned to decisional drivers compared to import flows. This may suggest that the higher share of incoterms used belongs to the cluster of Freight Prepaid Terms, which allocate to the exporter higher responsibilities and costs to sustain respect to the importer.
- Some drivers, such as transportation cost, lead time and lead time variability, show a high importance attributed by managers, regardless any product characteristics. On the contrary, damage and theft risks, as well as inventory carrying cost and maximum load capacity, are highly related to product characteristics and their relevance vary according to product flow and PVD.
- Environmental driver is not considered as one of the top attributes, but on the contrary has always one of the lowest weights, regardless product features.

Moreover, by computing the overall scores for each situation considered, the following outcomes came out:

- Air freight results to be the optimal solution for goods characterized by high PVD in both import and export activities.
- Rail freight results to be the optimal solution for goods characterized by low PVD in both import and export activities.

A sensitivity analysis has been carried out, in order to evaluate the impact of two relevant factors affecting business and logistics strategies in the last years: Covid-19 pandemics and sustainability awareness. The first topic has been analyzed under a cost perspective, varying pre- and post-pandemics fares within the model, and verifying whether optimal solutions were subject to changes. On the other side, the impact of sustainability awareness on freight optimization has been evaluated by imposing a medium-high fixed weight to the attribute related to the environmental criteria, in order to assess whether results were different from the extant outcome by considering the increasing momentum that environmental aspect is gaining in the last years. From these two analyses, the following considerations emerge:

- Transportation fares prior to Covid-19 pandemics confirm air freight as the optimal solution for high PVD in both import and export activities, while reveal sea freight to be the optimal solution for low PVD in both import and export activities, instead of rail freight. The reason to this change in the optimal solution for low PVD from sea to rail freight is related to the dramatic increase of transportation fares occurred due to the pandemics. Indeed, sea freight fares has risen far more than rail freight fares, causing a shift in the optimal solution.
- By imposing a medium-high level of importance to the environmental attribute, rail freight is confirmed as the optimal solution for low PVD in both import and export activities. However, air freight is no more considered as the

best alternative for high PVD, due to its scarce performance in terms of environmental sustainability, and rail freight results to be the optimal solution even for this cluster.

Therefore, considering a hypothetic timeline, the pre-covid situation was characterized by air freight and sea freight as the optimal solutions respectively for high and low PVD in both import and export flows. The occurrence of pandemics shifted the optimal solution for low PVD from sea to rail freight, due to a much higher increase in sea fares compared to rail fares. Moreover, looking at the future and the growing relevance that sustainability is having within companies, the environmental factor will acquire more and more importance in logistics strategies, making rail freight the optimal freight solution also for high PVD.

Although rail freight has been proved to be the optimal solution in case of both low and high PVD in present and future scenarios, in some cases reality deviates from these results. Indeed, countries like Germany and Poland play a major role in international rail transport, and thanks to important logistics hubs such as respectively Duisburg and Lodz, they have been able to exploit the opportunities opened up by BRI and allow national companies to optimize their logistics choices. On the other side, Italy, Spain or France, which are not provided with an appropriate rail infrastructure connected with the Belt and Road network, are not able to ride the change in international freight strategy and take advantages from the new solution offered by BRI.

Nevertheless, the presented model helps the decision-maker:

- to have an overview of the available international freight solutions;
- to consider relevant decision drivers for the choice of the best freight mode;
- to understand the factors influencing the importance attributed to the decision drivers;

- to compare different freight solutions on the ground of the selected decision drivers, to come up with the optimal solution with respect to his logistics needs and requirements;
- to understand the impact of Covid-19 and the influence of environmental awareness on international freight industry.

Therefore, this dissertation has a double value, covering both theoretical and practical aspects. Indeed, on one side it provides a contribution to the literature, filling the gaps related to international freight decision-making in the context of the Belt and Road Initiative. On the other side, it provides a tool to managers for the choice of the best international freight solution, and offers a clear overview of both the present situation and future developments of the topic.

9.1 Future Development

Although the present master thesis has brough a wide contribution to the literature, future developments are possible to be determined, on the ground of some considerations. First, the model may be enlarged by considering also food products, and evaluating freight alternatives on the ground of further peculiar characteristics such as perishability. This can be an important step to cover all product categories that managers may deal with, in order to make the model a complete tool to rely on.

Another development to this model may be represented by the analysis of domestic transport. In particular, this dissertation focuses on international freight solutions, without taking into account pre-carriage and on-carriage transports, which refer to the movement of goods respectively from the point of origin to the logistics hub in the country of origin, and from the logistics hub in the country of destination to the destination point. A comprehensive model considering both domestic and international transport may give an overall understanding of the problem to decision-makers, and help them to design a complete distributive strategy, from the origin to the destination point.

Moreover, in order to better evaluate the present environment, which has been dramatically disrupted by the pandemics, the impact of Covid-19 can be further analyzed, considering other parameters such as for instance lead time and lead time variability. Indeed, as reported by journals and technical reports, ports and airports congestion, as well as containers' lack, cause delays in shipments which may affect the performances of the freight alternatives and hence the optimal solution.

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