Developing a phased approach for strategic distribution center location selection in FMCG Industries

Master Thesis

Chen Hu

TU Delft

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Chen Hu (5456630)

Developing a phased approach for strategic distribution center location selection in FMCG Industries

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Chair:	Jafar Rezaei,	TU Delft
Supervisors:	Marcel Ludema,	TU Delft
	Mark Duinkerken,	TU Delft

TU Delft

Preface

It has been a long journey since Aug 20, 2021. As it comes to an end, the happiness in your mind may not be as overwhelming as you expected. Since this moment has already surrounded for a thousand times. But I made it. The world is my oyster.

Firstly, I extend my heartfelt thanks to my three supervisors, especially Marcel. Your patience and endless guidance have been invaluable in helping me complete this thesis. Professor Jafar, your encouraging words have filled me with confidence, and Professor Mark, even though you couldn't be present at the final presentation, I will always cherish our meaningful meetings in your office. Thank you for everything.

To my dear family, especially my parents, your unwavering support has meant the world to me. I hope this achievement makes you proud, and I consider it a beginning rather than an end. Let's celebrate together with champagne and hugs. To my maternal grandparents, thank you for waiting so patiently for this day. I love you dearly, and I can't wait to explore the free world with you. Grandpa, your wisdom kept me safe, and this master's thesis is dedicated to your memory. RIP.

I would also like to thank all my classmates in these two years, you embrace me with kind and careful. Thank you, Rui, Haoyu, Xinran, Ximing and all my Beijing classmates, hope you enjoy a wonderful life in your future. I look forward to treating you all to ramen in Tokyo when we meet again. To my college friends, Meng, I can't wait to share my story with you, and Daiwei, keep going.

Special thanks go to my high school friends. Thank you Nine, wish we can hold our friendship like this forever. Thank you Qinghua, without your help in reference, there is no way I can graduate this fast. Hope you can also graduate soon, and we can change our English name card together.

To all those who supported me during my master's, I am deeply grateful for your contributions. This has been a long dream, and now it is time to wake up and keep moving forward.

Akimoto Manatsu, this thesis is also for you, I will go to Tokyo, EVENTUALLY.

Summary

In the realm of Fast-Moving Consumer Goods (FMCG), logistics has emerged as a key determinant of competitive advantage. With the rapid shift of consumer demands and the expectation for swift responses, there is a pressing need to establish modern urban distribution centers. To address the distribution center site selection problem for FMCG companies, this thesis project aims to develop an approach that incorporates a series of factors through multi-criteria analysis. Generate an alternative choice set and ultimately identify an appropriate location by quantitative or qualitative methods. This demand gives rise to the following design objective:

To design an approach for FMCG companies with different business strategic objectives to determine an appropriate distribution center site selection.

To achieve this design objective, a 5 step of phased method is created. This method began with the generation of factors determining the location of the distribution center. Then constraints, requirements are established as the input for a morphological chart to create alternative locations for distribution centers and their variations. The multi criteria decision method (MCDM) was applied to evaluate alternatives and rank the final alternative list to find the best-performing alternatives. Finally, the practicality of this method was evaluated through a case study.

Current state of distribution center location problem

The problem of distribution center location selection is crucial for many organizations due to its impact on operational efficiency, costs, and customer demand. This issue is particularly pronounced for FMCG companies because of their rapid sales cycles and need for frequent inventory replenishment. The need for distribution center site selection arises from various scenarios, including company expansion, supply chain optimization, mergers and acquisitions, market changes and policy shifts. Choices when selecting a new distribution center location can include expanding existing facilities, constructing new ones, sharing a distribution center or outsourcing to a third party.

Desired state of distribution center location problem

The desired outcome of the distribution center location problem would be achieved by implementing the 5 step of phased method. However, the exact result will depend on the individual objectives and strategies of different companies. These objectives may include improving supply chain efficiency, minimizing total costs, enhancing service quality, adapting to market demand changes, complying with policy & regulatory requirements and maintaining competitiveness.

Application of the 5 step of phased method

- Determine factors identification
  In the practical application of this 5 step of phased method for selecting determining factors, aspects like company size, type of product, demand urgency and desired outcome should be considered. If a company's goal is to improve supply chain efficiency, more emphasis should be placed on factors directly affecting supply chain management. If the objective is to enhance competitiveness and capture market share, then factors which are closely related to adaptability and flexibility should be prioritized. If the company aims to minimize total costs, then it should focus on factors which are directly related to cost.

- Alternatives generation
  In the morphological chart, various general functions and attributes that a distribution center should possess are included. Different business goals and strategies within each company may influence the choice of alternatives derived from this morphological chart. If a company aims to minimize costs, it may be more concerned with location selection and the possibility of securing low-cost land. If the company's goal is to improve supply chain efficiency, then optimizing functions such as receiving, storage and pickup may be prioritized.
- Alternatives evaluation
  At times, decision-makers may face time constraints necessitating quick decisions. These circumstances could arise from rapid market changes, actions by competitors, or urgent internal needs. Under such pressure, decision-makers may not have sufficient time to thoroughly conduct this 5 step of phase method and may need to adopt a quick approach by scaling down some steps. This rapid approach involves using a scorecard to determine the most crucial factors, generating a limited number of alternatives based on these factors, and then evaluating the final alternatives based on decision-maker preferences.

Design process of the 5 step of phased method

1. **Determining Factors Identification:**
   First all the factors influencing the location of the distribution center are identified from literature review. These factors can span multiple dimensions including supply chain management, transportation and geography.

2. **Constraints Selection:**
   Next, constraints for the location of the distribution center were selected from these determining factors.

3. **Requirements Outlining:**
   Thirdly, this method outlines requirements based on the functions of the distribution center. This step ensures that the selected location enables the distribution center to fulfill its intended roles effectively.

4. **Alternative Generation and preselection using Morphological Chart:**
   The fourth step involves generating alternatives using a morphological chart. This systematic approach facilitates the exploration of various potential solutions, offering a wide array of possibilities for the location decision.

5. **Alternative Evaluation**
   In the fifth step, MCDM can be used to calculate evaluation factor weights and then rank the final alternative list. It ensures an objective and transparent decision-making process, facilitating the selection of an appropriate distribution center location based on the calculated scores. MP is another accurate calculation method which can be applied for quantified factors and directly get the optimal solution.

Case study

A case study about merging two FMCG companies is given to evaluate the effectiveness of the 5 step of phased method. By using this 5 step of phased method, it aims to find an appropriate distribution center location problem for this merging company, which includes the selection of factors, using a morphological chart to generate alternatives, applying best worst method to provide weights for each factor, and using quantitative and qualitative analysis to rank alternative list.

Firstly, in the step of choosing determining factors, the motivation includes the objective of the merging company, which are minimize cost, be adaptable to market change and improve the supply chain efficiency. In order to satisfy the objective of minimizing total cost, the determining factors include logistics cost factors and business environment factors. In order to satisfy the objective of being adaptable to market change, the evaluation factors include proximity and flow related factors, accessibility and infrastructure. In order to improve the supply chain efficiency, the evaluation factors include proximity, flow related factors and logistics cost factors. The last factor is natural environmental factor, it is derived from the company's need for environmentally friendly.

Secondly, constraints for this case study includes:

1. This distribution center must meet the local legislation.
2. This distribution center location must apply with the safety health and environment rules in the company.
3. This distribution center location must consider the natural disaster risk.
4. This distribution center must have good access to the nearest highway.
5. This distribution center must have hazardous material division to storage special products.

They are based on determining factors which may limit the available options for distribution center location. As qualification factors that you cannot control, those constraints are used to restrict the available options for distribution center location.

Thirdly, functional requirements for this case study include function storage, receiving, shipment, placement and product input/output. For each functional requirement it has a corresponding attribute as non-functional requirement. These attributes include:

1. The special storage area of this distribution center must be of high quality.
2. The process of receiving and dispatching products must be fast and synchronisable.
3. The loading dock must be designed to support multiple trucks for simultaneous operation without interfering with each other.
4. The distribution center handling equipment must be automated.
5. The distribution center inventory management and forecast analysis system must be updated.

Fourthly, functions and attributes for a new distribution center location are used in a morphological chart to generate alternatives. In case study, the total number of combinations in morphological chart is 82944. However, by classifying the means to best means and possible means, the number of combinations can be limited to 6:

1(a). Expand current distribution center for Company Alpha.

1(b). Expand current distribution center for Company Beta.

2. Find new location in the neighbor cities and build it in empty land or industrial estates.
3. Outsource to logistics company in the neighbor cities.
4. Find new location in a new city and build it in empty land or industrial estates.
5. Outsource to logistics company in a new city.

Finally, after determining the final alternative list by morphological chart, BWM is used to identify factors weights. After combining the average weight for both decision makers, Distance to customers (0,3109) is the most important factor while choosing a new distribution center. And the least important factor is Taxes (0.0359). Then quantitative and qualitative analysis is used to calculate factor scores, applying min-max normalization to normalize factor score to the same range for comparison, and calculating the total performance by a linear-additive function. Based on the results, alternative 1(b) has the highest score (0.7797). Alternative 3 has the second highest score (0.7493). Alternative 1(a) has the lowest score (0.1760). Meaning that alternative 1(b) is the most appropriate location for this case.

Evaluation

By utilizing this 5 step of phased method in a case study to find an appropriate distribution center location for two merging companies, the effectiveness of this method can be evaluated. Firstly, the objectives of these two companies are taken into account during the utilization of this method. Since the objective for the merging companies is to minimize cost and improve supply chain efficiency, these objectives play an important role in determining factors, constraints and requirements. Moreover, in this process, interviews of decision-makers in the company are also involved. Some customized requirements are used in this case study. All factors, constraints, and requirements satisfy the standards of the company. After generating an alternative list for this case study, it is obvious that alternatives 1(b), 3, 4, and 5 share a common characteristic of being geographically close to each other. Alternative 1(b) is the current location, while the others are situated in nearby cities. For alternatives 1(a) and 2, they are close to each other and located in another country. In the last step of evaluating alternatives, BWM is used in this case study on three decision-makers from the company to calculate the factor weights. After using quantitative and qualitative analyses to calculate the performance of each alternative, it is found that alternative 1(b) has the best score among all of them. This is because alternative 1(b) has a higher score in the "Motorway network accessibility" and "Proximity to neighbors" factors. This suggests that the location enjoys convenient access to highways, facilitating transportation, while being situated away from residential areas, minimizing disruptions to daily life. Another important reason is that this location performs significantly better in the 'Distance to customers' and 'Transport cost' factors, which carry more weight compared to other factors. Taking into account all these reasons, alternative 1(b) emerges as the appropriate choice for the distribution center location in this case study. Finally, after utilizing this 5-step phased method in the case study, the appropriate choice for the distribution center was found with good reasons. The effectiveness of this method can be evaluated.

Conclusion and recommendations

In general, this thesis project presents a resolution to the distribution center location problem through the implementation of a 5 step of phased method. It provides a structured decision-making instrument for decision makers, assisting in identifying an appropriate distribution center location relevant to various scenarios. It is used to provide decision-making assistance and strategic direction for companies grappling with distribution center location challenges. And finally, a case study about merging two FMCG companies is given to evaluate the effectiveness of this 5 step of phased method.

Some recommendations for further research include:

- In the real case some companies may face particular constraints or specific assessment factors that may not be taken into account in this approach. it is suggested to increase the number of factors and requirements in the future.
- In the case study the decision maker who are interviewed to determine factor weights are limited. With more people involved in this process, it will increase the accuracy of final result. Moreover, in the case study some data are difficult to obtain such as land cost. Thus, in this study it is replaced to land area which is not so accuracy for the final result.
- This thesis project uses morphological chart to generate alternative on basis of requirements and other aspects. However, in real life the possible means for each function has many diversities which can highly enrich the available combinations for alternative.

Content

List of figures

List of tables

1. Introduction

1.1Background, significance and scope

1.1.1Thesis project background

Since the 1990s, more and more enterprises have been paying attention to cost control, and the control of logistics costs has the highest priority. In order to control and reduce logistics costs, many regional or national policy have been proposed to support the development of the logistics industry. It caused rapid development of the logistics and distribution industry with more and more diversified service models and improvement in infrastructure. The quality development of logistics is an important part of the quality development of the economy. It is also an important force in promoting high-quality economic development. With the rapid development of the logistics industry and the intensification of market competition, many logistics companies have emerged, but at the same time, more logistics companies are bankruptcy. The study found that inappropriate siting is one of the main factors for the bankruptcy of logistics companies (Wang, Chen et al. 2020).

Facility location problem is a decision problem which aims to determine the best facility location in a given area to obtain certain requirements and objectives. It is a process to reach balance between service demand and the cost for facility operation. Many factors such as geographical location, market demand, transport costs and environmental factors should be taken into consideration in the facility location problem. The facility location problem is a broad field of study that covers a wide range of different types of siting problems, such as retail store location problem, logistics distribution center site selection problem, service facility location problem, landfill location problem and telecommunication base station location problem (Farahani and Hekmatfar 2009).

- Retail store location problem:
  Identify the best retail shop locations to maximize sales and profits.
- Logistics distribution center site selection problem:
  Identify the best plant location to meet production and distribution needs and minimize production costs.
- Service facility location problem:
  Identify the best location for services such as hospitals, police stations and fire stations which can maximize service coverage and efficiency.
- Landfill location problem:
  Identify the best landfill site location to meet municipal waste disposal needs and minimize environmental impact.
- Telecommunication base station location problem:
  Identify the best location to maximize coverage of the service area and improve the quality of network communications.

Among all kinds of facility location problem mentioned before, the logistics distribution center site selection problem is a specific application of the facility location problem, which is concerned with the siting of a center for logistics distribution. This problem can be generalized as: How to choose the right location for a logistics distribution center? This decision problem combines factors in many aspects which involves optimal logistics and distribution solutions, service coverage, transportation, environmental factors, market demand and other factors. Finally, it aims to reduce logistics costs, improve distribution efficiency and meet customer needs.

Currently, distribution center has become a significant part of modern logistics. And the issue of choosing the location of logistics and distribution centers is receiving more and more attention. Distribution center is a hub which could connect factories and customers. Finding an appropriate distribution center location could improve local logistics operation service and control distribution costs such as cost of labor, transportation and storage. Therefore, the selection of distribution center location will affect the performance of the logistics system and the improvement of the economic efficiency of logistics.

In order to address the logistics distribution center site selection problem, various methods can be employed, including both qualitative and quantitative approaches. The former largely depends on subjective judgments and historical experiences, while the latter is typically more accurate and can yield reliable results. However, many qualitative factors often get overlooked in real-world cases by simplifying the complexities involved (Gu and Wei 2015). Therefore, this thesis combines both qualitative and quantitative methods to enhance distribution center location decisions. A generic method is proposed in this thesis, and its effectiveness is evaluated through a case study involving two merging FMCG companies.

1.1.2Thesis project significance

The location of the distribution center will have a direct impact on the efficiency and service quality of the entire logistics system. For most enterprises, the location of a logistics distribution center is the most important strategic planning issue in logistics. A reasonable distribution center location will enable more efficient turnover and storage of goods, not only shorten the distance between the distribution center and the customer, but also reduce the distribution cost and the quality of service, improve the speed of distribution and better connect production and consumption into a whole. Once a distribution center has been selected, it will have a direct impact on the cost and efficiency of future deliveries.

1.1.3Thesis project scope

This thesis project focuses on addressing the distribution center site selection problem, a key component of broader facility location problem. The proposed method can be implemented by FMCG companies to solve this problem, tailored to their specific objectives. On the one hand, this method is useful in identifying an appropriate distribution center location for an individual FMCG company. On the other hand, it can also be leveraged during company mergers or acquisitions, situations in which the demand for locating a new distribution center typically increases.

Moreover, the major determining factors in this method are supply chain efficiency, cost and geographic location. However, it also considers the internal layout and operation of the distribution center. Since the internal layout can influence functionality and operational efficiency, it is an important consideration. Furthermore, the requirement for specific techniques or equipment can also influence the choice of location. Therefore, within this method, all these elements can be selected and prioritized by decision-makers.

This method aims to provide a preliminary framework for decision-makers, enabling them to use this method to tackle different case studies. However, the complexity of case studies varies significantly in reality, and this method is designed with adaptability to such diversity in mind. It is useful for solving both relatively simple location problems where only a few factors and alternatives need to be considered, as well as complex location problems involving numerous alternatives and a large group of decision-makers each with their own opinions.

1.2Thesis project objective and question

This project aims to solve a distribution center site selection problem, while considering a series of factors in multi-criteria analysis and using both quantitative and qualitative method to generate an alternative choice set and finally find an appropriate location. The design objective of this thesis project can be presented as following:

To design an approach for FMCG companies with different business strategic objectives to determine an appropriate distribution center site selection.

With the design objective in mind, some questions are derived:

1) *What is relevant background knowledge in the field of facility location problem?*
2) *What is the current state of distribution center location problem found in FMCG industry?*
3) *What are determining factors which can influence the location of distribution center?*
4) *Which methods can be used to solve distribution center site selection problem?*
5) *What alternative and corresponding variants can be generated for distribution center?*
6) *What method has been developed in this thesis project to solve distribution center location problem, and what does it consist of?*
7) *How to apply this method in real case study while considering different company objectives?*
8) *How to determine an appropriate location from all the alternatives lists?*
9) *What is the final alternative list after combining quantitative and qualitative score calculation?*

1.3Thesis project outline

- Chapter 1 Introduction:
  The background of facility location problem and its classification will be introduced first, and the distribution center location project will be presented in this chapter with the project objective and scope. Several questions are formulated to give more insight to this thesis project.
- Chapter 2 Thesis project methodology:
  In the second chapter, the sub-questions and the location of these solutions in this thesis can be found in a structure figure. Thesis approach includes content and method are introduced. Finally, literature review will be done in four aspects.

- Chapter 3 Current and desired state of distribution center location problem:
  This chapter firstly describes the concept of logistics and introduces the various forms of logistics involved in FMCG companies. Then the current status of distribution center site selection is introduced and finally the desired status after solving this problem is explained.
- Chapter 4 The design process of a 5 step of phased method:

This chapter explains this method in detail with 5 dimensions. Determining factors; constraints; requirements; morphological chart and distribution center site selection method.

- Chapter 5 5 step of phased method description and application:
  This chapter firstly summarizes each step for this method. And then use some applications under different situation to illustrate in detail how to apply this 5 step of phased method to site selection.
- Chapter 6 Case study: The merger of two companies in the FMCG industry:
  In this chapter, the 5 step of phased method is used in a case study to verify its practicality.
- Chapter 7 Result and Recommendation:
  The performance of this 5 step of phased method in the case study will be discussed. The limit and some new idea for this approach can be found for further research in the future.

2. Thesis project methodology

2.1 Introduction

This chapter aims to demonstrate the methodology of this thesis project in five main sections. Firstly, in chapter 2.2, a detailed breakdown of the sub-questions that constitute the design objective and illustrate their respective positions within the overall thesis structure. It aims to offer readers a clear roadmap to understand the thesis's holistic architecture and logical flow. The subsequent sections comprise a review of existing literature, introducing a range of methods and concepts closely aligned with the 5 step of phased method.

Chapter 2.4 focus on how to identify and select the key factors determining distribution center site selection. This step is crucial to the 5 step of phased method as it lays the groundwork for understanding and analyzing the location selection issue. Next, chapter 2.5 introduces a series of multi-criteria decision-making methods which can assist in quantifying and comparing the advantages and disadvantages of different location selection alternatives. Chapter 2.6 discusses some fundamental theories and methods concerning the facility location problem which provide theoretical support and practical guidance. Lastly, chapter 2.7 presents the tool of the morphological chart, which can systematically help decision maker generate alternatives, thus laying the foundation for further decision analysis.

Overall, this chapter is designed to provide a comprehensive framework that aids readers in understanding the thesis project methodology, setting the stage for the forthcoming analyses and discussions.

2.2 Thesis project steps

This chapter first explains required data, method and tools for sub-questions in detail and these steps will be summarized in thesis structure.

2.2.1 Data, method and tools collection for sub-questions

1) *What is relevant background knowledge in the field of facility location problem?*

   This question aims to find background knowledge about facility location problem, the classification of facility location problem is derived from literature review. The significance of researching in this area is explained after solving this problem.

2) *What is the current state of distribution center location problem found in FMCG industry?*
   (a) *What are the functions and principles for distribution center site selection?*
   (b) *Why FMCG companies need to find a new distribution center?*
   (c) *What impact does an appropriate distribution center have on a FMCG company?*

   This sub-question aims to find the current state of distribution center location problem. Firstly, data from literature about distribution center location problem are collected, some general functions and principles that a distribution center site must follow are determined. And then the reason why companies need to find a new distribution center is explained in many directions. Finally, the desired state is demonstrated about the result after solving this problem.

3) *What are determining factors which can influence the location of distribution center?*
   (a) *How many determining factors can we find in total and what are their sub-factors?*
   (b) *How to classify determining factors?*

   This sub-question focuses on finding determining factors for distribution center site problem. The factor list was generated by literature review which provide various determining factors from different categorizes. This thesis project synthesizes the findings from multiple literature to derive a comprehensive result. This result can be applied to generalized distribution center location problems.

4) *Which methods can be used to solve distribution center site selection problem?*
   (a) *Which multi criteria decision making method can be used and what are the advantages?*
   (b) *Which mathematical programming method can be used and what are the advantages?*

   The aim of this sub-question is to find methods solving distribution center site selection problem. From literature review both quantitative and qualitative methods can be found to solve this problem. However, under quantitative methods there are other methods such as multi criteria decision making method and mathematical programming method. The advantages and disadvantages for each method are considered.

5) *What alternative and corresponding variants can be generated for distribution center?*
   (a) *What are general constraints and requirements?*
   (b) *Which method can be used to generate alternative?*

   This sub-question has the goal to find alternative list for distribution center. The constraints, requirements and morphological chart are determined by literature review. The idea is to find a long list which contains many possible options. And then narrow down the scope by using morphological chart to find combinations. In this sub-question constraints are qualification factors generated from determining factors. And requirements are determined after considering the general functions that a distribution center should possess. The morphological chart provides many possible means for each function.

6) *What method has been developed in this thesis project to solve distribution center location problem, and what does it consist of?*

   This question seeks to find out the method developed in this thesis project. Based on the results from previous questions, a phased method which comprising five steps, has been created to facilitate the process of selecting a distribution center location. In this method firstly determining factors for distribution center location will be generated. After that all alternatives and corresponding variants for the new distribution center location will be generated by deciding constraints, requirements and using morphological chart. Then

MCDM is applied to weight evaluation factors. On basis of factor weights and qualitative and qualitative calculation, alternative which has the best performance can be found. Moreover, in this method each step offers a variety of options to ensure adaptability for different case scenarios.

7) *How to use the 5 step of phased method while considering different company objectives?*
   (a) *How to select determining factors on basis of company objective?*
   (b) *How to generate alternatives on basis of company objective?*

   This sub-question focuses on application of this 5 step of phased method. For different company objectives the application of each step is also different.

8) *How to determine an appropriate location from alternatives list?*
   (a) *What are the evaluation factors used to calculate the weights by MCDM and how to get them?*
   (b) *Which factor is objective / subjective and how to evaluate it to obtain the score for determining alternative performance?*

   This sub-question aims to generate and measure evaluation factors. Firstly, evaluation factors are derived by interviewing from determining factors. Moreover, during the interview a score card will be used to compare different evaluation factors. The result is the input for MCDM to weight each factor. Finally derive the factor rank on basis of their weights. After determining factor weights, both qualitative and quantitative analysis will be used to measure alternative performance in each factor.

9) *What is the final alternative list after combining quantitative and qualitative score calculation?*
   (a) *Which alternative has the best performance after the calculation?*
   (b) *What are the advantages of this alternative that make it better than others?*

   This sub-question aims to use multi-criteria analysis to find the most suitable distribution center location. The scores for each alternative can be obtained by calculating the performance of each alternative in each factor, multiplying it by the corresponding factor weight, and then summing the results. The higher the final score, the greater the likelihood that the location is suitable for a distribution center.

2.2.2Thesis structure

The structure of this thesis project used to address the main project topic is described in this section. Figure 2.1 provides a summary of the sub questions, relevant method and corresponding position in this thesis.

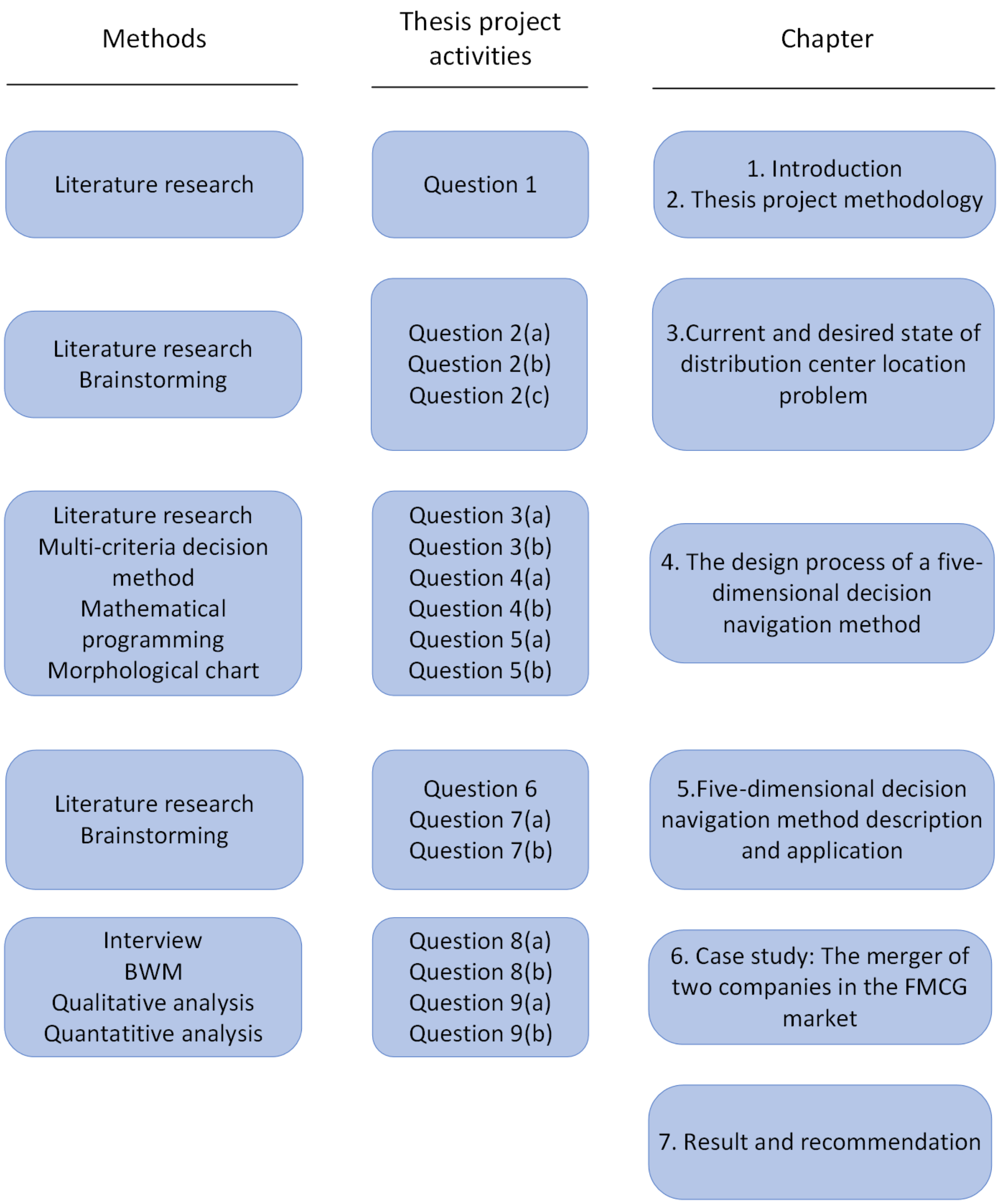

Figure 2.1 Structure of this thesis

2.3Thesis project approach

2.3.1Thesis project content

This thesis presents a method on the generalized distribution center site selection problem. The foundation of this method is analyzing various determining factors affecting the location selection of distribution centers and employing a morphological chart to generate alternatives. The MCDM is utilized in conjunction with questionnaires directed towards decision makers to calculate the weights of evaluation factors. Ultimately, a blend of quantitative and qualitative analyses is used to rank alternatives, in order to identify an appropriate location for the distribution center. The specific study contains the following points:

1. Basic theoretical research:
   The basic theory and classification of facility location problem is explained. Study relevant literature and control certain theoretical methods. The literature review focus on finding distribution center site selection method, the main factors involved in distribution center site selection and tools for alternatives generation.
2. Analysis of the current situation:
   A theoretical analysis is made about the current situation which focus on the concept, principles, functions of distribution centers. Moreover, the possible measures that a company will generally conduct to find a new distribution center are also considered.
3. Approach design process:
   Based on theoretical research and current situation analysis. Further clarify the basic factors influencing the location of the distribution center and alternatives generation procedure. Creating a 5 step of phased method to solve distribution center location problem.
4. Application of this approach:
   Summarize possible solutions for this generic approach. Using case study to further testify the practicality of this approach. The shortcoming of this approach is analyzed and discuss the next research direction.

2.3.2Thesis project method

The thesis project methods used in writing this thesis are literature review, interview, combination of qualitative and quantitative method and case study method.

1. Literature review: This thesis is built upon a wealth of previous research in the field. During the research process, this thesis collected and analyzed a variety of books and literature related to facility location problems, serving as the primary theoretical reference for this thesis. Other literature studies include topics such as the morphological chart, multi-criteria decision-making method, and factors involved in facility location problems.
2. Combination of qualitative and quantitative method: This thesis first analyzes the site selection principles, functions and objectives of a logistics distribution center by means of qualitative analysis. And construct some model to solve mathematical programming problem quantitatively. Finally, a multi-criteria analysis is used to rank alternatives and arrive at an optimal site.
3. Case study method: This thesis uses a specific company's distribution center site selection problem as the research object. Analysis of site selection through specific case, validate the project methodology and the practicality of the proposed approach.

2.4Literature review on factors determining distribution center site selection

Distribution center site selection is under the scope of logistics system optimization. At first, many scholars only considered cost factors in such problem, which was minimize cost for a single objective. But as the research progressed, it became clear that not all decision makers were only pursuing the objective of minimizing logistics costs, but also other influencing factors such as the shortest route, the least impact on traffic congestion and the least environmental pollution. In fact, the location of distribution center involves the interests of different factors, and therefore requires scholars to consider the impact of different factors on the location problem from different levels, for example, from the consumer and enterprise levels, both of which have different impacts on the location problem. Or from the customer service and logistics cost level, normally people cannot satisfy these two factors together. The classification of factors can also be divided into subjective factor which is ambiguous and difficult to measure quantitatively and objective factor which is measurable and can be quantified. Subjective factors are normally described by experience, preferences and feeling. This category is represented by local labor and proximity to suppliers and customers because decision-makers should determine the importance weight on basis of their opinions. Objective factors can be described as exact numbers such as distance, labor and transportation cost, quality of infrastructure and market demand. Ozcan used a game card to decide five criteria which are generated for distribution center site selection, it includes unit price per square meter, stock holding capacity, average distance to market, average distance to suppliers and movement flexibility (Özcan, Çelebi et al. 2011). Those criteria cover the area of capacity, cost and suppliers. Demirel considered experts suggestion creating five criteria and 16 factors under all the criteria. Those criteria include cost, labor, infrastructure, market and environment (Demirel, Demirel et al. 2010). Mangiaracina summarized top 5 factors for distribution network design, the most popular is demand level and followed by cycle time, distance to customers and suppliers, demand volatility and delivery frequency. The number of appearances for factor demand level has the most frequency which is 65% among 160 papers related to distribution network design (Mangiaracina, Song et al. 2015). Onstein did a literature review about distribution structure decision and proposed three categorizes for factors: supply chain management, transportation and geography (Onstein, Tavasszy et al. 2019). Under supply chain management, the main factors that will facilitate decision maker in the company are demand level such as high product volume, service level such as delivery time and logistics cost include inventory cost, storage cost and delivery cost. But it is difficult to qualify those factors and the calculation related to cost is normally imprecise. Transportation is about using disaggregate or aggregate model to measure product flow from distribution center to customers in a quantitative way. And geography includes accessibility, labor and taxes.

The influencing factors from an enterprise perspective can be broadly divided into cost, social environment, the company's own characteristics, market demand, etc. In modern logistics, companies need to consider the overall business environment, the level of logistics services, the cost of facility construction, the company's operating costs and local province policy when selecting the location of logistics distribution center. Verhetsel analyzed factors which will influence the location of logistic company and found that land price, accessibility to the port and the location of other relevant logistic center were the three most important factors (Verhetsel, Kessels et al. 2015). Government policy will also play an important role. Hu regarded government penalties for substandard products and the cost of dealing with such pollution, built a two-tier multi-objective logistics node location model that considers environmental impact factors and logistics cost factors (Hu 2007).

2.5Literature review on multi-criteria decision-making methods for location selection

Here a literature review is demonstrated to have more insight into the chosen distribution center site. The optimization of logistic distribution center is a part of optimization of logistic systems which will be influenced by several qualitative and quantitative factors. For this optimization, a conventional approach is to use multi-criteria decision-making method which has a wide range of application in solving distribution center site selection problem.

A multi-criteria decision-making problem is generally used to describe a problem with several alternatives which need the decision maker to analysis. The analysis standard could be based on several criteria which could help decision maker to find the optimal alternative, or to make a list and rank all the alternatives (Rezaei). The process of utilizing multi-criteria decision-making problem could be divided into 5 phases. Firstly, a clear research objective should be formulated with alternatives and criteria. Secondly, multi-criteria decision-making problem include both quantitative and qualitative criteria which have various unit of measure (Özcan, Çelebi et al. 2011). Based on the criteria each alternative could be analyzed. Thirdly, the weight of each criteria could be found. Fourthly, the final decision could be made with respect to evaluation result. Finally, the robustness and reliability could be checked for the final decision (Rezaei).

In the range of using multi-criteria decision-making methods, Analytic Hierarchy Process (AHP), Choquet integral, Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Elimination and Choice Expressing Reality (ELECTRE), and Best Worst Method (BWM) are more recognized and widely used methodologies. Choquet integral method is based on fuzzy measurement. The importance of one criterion or the combination of several criteria should be decided first by fuzzy integral. So the fuzzy measure is made up of a set of importance value. Fuzzy measure is generally used for criteria which has a strong tendency to interact with each other. Thus, with the real numbers coming from fuzzy measures, Choquet integral could be used to solve location selection problem by simulating human decision-making process. Tan and Chen introduced an intuitionistic fuzzy Choquet integral which consider the intercommunication between criteria. Moreover, two operation laws are set first to determine fuzzy values. The result demonstrated that the innovation of using intuitionistic fuzzy set theory instead of fuzzy set theory increased the practicability of solving real life location selection problems (Tan and Chen 2010). Demirel solved a location selection problem for a logistic firm in Turkey by applying the generalized Choquet integral. Fuzzy measure play a significant role here to integrate information between 5 criteria: cost, market, labor characteristic, infrastructure and macro environment and 16 sub-criteria (Demirel, Demirel et al. 2010).

As a measurement theory, the majority utilization of AHP is to capture the interaction among comparisons in continuous or discrete level. There are two approaches to derive these comparisons: quantitatively or qualitatively. In the first approach it is based on practical observations. And in terms of qualitatively, a specific evaluation scale will be used to demonstrate the preference between each criterion. AHP mainly focus on the criteria deviation and the degree of this deviation level. As an effective tool in multi-criteria decision-making, AHP usually requires a hierarchical structure to reproduce the problem. And several pairwise comparisons between each criteria will be established in this network (Rodriguez 2002). The basic idea of AHP is to analyze the relevance of all the factors in a target system, to build a hierarchy and then to obtain the weights of the elements of the same level relative to the factors of the previous level by comparing the criteria of each relevant element of the same level. Based on the combined weights of the next level and the previous level, the relative weights of the elements in the bottom level of the solution to the total target level are calculated and ranked in order of weight, with the highest weight being the best solution. The essence of this method is to make comparisons and then make decisions. The hierarchical model which is built by AHP can be divided into the following steps: building a hierarchical model, constructing a matrix of judgement and ranking the hierarchy individually and making consistency judgement. Zhang used AHP in a MF warehouse service to compare two new layouts and the original one. Firstly, the elements of the criterion layer were listed and the hierarchy was constructed; secondly, a survey questionnaire was created among the warehouse employees. After that, a pairwise comparison data source was established from the survey, and then the feature vectors were obtained by calculating the data; finally, after determining that the data met the consistency requirements, the weight values of the scheme were calculated (Zhang 2018).

Best worst method is one of the multi-criteria decision-making methods which was created by Jafar Rezaei. It uses pairwise comparisons to determine the weight of various criteria and results in multi-optimality (Rezaei 2016). The major utilization of BWM is offering weight to a series of criteria and then ranking all the alternatives. BWM could help decision makers to determine the criteria weight in both direction (qualitative) and strength (quantitative) ways.

Thugudam applied BWM to a polymer industry to find out its quality dimensions. The optimal solution is derived which will reduce the waste generation in the production process (Thugudam 2020). Yao used BWM to calculate each indicator weight in Jiang Ya reservoir project. In order to select preferential resettlement area near this reservoir. By utilizing BWM in this reservoir resettlement area selection, the process of selecting resettlement areas can consider information from a wide range of participants. Thus the selection of resettlement areas can be carried out in a more scientific and comprehensive manner (Yao 2020). Liu conducted a scientific assessment of the location of existing hospitals and optimal site selection for new hospitals in order to achieve a rational allocation of urban healthcare resources. BWM was applied here to calculate indicator weights. The outcome validated the applicability and accuracy of this model in the quantitative analysis of urban hospital site selection (Liu 2022). A fuzzy best-worst method is used by Hafezalkotob who wants to analysis the influence of imprecise comment in the whole preference ranking system. They combine the thinking of sophisticated decision makers and the thinking of experts. With the utilization of this brand-new decision-making approach, they transferred preferences from experts to triangular fuzzy numbers which can be regarded as input in the linear programming model. This model is used to help experts find a balance point between democratic and autocratic, which are traditional decision modes (Hafezalkotob and Hafezalkotob 2017). In the application of sustainable architecture, BWM was used to determine the weights of the criteria, in that research there is a special criterion which is the architecture sustainability has been prioritized. Finally six alternatives were derived and their ranking was calculated by mathematical statistic (Amoozad Mahdiraji, Arzaghi et al. 2018). In Changsha, a case study focus on smart bike-sharing programs used BWM to weight various both customer and company requirements. The result criteria coefficients can be used further to rank alternatives and select the most optimum one (Tian, Wang et al. 2018). In order to find the suitable power plants size for fossil or renewable resources, BWM and TOPSIS methods are used together to determine the indicator weight first and come up with the best combination (Omrani, Alizadeh et al. 2018). Liu used a two-phase integrated model to select supplier location for green food. In this study the type of criteria was divided into subjective and objective. BWM was used here to obtain subjective criteria weights which would be regarded as an input for the upcoming supplier rank determination (Liu, Xiao et al. 2018).

2.6 Literature review on facility location problem

In many fields of science the location selection problem has been researched thoroughly, which includes location science, industrial engineering, computer science, mathematics and economics (Drezner and Drezner 1995). This leads to several different terms to represent this location selection issue, which includes facility location problem, site selection problem and retail location problem. And there are also many objectives even inside the same term. For example the objective of facility location problem could be minimize the total transport cost such as time, distance and consumed energy among all the customer, and it could also be minimizing the maximum transportation cost between every origin-destination pair (Contreras and Fernández 2012).

But people have concentrated on solving facility location problem in both continuous and discrete choice model in the last few decades. And it has a history of studying by academics for over a century. It is usually used for private corporation (such as warehouses/production centers, plants, communication network design, transport centers, etc.) and government agencies (such as emergency services, health centers, blood banks, waste treatment plants etc.) in the form of formulation, modeling or algorithm design (ReVelle and Eiselt 2005). Generally, the objective function for facility location problem aims to minimize the total cost. In order to achieve this objective, all the facilities should be located on basis of different demand for all customers. But there are also other constrains that it might follow which will cause different objective functions. For example: deciding the location of beach rescue teams to minimize rescue time, deciding on the location of the ATM so that the customer who comes to withdraw money gets the best service, deciding on the location of the warehouse to minimize the time to reach the sales market (Hale and Moberg 2003). For all those different cases the model which will be utilized are different.

In the 21st century, the logistics industry is becoming a new economic hotspot. With increasing competition in the market, it is difficult for individual companies to be competitive in all aspects of their business and operations. It is necessary to concentrate on production and outsource non-core activities such as warehousing and distribution to third parties. Whereas the warehouse location problem can be regarded as a precursor of the facility location problem. As the key to the logistics network, there are many literatures about solving facility location problem by optimization. Two mathematical model could be summarized based on various studies by Owen (Owen and Daskin 1998). They could be divided into (1) Static and deterministic location problem and (2) Dynamic location problem. The difference between these two categories is the complexity of the location selection problem. The latter one has advantage in dealing with uncertain requirements which might happen in the future. So the robustness will be guaranteed with the using of dynamic location problem, the result is more likely to adapt to different changes over time. For static location problem, the objective of such optimization model generally have 3 categories (Owen and Daskin 1998):

- How to minimize the total transportation cost
- How to minimize the maximum distance between each node and the facility
- How to maximize the covered demand

The study of static and deterministic location problem started by Weber first (Weber 1929). He considered how to decide a single central facility so that the total distance between this facility location and a number of demand centers (Farahani and Hekmatfar 2009). Weber's problem is normally used Euclidean distance as service cost to describe total distance associated with central facility and customers. And weber problem can be described as following: Given a number of customer points on a 2D-plane, determine the location of the single facility inside a limited area P so that the total distance between customers points and the single facility could reach the global minimum value (Maranas 2009). A heuristic procedure was proposed to solve warehouse siting problem (Kuehn and Hamburger 1963). The advantage of this method is making the model more flexible which can be applied for large scale warehouse siting problems involving hundreds of warehouses. Cooper came up with a warehouse location problem which is a generalized Weber problem, this model takes minimizing transport or service cost as the objective function, and investigates how to select m service points on a plane to determine its service area (Cooper 1963).

As a classic location problem, P-median problem is another static and deterministic location problem. The objective of this model is to minimize the travel distance between demand notes in a network with different weight. It could be achieved by locating P-facilities on this network where all the demand node can be connected by each facility (Church and ReVelle 1976). Such problem is called P-median problem which was introduced by Hakimi first (Hakimi 1964). He proved that there is always at least one optimal solution can be found in the given network, no matter how many numbers of facilities are set before for this model. P-median problem has many variants, one of them is to capture new customers as much as possible by locating facilities around all customers. Under this situation, an assumption was made that the products from each facility are the same and customers have a preference on choosing the nearest facility (ReVelle 1986). This version of the P-median problem demonstrated that it can be used to support strategic decision making. This P-median problem can be regarded as a weber problem if P = 1 and it has been researched by Miehle (Miehle 1958). Rosing was also investigating this generalized weber problem by heuristic search strategy and it aimed to find the optimal solution through a combination of local and global search (Rosing 1992). He also proposed a heuristic pruning method to reduce the search space. This optimal method made a combination to achieve higher compute efficiency and result quality. Scholars have used different distance measurement in this P-median problem, such as rectilinear distances and Euclidean distances. Pritsker considered the distance between facilities and the location constraints of existing facilities with rectilinear distance (Pritsker and Ghare 1970). The objective of this problem was minimizing the total cost and it was applied to an existing problem with 100 new facilities to check the efficiency of this model. Chen used Euclidean distances while considering the attractive and repulsive of different facilities, which included positive and negative weight number for different facility (Chen, Hansen et al. 1992). However, the class of P-median problem is NP-hard which leads to difficulties in solving this problem (Gary and Johnson 1979). But some integer programming and heuristics can be used to solve this kind of problem.

As another NP-hard problem, P-center problem is one of the classic location problems. Hakimi investigated this P-center problem by introducing this example: how to distribute the policemen in a highway so that each vehicle should be less than a given distance D from the nearest policemen. And it aims to minimize the number of policemen in this given highway (Hakimi 1965). In general, P-center problem focus on minimizing the maximum distance from customer to facility, which concentrate on avoiding the probability of worst-case scenarios. Such as determining the location of fire stations and first aid stations. Drezner proposed a method to minimize the maximum distance by determining new facility location, and the distance could be rectangular distance, Euclidean distance and general distance (Drezner and Wesolowsky 1978). This P-center problem has two categorizes on basis of facility location choices. If the facility is fixed to the node of the network, this P-center problem becomes to a vertex center problem. However, if the facility location is unlimited in the whole area of the network, it becomes to an absolute center problem (Owen and Daskin 1998).

Another classic facility location problem is covering problem. It was firstly proposed by Toregas, who investigated emergency facility location and included a specific constraint which require each demand point as a cover area (Toregas, Swain et al. 1971). The covering problem has two categorizes: location set covering problem and maximal covering problem (Schilling 1993). The location set covering problem is applied in situation which aims to minimize the number of facilities while meeting the service requirements of all demand points. Many solver can be used for this covering problem, such as heuristics, exact algorithms, meta-heuristics and mixed integer programming methods (Schilling 1993). Caprara studied the algorithm for location set covering problem which includes heuristic and exact algorithms. These algorithms attempt to find an approximate solution by selecting the set that can cover the maximum number of facilities. And it turned out that these heuristic and exact algorithms have better performance in solving this covering problem (Caprara, Toth et al. 2000). Hogan studied backup coverage as a criterion in modeling maximal covering problem. The objective is to cover as many facilities as possible with limited resources. Other variants were also discussed here such as backup coverage with capacity limitation or time window. It was also used to solve backup coverage issues in reality, such as siting fire station and ambulance station (Hogan and Revelle 1986).

2.7 Literature review on alternatives generation

In this project the state-of-art about alternatives generation will be analyzed. Since the alternative which will be generated in this project is mainly about finding appropriate distribution center site. Therefore, morphological chart will be introduced here as a strong method which could collect possible means for sub-functions of this problem.

Morphological chart is used to broad the area of research region by offering a structural way to describe the design problem itself. Many solutions can be generated by using morphological chart in a systematic analysis method and it is usually combined with brainstorming especially in a teamwork. Normally the research subject could be expanded to lots of options and many of them are irrelevant or disobeyed with the criteria. Therefore all the final combinations should be limited to the most appropriate or attractive options (Moultrie). Morphological chart is normally used to describe the function of a product in a visual format. For each function, it has several means to achieve the aim of this function. It is possible that all the means under one function are acceptable but there are also cases that only one of them can be used to describe this function. This chart provides a clear representation of all function-related solutions and many different combinations of means can be generated from it. In this method, many sub-solutions that cannot be fully considered in the early stage can be detected. And with a proper utilization, the weight of customers' opinion will be increased to form more customized solutions.

Fritz Zwicky developed General Morphological Analysis (GMA) method (Ritchey and Ritchey 2011) which is the basis of morphological chart. It can be used in a qualitative way to solve problem by creating functions and a large number of means under each function. Finally combine a series of means as an alternative for the target solution (Moultrie). The benefits of using morphological chart include expanding number of solutions for a problem and using combination to generate novel ideas that cannot be easily thought (Richardson III, Summers et al. 2011).

In the process of drawing a morphological chart, the functions should be listed first which contains major function that this product should cover and with a brief generalization. The methods used in this process include brainstorming, function analysis and interview experts or customers to have specific requirement for each function. But it is better to have independent functions so that the morphological chart could have the best result (Cross 2021). After listing all the functions, the means for each function should be generated. These means include existing knowledge or new ideas. The number of means will also have impact to the result of this morphological chart, it will have the best performance with more means and less functions (Smith, Richardson et al. 2012). Normally, the number of functions between 8-12 is recommended (Cross 2021). In terms of means combination, some means might violate with the constrain of the project so that they could be eliminated by observation. But there are other methods can be used in this process, such as ranking all the functions and based on function to select means which will have the best performance to the solution. Or ranking each means in a row and select the one with highest score (Magrab, Gupta et al. 2009).

2.8Conclusion

In conclusion, this chapter provides a robust framework for the 5 step of phased method, offering a clear understanding of the key factors, decision-making methods, facility location problem and alternatives generation in the context of distribution center site selection. The following chapters will build upon this foundation, applying the concepts and methods introduced here to further analyze and resolve the thesis project questions.

The conclusion of this chapter includes the answer to question 1 which can be found below:

1) *What is relevant background knowledge in the field of facility location problem?*

The facility location problem is a broad field of study that covers a wide range of different types of siting problems, such as retail store location problem, logistics distribution center site selection problem, service facility location problem, landfill location problem and telecommunication base station location problem (Farahani and Hekmatfar 2009). The location of the distribution center will have a direct impact on the efficiency and service quality of the entire logistics system. A reasonable distribution center location will enable more efficient turnover and storage of goods, not only shorten the distance between the distribution center and the customer, but also reduce the distribution cost and the quality of service, improve the speed of distribution and better connect production and consumption into a whole.

3. Current and desired state of distribution center location problem

3.1 Introduction of relevance theories and concepts

3.1.1 Logistic

The continuous development of the logistics industry has been going on since the end of the 20th century. During this time the definition of logistics by scholars is also changing. However, widely accepted definitions of logistics currently include those based on logistics management and those based on logistics functions. This trend reflects the importance and evolving trend of logistics on a global scale, as well as the evolving perception and understanding of the concept of logistics among scholars. In a book by Farahani, he described the concept of logistics as an activity to reach the highest satisfaction of consumer by dealing with products and materials inventory and mobility (Farahani and Hekmatfar 2009). Cristopher considered logistics as an important part of the whole supply chain. In order to meet customer demand, it requires planning, control, implementation and stocking of products, services and related information resources to achieve effective and efficient flows from the place of production to the place of demand (Christopher 2016). On basis of logistics function, Japanese scholar describe logistics as an economic activity that involves the physical transfer of material goods from suppliers to customers, creating temporal and spatial value. In China, logistics is defined as the process of the physical movement of goods. Including the implementation and management of the basic functions of transport, storage, loading and unloading, handling, packaging, distribution processing, distribution and information processing (Committee 2021).

3.1.2 FMCG logistics

Fast-moving consumer goods (FMCG) logistics companies are companies that produce, procure, store, distribute and sell consumer goods for daily use and play an important role in the production and distribution of consumer goods for daily use. The logistics activities of FMCG logistics companies cover a range of processes from raw material procurement, production and processing, storage of finished products to sales and distribution (Manders, Caniëls et al. 2016), with the aim of meeting consumer demand for consumer goods. In this process, FMCG logistics companies need to establish an efficient logistics system, including logistics planning, construction and management of logistics facilities, design and optimization of logistics operation processes, as well as construction and application of logistics information systems.

The logistics activities of FMCG companies can be divided into multiple stages, including procurement logistics, production logistics, warehousing logistics, sales logistics, and reverse logistics (Nemati and Alavidoost 2019). The whole process starts from purchasing raw material, goes through manufacture, transportation, warehousing and selling, ends with the final delivery to the end user for consumption. FMCG logistics can be divided into FMCG procurement logistics, FMCG production logistics, FMCG warehousing logistics, FMCG sales logistics and FMCG reverse logistics.

- FMCG procurement logistics mainly includes activities such as raw material procurement, supplier management, and purchase order processing.
- FMCG production logistics involves production planning, production process management, and industrial inventory management.
- FMCG warehousing logistics includes activities such as finished product warehousing management, inventory management, and maintenance and updating of warehousing facilities.
- FMCG sales logistics includes order management, distribution management, and after-sales services.
- FMCG reverse logistics mainly refers to activities such as return handling and waste recycling.

FMCG companies need to continuously optimize and upgrade their logistics management based on market and consumer demands, in order to improve logistics efficiency and reduce logistics costs, and thus maintain their competitiveness and market position.

3.1.3Functions of the distribution center

Distribution center is a hub connecting supply and sales, which can significantly improve logistics transport speed and service quality. As a key node in the logistics system, distribution center is responsible for coordinating logistics activities upstream and downstream of the supply chain, including storage, collection and delivery, sorting, packaging and information management (Jacyna, Lewczuk et al. 2015).

1) Storage function
Distribution centers are mainly used to satisfy sales and distribution purposes. However, in order to deal with the uncertainty of the consumer market, distribution centers not only distribute goods, but also store a certain amount of goods, which is one of the important functions of distribution centers. In general, distribution centers have a large storage area and capacity to store large amount of goods.

2) Collection and delivery function
Raw materials, components and products which are produced by factories need to be collected and shipped at the distribution center. Because in distribution center raw materials and components need to be consolidated before entering the production assembly line. And products need to be collected in the distribution center and then ship to customers. Large-scale socialized logistics distribution centers can realize functions such as cargo collection, transfer, loading, and delivery.

The delivery function is a main function for a distribution center. Because distribution center has a huge daily throughput, and according to the needs of each customer, a wide range of goods are combined to form the most economical batch of goods for transport. Then the products are combined and distributed to their destination.

3) Sorting function

Sales and procurement orders need to be handled inside the distribution center. The distribution center needs to repack the product according to the order requirements before they can be sent to the customer. Different customers have various product requirements in each order. The sorting function in a distribution center aims to solve this diversity for different customers. In order to satisfy the needs of the end user, products are sorted in the distribution center according to transport requirements and individual customer requirements.

4) Packaging function

Modern logistics distribution centers should have the ability to process and package products. By performing simple processing and packaging of products, the transportation and further processing of products will be facilitated. The distribution center can process and package goods according to customer requirements and distribution principles. By packaging products, the distribution center could achieve the specific needs of customers for products. And also reduce transportation costs by standardizing product packaging.

5) Information management

The daily volume of products entering and exiting the logistics center is enormous. And the concentration of multiple functions could generate a large amount of logistics and information flow, such as obtaining and processing sales and inventory data. Those information flow could help companies make better decisions and optimize activities such as inventory management and logistics distribution. On a daily basis, distribution center collects, organizes, processes and analyzes a large amount of information generated using scientific methods in sales and supply chain management teams to improve the operation of the distribution center.

3.1.4Principles of distribution center site selection

Distribution center site selection refers to the planning process of selecting a location to set up a logistics distribution center in an economic region with several supply points and several demand points.

An effective logistics distribution center site selection strategy aims to optimize the benefits throughout the entire logistics process. The whole process starts from gathering, transshipment and distribution of products at the distribution center, and ends in final delivery to demand points. Logistics distribution center is normally surrounded by numerous buildings, structures, and fixed mechanical equipment. Such situation makes relocation extremely challenging when the distribution center is established. Consequently, an inappropriate site selection can result in long-term costs. The site selection for logistics distribution centers is a crucial aspect of the overall planning process. A reasonable site selection strategy could enhance the efficiency of products handling and improve customer satisfaction at the distribution center. Moreover, it could ensure the overall optimization of benefits throughout the logistics stages.

The following principles should be observed in distribution center site selection:

1) Economical principle

Distribution center site selection involves a range of costs, such as initial construction costs, land costs, and subsequent logistics and operational expenses (Farahani and Hekmatfar 2009). The location of the distribution center directly affects both construction and operational costs. Different site selections have their respective advantages and disadvantages, which requires objective and rational analysis and careful consideration. Distribution center site selection should aim to minimize initial construction expenses and subsequent operational costs, while also considering the impact of the location on the overall economic efficiency of the company.

2) Coherence principle

A distribution center does not exist as an independent item; however, it should be analyzed from a systemic perspective, considering its relationships with other distribution centers and production facilities. The site selection should be coordinated with the entire distribution network to facilitate collaboration with other facilities and optimize the allocation of logistics resources (Aras, Aksen et al. 2008). The facilities and equipment, transportation capacity, and processing capabilities of logistics distribution centers should be well-matched and coordinated with all the distribution center for the target company. Both excessive capacity and insufficient capacity could lead to distribution efficiency reducing and associated costs increasing.

3) Adaptability principle

Distribution center aims to deliver products to customers more effectively while minimizing logistics costs during this stage. Therefore, the site selection should be adapted to the distribution of customer demands. Furthermore, the location of distribution center should comply with local economic development policies. Since the site selection is typically not independent and it must adhere to national or regional legal regulations and policy requirements. It will also have better performance while aligning with local economic development strategies (McConnell and Schwab 1990). Simultaneously, considering potential market changes, distribution center should possess a certain degree of flexibility to adapt those possible changes.

4) Strategic principle

As enterprises continuously develop and expand their business scope, distribution centers should be correspondingly established. The objectives are to better penetrate the market, enhance customer satisfaction, maintain company's economic benefits and ultimately achieve growth in business performance. Therefore, site selection for distribution center should consider sustainable development and be approached from a strategic perspective. The site selection should also focus on environmental protection, minimizing the impact on the ecological environment. This includes avoiding locations in ecologically sensitive areas and ensuring compliance with environmental regulations (Eskandarpour, Dejax et al. 2015). Other strategic decision involves selecting sites with convenient transportation access to ensure the rapid and efficient movement of goods. It considers the availability of various transportation modes, such as highways, railways, air and water transport.

3.2Current status of distribution center site selection

3.2.1Practical applications for distribution center siting

The problem of distribution center site selection is often associated with corporations, as they need to consider factors such as operational efficiency, cost, customer demand, and competitiveness. Distribution centers are crucial components in a corporation's supply chain, and their location has a significant impact on overall corporate operations. However, the problem of distribution center site selection is not limited to commercial enterprises; it can also involve non-profit organizations and governmental departments. For instance, the location selection for disaster relief storage and distribution centers, public health supply storage facilities, and governmental reserves which must consider cost, efficiency, and service quality. These scenarios can be collected in the range of practical application for distribution center siting.

Furthermore, as mentioned in chapter 3.1.2, FMCG companies particularly rely on efficient supply chain and logistics management due to their products' rapid sales cycles and frequent stock replenishment needs. These types of companies might face distribution center site selection problem more frequently because they need to ensure rapid and efficient product delivery to consumers and from factories. In contrast, other types of companies, such as those in manufacturing or services, might not encounter distribution center site selection problem as frequently. This is because their products or services might not have as high inventory turnover rates as FMCG companies, or their supply chains and distribution networks might not be as complex.

3.2.2Scenarios triggering the need for distribution center site selection

The need to solve distribution center site selection problem may arise in a variety of scenarios, including but not limited to company expansion, supply chain optimization and changes in policy and regulations. In these diverse scenarios, resolving the site selection problem holds significant importance for optimizing the supply chain, reducing costs and enhancing company competitiveness. Company should evaluate and adjust the location of their distribution centers in line with their strategic objectives and market environment. Here are some typical scenarios:

- Company expansion: As companies scale up, open new markets, or enrich product lines, companies may need to establish new distribution centers to support business growth. In this situation, companies need to solve the distribution center site selection problem to ensure that the new location can meet market demand, reduce transportation costs, and improve service quality.

  The location of Jindong’s (JD) logistics center is a good example of re-locating a logistics center due to expansion. With the rapid expansion of business in recent years. To better meet consumer demand, JD has established several logistics centers across China. in 2019, JD locate a large intelligent logistics center in Changchun to serve consumers in the region (News 2019).

- Supply chain restructuring: Companies may periodically evaluate and optimize their supply chains to improve operational efficiency, reduce costs, and meet customer needs. During this process, distribution center location problem should be taken into consideration.

  Amazon as a leading global e-commerce company, has undertaken significant supply chain restructuring and optimization in Europe in recent years to meet the challenges of its rapidly growing business. Amazon has established several large logistics centers in Poland to serve its consumers in the CEE region (Staff 2017). The location of these logistics centers is based on Amazon's restructure of its supply chain.

- Company acquisition: During company reorganization, acquisition or merger, the location of distribution centers may need to be reconsidered. A new company structure may result in changes in market coverage, product lines or customer needs, thus requiring a re-planning of the distribution center network.

Marriott International became the world's largest hotel group after completing the acquisition of Starwood Hotels and Resorts International in 2016 (International 2016). Following the completion of the acquisition, Marriott needs to integrate the logistics and supply chain networks of the two companies to improve operational efficiency and reduce costs. In the process, Marriott should reconsider the location of its logistics centers to better support the new scale of operations and market reach.

- Policy and regulatory changes: Changes in government policies and regulations may affect the location selection of distribution centers. For example, adjustments in tax incentives, land-use regulations, or environmental regulations may cause companies to reconsider the location of their distribution centers.

  SF Express has established a large logistics center in Dongguan City, Guangdong Province, China. During the site selection process, SF Express fully considered the policy support and regulatory requirements of the local government to ensure the project's compliance (Jiang, Jin et al. 2015).

- Market changes: Changes in the market environment and customer demand may also lead companies to reconsider the location of their distribution centers. For instance, increased consumer demand for fast delivery may prompt companies to set up distribution centers close to large cities and consumer concentration areas to shorten delivery times.

  Alibaba's Cainiao network has set up a large number of distribution centers across China. These logistics centers are located in first- and second-tier cities to better meet consumer demand. Cainiao's logistics center in Kunshan, Jiangsu province, was designed to serve consumers in Shanghai. This distribution center location is decided on basis of an in-depth analysis of the company's sales data, local market change and delivery needs in these regions (Amling and Daugherty 2020).

- Competitive pressure: Facing the pressure from competitors, companies may need to adjust the location strategy to improve their competitiveness in the market. By optimizing the location of distribution centers, companies can reduce costs, improve service quality, thus gain an advantage in intense market competition.

3.2.3Existing options in distribution center site selection

When deciding the location for a new distribution center, a company has some options such as expanding an existing distribution center to meet new requirements, building a new distribution center, share a distribution center with other companies and outsourcing to third-party company. But the company needs to weight these options against its business needs, cost budget, and market strategy. After analyzing and evaluating these options, the company can select the distribution center location scheme that best suits its needs.

- Constructing a new distribution center independently: A company can choose to purchase land from logistics park and build a new distribution center on its own. This option allows the company to design and plan the distribution center according to its specific needs but may require substantial investment and a long construction time.

- Choosing existing facilities: A company can continue use its existing facilities to serve as a distribution center if it meets all the requirements and factors for a new distribution center. For example, if this existing facility has an excellent location which can minimize the travel distance to all customers. In this situation, the company might continue with the existing facilities and make some changes inside, such as expanding the size to accommodate higher demand, or installing new technology/equipment to adapt other requirements. This option can save construction costs and time, and it also offers a degree of flexibility.
- Shared distribution center with other companies: Sharing a distribution center with other companies or partners can distribute costs, risks, and resources. This option may be more attractive to smaller companies or those in the process of expansion.
- Outsourcing to third-party logistics (3PL) companies: Outsourcing the operation of the distribution center to a third-party logistics company, which would take responsibility for storage, distribution, and transportation tasks, can alleviate operational pressure on the company and allow it to focus on its core business.

3.2.4Current site selection: implications and consequences

If a company cannot find an appropriate distribution center location, it can lead to a multitude of negative consequences. These potential implications include:

1. Increased operational costs: A distribution center in a bad location may result in inflated transportation and warehousing costs. If the location is far from suppliers or major local markets, the company may face higher logistics expenses due to longer transportation routes and higher labor cost. Additionally, if the location has high land cost or tax costs, the expenses can also escalate. Moreover, if a rapid growth in demand for the products the company sells is predicted in the future, using the existing distribution center would significantly increase operating costs.
2. Reduced service quality: Inadequate site selection can also degrade the quality of service. Longer distances between the distribution center and consumers can result in untimely delivery, which may frustrate customers and lead to a decline in customer satisfaction and loyalty. Moreover, if the distribution center location does not facilitate easy accessibility, it may cause unhappiness and frustration among company employees.
3. Supply chain inefficiencies: A poorly located distribution center can lead to inefficiencies in the supply chain, such as increased lead times, stockout and overstocking. This could disrupt the smooth flow of goods from suppliers to consumers and negatively impact the overall efficiency and performance of the supply chain.
4. Reduced competitive advantage: Given that logistics and supply chain management are critical aspects of a company's competitive strategy, a poor site selection can compromise the company's competitive position. It could weak the price advantage derived from comparing the company with other competitors and ultimately impact the company's market share and profitability.

3.3Desired status after using 5 step of phased method to solve this problem

The 5 step of phased method developed in this thesis is intended to assist companies that aim to establish a new distribution center or change its location (current status).

This strategy seeks to address these issues and ultimately find an appropriate location for the distribution center (desired status). Various strategic objectives for different companies can be found below:

1. In the desired status, the distribution center should significantly bolster the operations of the company (Ar-racking 2023).

- Supply chain efficiency: In desired status, the distribution center should be strategically located to ensure seamless integration into the company's existing supply chain. This means it should be positioned in a manner that allows for efficient procurement of goods, transformation and the final delivery to consumers. An appropriate distribution center can improve supply chain responsiveness, reduce lead times, and ensure timely delivery of products to consumers, thereby promoting customer satisfaction and loyalty.

- Cost minimization: In desired status, an appropriate location should take into consideration the goal of minimizing operational costs, including transportation and warehousing costs. The location should be such that it reduces the distance between the suppliers, the distribution center, and the consumers, thereby lowering transportation costs. Additionally, the location should be in a region with affordable warehouse costs, including rent and taxes.

- Service quality enhancement: In desired status, an appropriate distribution center can play a pivotal role in increasing the quality of services offered to the customers. Shorter distances between the distribution center and consumers can lead to quicker deliveries, thereby ensuring prompt service. Moreover, an appropriate distribution center can help to maintain consistent service levels across various regions and during different periods, including peak demand times.

2. In the desired status, the distribution center should be adaptable to changes in the market and operating environment.

- Adapting to market demand changes: The selected location should be strategically positioned to respond to changes rapidly and efficiently in market demand. This might entail being located near key market or along major transportation routes for quick distribution. Choosing an appropriate location would be well positioned to handle the rapid growth in demand in the future. Revenues will be more than the required operating costs (Higginson and Bookbinder 2005).

- Complying with policy and regulatory requirements: Compliance with local, regional, and national policies and regulations is a critical aspect of site selection. An appropriate site would be in an area where the regulatory environment aligns with the company's operational practices and goals. This includes considerations such as environmental regulations, labor laws and tax implications.

- Competitive advantage: An appropriate distribution center location would enable a company to stay competitive. Location near to customers can offer faster delivery and reduce transportation cost so that companies can gain an edge over competitors. Additionally, proximity to suppliers can result in low supply cost, further enhancing competitive advantage (Wang, Gunasekaran et al. 2018).

3.4Conclusion

The purpose of this chapter is to provide the reader with the necessary background knowledge and theoretical foundation before starting to describe the design process of the 5 step of phased method. This chapter can be divided into three parts, the first part introduces the relevant theories and concepts such as various forms of logistics involved in FMCG companies and the function, principle of logistics distribution center. The second part introduces the current state of the distribution center location problem, including options, specific applications, and practical scenarios. The third part presents the desired state which is the result after solving this problem.

The conclusion of this chapter includes the answer to sub question 2(a), 2(b) and 2(c) which can be found below:

2) *What is relevant background knowledge in the field of facility location problem?*
   (a) *What are the functions and principles for distribution center site selection?*

Distribution center as a hub connecting supply and sales, which can significantly improve logistics transport speed and service quality. As a key node in the logistics system, distribution center is responsible for coordinating logistics activities upstream and downstream of the supply chain, including storage, collection and delivery, sorting, packaging and information management (Jacyna, Lewczuk et al. 2015). For a distribution center it should observe principles such as economical, coherence, adaptability and strategic.

(b) *Why companies need to find a new distribution center?*

The need to solve distribution center site selection problem may arise in a variety of scenarios, including but not limited to company expansion, supply chain optimization, changes in policy and regulations, be more competitive and adapt to market change.

(c) *What impact does an appropriate distribution center have on a company?*

After find an appropriate distribution center location, firstly it will significantly bolster the operations of the company and adapt the company to changes in the market and operating environment.

4. The design process of a stepwise approach: 5 step of phased method

4.1Introduction

A 5 step of phased method was introduced in this chapter to solve distribution center location problem. This method has 5 steps include determining evaluation factors, constraints and requirements, generating alternatives by morphological chart, and using MCA to evaluate location alternatives. Through this comprehensive process, decision makers can find an appropriate location for the distribution center on basis of different company objectives. During the explanation of approach steps, sub question 3(a), 3(b), 4(a), 4(b), 5(a) and 5(b) are solved in this chapter.

4.2Step1: Determining factors

4.2.1Factors influencing the location of distribution center

Ballou in his book divided distribution center location decision method in two levels (Ballou 1992):

1. Corresponding to all the current warehouse's location, how to balance transport cost, inventory cost and handling cost so that a new warehouse could be located.
2. After the decision of geographic region which will be used for a new warehouse location, the area of town or industrial land should be identified. So that the relative location of the new warehouse compare with the town or industrial land should be determined.

Determining factors for distribution center location can be further divided into qualification criteria and evaluation criteria. They play different role in the logistics center site selection problem. Qualification criteria are the basic selection of candidate sites, while evaluation criteria are used to score and rank the candidate sites that meet the qualification criteria to find the best one. Farahani discussed in detail about the role of qualification criteria and evaluation criteria in finding third party logistics company, this concept is also suitable in this distribution center selection issues (Farahani and Hekmatfar 2009).

- Qualification criteria are required to determine the location of a logistics center and are often considered as binary constraints. The logistics center site either meets these binary conditions or not. If a candidate site does not meet the qualification criteria, it is excluded from the candidate list and is not considered further. Those qualification criteria will be used as constraints for case study in the next chapter.
- Evaluation criteria are used to score and rank candidate locations to find the best site for a logistics center. The evaluation criteria are usually a set of quantitative or qualitative indicators that can be used to compare the strengths and weaknesses of different locations. Those qualification criteria will be used as input for multi-criteria analysis in case study.

According to (Onstein, Ektesaby et al. 2020) and (Onstein, Tavasszy et al. 2019), there are many factors which can be used to help decision makers to choose a place for a distribution center. They can be divided into three categories: supply chain management, transportation and geography. The following decision factors in Table 4.1 are factors used in this thesis project.

Supply chain management: Determining distribution center location is a significant research area in supply chain management. This process involves factors such as service level, logistics cost, product characteristics which are essential aspects of managing a supply chain effectively. These factors contribute to the overall efficiency, cost-effectiveness, and competitiveness of the supply chain.

Transportation: Factors under transportation are matched well with factors under supply chain management. And it aims to build quantitative models to describe freight flow. Proximity and flow-related factors are closely related to transportation. These factors affect the ease of moving goods and services between the distribution center and its customers or suppliers. They also influence the overall transportation costs and the efficiency of the logistics process.

Geography: Business environment factors and natural environmental factors are directly related to the geographical location of the distribution center. Geography focuses on analyzing the impact of spatial location distribution on logistics centers. These factors include local regulations, labor market, climate, and other location-specific aspects that may impact the performance, operational cost, and environmental sustainability of the distribution center.

Table 4.1: Main decision factors and sub-factors for distribution center location

Categorize	Main factors	Sub-factors	Description	Mention in literature
Supply chain management & Transportation	1. Proximity and flow related factors	1a. Distance to customers/consumers	Distance from distribution center to customers of the company or the target consumer markets.	3
		1b. Distance to suppliers/producers	Distance from distribution center to suppliers of the company or producers owned by company.	4
	2. Logistics cost factors	2a. Transport cost	Transport distance, mode and means between distribution center to customers and suppliers	14
		2b. Inventory cost	Warehouse rent capital, equipment investment, human resources and inventory management	12
		2c. Warehousing cost	Handling cost, storage cost and labor cost	11
	3. Service level	3a. Cargo flow		2
		3b. Delivery time	Time from placing an order to customer delivery	3
		3c. Delivery responsiveness	Responsiveness after placing an order	3

		3d. Customer support	After-sales service, maintenance and technical support	1
	4. Product characteristics	4a. Packaging density	Number of packaged products per unit volume	2
		4b. Value density	Value of a product per unit of volume or weight	3
		4c. Product vulnerability	Special facility such as moisture resistance to protect product	3
Geography	5. Accessibility	5a. Motorway network accessibility		9
		5b. Port accessibility		7
		5c. Rail accessibility		7
	6. Infrastructure	6a. Available transport infrastructure	Various facilities used to support the transportation of products and people	9
		6b. Congestion	Traffic congestion between distribution center to customers	3
	7. Business environment factors	7a. Taxes	Corporate income tax or value added tax in the target area	7
		7b. Zoning policies	Government planning and management of land use and development in the target area	7
		7c. Labor market availability	The quantity and quality of labor in the target area	4
		7d. Labor cost		5
		7e. Land cost	Land price per square meter	5
	8. Natural environmental factors	8a. Geographical factor	Terrain topography of the target area	8
		8b. Noise factor	Distance to residential areas	5
		8c. Climate factor	Local humidity, temperature, wind, salt and rainfall	9

4.2.2Factor classification

Table 4.1 presents 25 factors totally which can be divided into 8 main factors. Currently there are basically 3 categorizes which can cover these factors: supply chain management, transportation and geography (Onstein, Tavasszy et al. 2019). Supply chain management and transportation focus on service level and logistics cost. And geography focus on environment and institutional factors. Table 4.1 contains factors from these three categorizes and are divided into 8 main factors. Four of them are from supply chain management and transportation: (1) Proximity and flow related factors,

(2) Logistics cost factors, (3) Service level factors, (4) Product characteristic factors. Another four of them are from geography: (5) Accessibility factors, (6) Infrastructure factors, (7) Business environment factors, (8) Natural environmental factors. Those factors can be further divided into internal or external factors to a company (Onstein, Ektesaby et al. 2020). Moreover, the factors in Table 4.1 will be divided into qualification and evaluation factors in case study which will be analyzed later.

These 8 factors were finally chosen because of the following considerations:

- Reducing transportation time, costs, and increasing overall efficiency of the supply chain.
- Maintaining a competitive edge in the market.
- Increasing customer satisfaction and maintaining a good reputation.
- Accommodating the unique needs of the products.
- Being accessed by various modes of transportation.
- Avoiding potential risks.

A detailed explanation about each factor can be found below:

1. Proximity and flow related location factors

   The location of distribution center should consider the flow of products and the distance to suppliers or customers. If the logistics distribution center is mainly for the distribution of raw materials and products to manufacturing enterprises, it should be close to the production enterprises. If the distribution center mainly distributes goods for retailers, it should be as close to the final customers as possible.

   a. Distance to customers/consumers

      Distance from distribution center to customers of the company or the target consumer markets (Davydenko 2015) (McKinnon 1984).

   b. Distance to suppliers/producers

      Distance from distribution center to suppliers of the company or producers owned by company (McKinnon 1984).

2. Logistics cost factors

   Logistics costs are a key component of business operations, especially today with the increasing importance of globalization and supply chain management. Logistics cost factors play a crucial role in the issue of site selection. Proper site selection can help reduce logistics costs and improve operational efficiency, thus enhancing the competitiveness of enterprises.

   a. Transport cost

      Transport cost including transportation distance, transportation mode and transportation means between distribution center to customers and suppliers. When selecting a site, the distance and convenience of transportation between the geographical location of factories, warehouses, distribution centers and the target market should be considered (Ashayeri and Rongen 1997).

   b. Inventory cost

      Inventory cost including warehouse rent capital, equipment investment, human resources and inventory management (Chuang 2002).

c. Warehousing cost

Warehousing cost including handling cost such as equipment, human resources and information system construction. And also storage cost and labor cost (Friedrich 2010).

3. Service level factors

Service level factors play an important role in business location issues. Excellent service levels help increase customer satisfaction, enhance business competitiveness and improve corporate image. When selecting a location, companies should take service level factors into account in order to achieve customer needs and business goals.

a. Cargo flow

The actual operation of the distribution center will require various costs, and without sufficient logistics volume, it will lead to continuous losses. Distribution centers are set up to better connect suppliers and customers, and sufficient cargo flow is a prerequisite to ensure the normal and stable operation (Hesse 2002).

b. Delivery time

Short delivery time increases customer satisfaction and loyalty. Proper site selection should ensure that the logistics center, warehouse or factory is close to the target market to reduce transportation time and improve delivery efficiency (Wanke and Zinn 2004).

c. Responsiveness

Responsiveness has a significant impact on customer satisfaction. It represents the order processing speed to satisfy various customer demand (Christopher 2016).

d. Customer support

Companies should ensure that the chosen location has good customer support facilities, such as after-sales service, maintenance and technical support (Christopher 2016).

4. Product characteristics

The characteristics of different products will have a different impact on logistics and warehousing needs, so people need to fully consider the product characteristics such as packaging density and value density when selecting a site.

a. Packaging density

Packaging density refers to the number of packaged products per unit volume. Products with high packaging density can effectively reduce transportation and storage space, thus reducing logistics costs (Wanke and Zinn 2004).

b. Value density

Value density is the value of a product per unit of volume or weight. Products with high value density may require higher security and insurance measures, thus increasing logistics costs. When selecting a site, companies should weigh the impact of product value density on logistics costs and security requirements to achieve a balance of cost and risk (Wanke and Zinn 2004).

c. Product vulnerability

Perishable products require special transportation and storage conditions, such as constant temperature and moisture resistance. When selecting a site, companies should ensure that the chosen location has the appropriate facilities and conditions to protect product quality and reduce losses (Ocampo-Terceros, da Silva-Ovando et al. 2023).

5. Accessibility

The daily throughput of the distribution center is very large, and the vehicles are frequently in and out. Such attribute increases the importance of accessibility in determining the location of the distribution center. Wide roads and fast interchanges are factors that must be considered in the preliminary site planning. Accessibility will directly affect the final turnaround speed and distribution cost of the distribution center. In the process of choosing the location of distribution center, people should pay close attention to the accessibility, which should be close to the important transportation highways and railroads to facilitate transportation (Melachrinoudis and Min 2000) (Verhetsel, Kessels et al. 2015) (Bowen Jr 2008).

a. Motorway network accessibility
b. Port accessibility
c. Rail accessibility

6. Infrastructure

The location of the distribution center and its operation after completion require infrastructure to support it. It is necessary to consider whether water, electricity, gas and heating are available in the city. Moreover, the site of distribution center has the highest requirement for transportation conditions. To ensure the fast inlet and outlet of distribution center, it should be as close to the transportation hub as possible, and at least two modes of transportation should be guaranteed.

a. Available transport infrastructure

Transportation infrastructure refers to the various facilities used to support the transportation of products and people, such as roads, railroads, ports, airports, etc. In siting issues, superior transportation infrastructure can provide more transportation options, reduce transportation costs, increase transportation efficiency and improve supply chain stability and reliability (Chopra 2003).

b. Congestion

Congestion leads to transportation speed reduction and more delays. In siting issues, congestion can have a negative impact on transit times, costs and corporate reputation (Tavasszy, Ruijgrok et al. 2012).

7. Business environment factors

The daily movement of goods in and out of the distribution center requires a large amount of labor to complete this work. Therefore, the high quality and labor-intensive conditions are one of the important considerations for the location of distribution centers. At the same time, the relevant policy environment, laws and regulations will also directly affect the sustainable development of the distribution center. A good investment policy is conducive to the next step of distribution center operations, which can provide a lot of convenience for companies. Government support can help the development of company logistics, which is also consistent with the economic principle of logistics distribution center site selection. So it is necessary to carefully study the relevant business environment before selecting the site (Chopra, Meindl et al. 2013) (Cidell 2011) (Hesse 2004).

a. Taxes

   Taxes include local corporate income tax, value added tax, etc. A lower level of taxation can reduce the operating costs of a company, thus improving its competitiveness.

b. Zoning policies

   Zoning policies refer to government planning and management of land use and development in the target area of distribution center, which includes land use types and building density.

c. Labor market availability

   The quantity and quality of labor that companies can obtain at the target location will be helpful to increase business operational efficiency.

d. Labor cost

   Labor cost occupies an important position in the cost structure of companies. Lower labor cost can reduce business operating cost and influence the attractiveness of business investment in each region.

e. Land cost

   Because of the large volume of incoming and outgoing goods, the logistics distribution center will cover a larger area, and the land resources in contemporary cities are very tight and the cost of land is high.

8. Natural environmental factors

   a. Geographical factor

      The location of the logistics distribution center should be as flat and high as possible to reduce the difficulty of construction. The flat terrain can ensure that the vehicles can enter and exit easily and quickly during the subsequent operation, which can improve the turnover efficiency of the distribution center and provide a guarantee for quick in and out (Shen 2007).

   b. Noise factor

      The logistics distribution center will generate a lot of noise when vehicles enter and exit. That means it should be as far away from residential areas as possible (Wei 2007).

   c. Climate factor

      The climatic factors that should be considered for the location of logistics distribution centers are local humidity, temperature, wind, salt and rainfall. The location of distribution center should avoid high humidity and windy places as much as possible, which will accelerate the corrosion of goods and the location should avoid these areas as much as possible (Ghiani, Laporte et al. 2004).

Among all these 25 factors, “Cargo flow” and “Product vulnerability” originated from the author’s brainstorming and were subsequently supported by literature review. These factors contribute to a more comprehensive assessment of the suitability of potential distribution center locations, ensuring that the chosen site meets the specific needs of the products and achieves economic benefits. Cargo flow is considered to avoid situations where operating costs are high and logistics volume is insufficient, leading to sustained losses. Product vulnerability, on the other hand, ensures the quality and safety of products during storage and transportation, thereby reducing losses and complaints due to product damage.

4.3Step 2: Constraints

4.3.1Introduction

Constraints and requirements which are needed by this new distribution center location selection has been determined by literature review. In this chapter all the constraints and requirements could be regarded as general constraints and requirements with universalization which can be applied for any new distribution center location selection. These processes are followed by a paper from Robertson. In the process of discovering requirements, many techniques can be applied such as abstraction, brainstorming, interviewing, mind mapping, case workshops, viewpoints etc. (Robertson 2001). However, specific constraints may vary depending on the case study. When selecting a site for a distribution center, it is important to determine which constraint must be met based on the actual situation and needs. Thus, it is quite significant to involve more stakeholders who have their own point of view, standard and experience for each case study. Some constraints mentioned below are followed by a handbook from Rushton and Croucher, which has thoroughly explanation about optimizing and managing supply chain. Constraints about searching new distribution center location is also included in this handbook (Rushton, Croucher et al. 2022). The requirements mentioned below are followed by a text book from Sauser and Shenhar, which provide general guidance on how to identify, analyze, and manage requirements and constraints in complex systems (Shenhar, Sauser et al. 2009). Kotonya and Sommerville also wrote a book about requirements engineering, which includes requirements acquisition, requirements analysis, requirements specification, requirements verification and requirements management. It contains a detailed description of functional requirements, non-functional requirements and constraints (Kotonya and Sommerville 1998).

4.3.2Distinguish and differentiate between constraints and requirements

Constraints equal to qualification factors mentioned in chapter 4.2.1. And in this generic approach, qualification factors in this chapter are all from Table 4.1, which can also have overlap parts compare with evaluation factors. Constraints are limitations on the design and implementation of the system. There should be no scores or ranking occurred in constraints, and it described mandatory requirement that the system must comply. Constraints can be influenced by external factors such as strategy, rules or budgets. Constraints usually include budget constraints, time constraints, technical constraints and legal constraints. Normally, those constraints will influence functional and non-functional requirements (Kotonya and Sommerville 1998).

Functional requirements are the functions that must be implemented by the system, normally it describes an action that the system should perform. Functional requirements focus on the basic functions such as the relation between input, process and output, data analysis, interface, interaction and decision making (Kotonya and Sommerville 1998). There are also other functional requirements which a project or system has a huge preference to own. Normally the stakeholders could have different expectations to the project or system, these functional requirements are used to describe their expectation or high-level goals. Constraints and functional requirements have various role in requirements engineering, the latter describes the action that system must have, and the former describes limitations on system design and implementation, but do not directly contain description of system function.

Non-functional requirements are requirements for qualities and attributes of a system, such as system performance, reliability and availability. Non-functional requirements describe how the function is performed in system and the demonstrated performance (Kotonya and Sommerville 1998). There should be no value judgements compare with functional requirements and non-functional requirements, non-functional requirements could also be quite significant to the system. And there is a connection between functional and non-functional requirements because each function that the system possess should have its own attributes. Normally for each functional requirement it should be followed by a non-functional requirement to describe its characteristic.

4.3.3Constraints

Here constraints are based on determining factors in Table 4.1 which may limit the available options for distribution center location. The constraints are qualification factors that you cannot control and used to restrict the available options for distribution center location. There are many constraints in a distribution center location process, such as budget, legislation, infrastructure, environmental etc. These constraints will limit the scope of your available choice set. For example, if the budget is limited, the company must purchase of rent a warehouse within the limit amount. However, specific constraints may vary depending on the case study. In this chapter some general constraints are generated which can be regarded as an example or initial thoughts for any case study. The explanation and reference of these 8 constraints can be found in Table 4.2 below.

Table 4.2: Constraints in distribution center location selection

Zoning policy constraint: The available options for distribution center location must apply with zoning regulations/ policy (Hesse 2004).	Land cost constraint: Stakeholder must have a financial restriction in purchasing or renting a new distribution center location (Badri, Mortagy et al. 1998).

Climate factor constraint: Environmental regulations, such as restrictions on emissions or waste disposal, must be considered when selecting a distribution center location (Sbihi and Eglese 2010)	Labor availability constraint: The availability of skilled labor is an important consideration when selecting a distribution center location. The availability of labor in a given area must be considered as a constraint (Vanichchinchai and Apirakkhit 2018).
Geographical factor constraint: The availability of suitable land for distribution center construction must be limited in certain areas, and therefore needs to be considered when selecting a location (Klose and Drexl 2005).	Product vulnerability constraint: The product characteristics, such as keeping hazardous materials away from other items need to be considered in distribution center location selection (Barbarosoğlu and Arda 2004)
Transport infrastructure constraint: Infrastructure such as bus stops or train station must meet the daily needs of employees during location selection process(Chopra and Meindl 2001).	Transport network accessibility constraint: Location selection must have good access to transportation, such as road, rail, port or airport accessibility (Melachrinoudis and Min 2000).

4.4Step 3: Requirements

4.4.1Functional requirements

Functional requirements define the specific capabilities that a warehouse must possess in order to meet its operational needs. They refer to the specific needs and capabilities that a warehouse must possess in order to fulfill its intended purpose effectively and efficiently. Functional requirements in distribution center design can be divided into two types: external factors which will make influence in distribution center surroundings and internal factors which will result technologies inside the distribution center (Jacyna, Lewczuk et al. 2015). In this project some functional requirements focus on internal of distribution center design, which include technologies and devices that a warehousing process will use. Internal factors will have impact on internal process for each distribution center, the typical elements of warehousing process can be found in Figure 4.1 (Jacyna, Lewczuk et al. 2015) below, as a series of order, receive, storage, retrieval, handling and shipment.

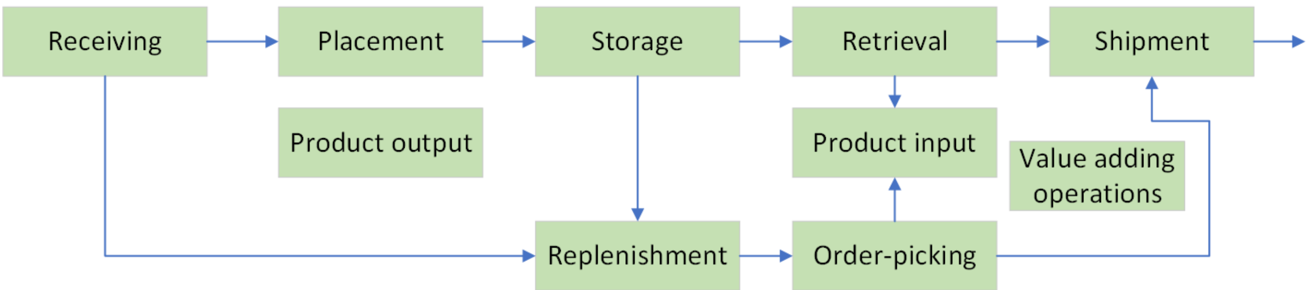

Figure 4.1: Typical elements of warehousing process

On basis of these typical elements in the process of warehousing,10 internal elements are found as general items on basis of literature review which can be found in Table 4.3. Those functional requirements include handling equipment, staff and space for warehousing task, technical performance, physical structure, information system, storage method and packaging operations (Shenhar, Sauser et al. 2009, Jacyna-Gołda, Merkisz-Guranowska et al. 2014, Jacyna, Lewczuk et al. 2015). The 'other references' column represents the number of papers found in this project for each functional requirement (Gu, Goetschalckx et al. 2007). And the 'reference in this project' column demonstrates the exact reference used in this table for explanation.

Table 4.3: Functional requirements in distribution center location selection

Explanation	Reference in this project	Other references	Typical elements
Distribution center should have function to receive products. It needs a receiving area for unloading, inspecting goods and recording receiving information	(Jacyna, Lewczuk et al. 2015)	4	Receive
Distribution center should have shipment function to load the sorted products onto a transport vehicle and prepare them for shipment. It requires loading and unloading equipment and information system to record shipment information and track the status of the products in transit	(Jacyna, Lewczuk et al. 2015)	4	Shipment
Distribution center should have function to move products such as handling technologies	(Shenhar, Sauser et al. 2009)	8	Placement
Distribution center should have function to store products and special storage methods such as freezing or air-conditioned	(Jacyna-Gołda, Merkisz-Guranowska et al. 2014)	11	Storage
Distribution center should have function to track and monitor products movement	(Shenhar, Sauser et al. 2009)	8	Product input and output
Distribution center should have retrieval function to select products from the warehouse according to the order requirements. The retrieval process requires efficient goods retrieval equipment and systems, such as automated goods transport system	(Jacyna, Lewczuk et al. 2015)	4	Retrieval

Distribution center should have value adding operation such as packing picked products to protect them and reduce losses during transportation. This process requires packing materials and packing equipment	(Jacyna-Gołda, Merkisz-Guranowska et al. 2014)	15	Value adding operation
Distribution center should have replenishment function. This function is based on inventory levels and demand forecasts to replenish products from reserve stock to the picking area. It requires an inventory management system to monitor inventory levels, as well as the equipment used to move products	(Shenhar, Sauser et al. 2009)	4	Replenishment
Distribution center should have function to pick products. This function is based on order information, which requires effective picking equipment and technology, such as picking vehicles and picking robots	(Jacyna, Lewczuk et al. 2015)	19	Order picking

4.4.2Non-functional requirements

Normally non-functional requirements and functional requirements should be one-to-one correspondence since each function that the system possess should have its own attributes. However, some additional attributes of the distribution center are also non-functional requirements such as availability, reliability, safety, environmental friendliness, etc. This chapter introduces 12 non-functional requirements. 8 of them are followed by typical elements mentioned in Figure 4.1 which can be found in Table 4.4. And the rest 4 of them are additional attributes can be found in Table 4.5 below:

Table 4.4: Some attributes followed by distribution center functions

Attributes	Explanation	Functions	Reference
Accurate Efficient	The distribution center must meet accurate and efficient product receiving and retrieval process. And ensure the accuracy of the order picking process by optimizing the picking process and reduce picking time.	Receive Retrieval Order picking	(Lee, Lv et al. 2018)
Reliable	The distribution center must be reliable in shipment process to ensure that the products are not damaged, and also the technical equipment.	Shipment	(Jacyna, Lewczuk et al. 2015)
Flexible	The distribution center must be flexible in placement process to be adaptable for different sizes and shapes of goods.	Placement	(Chan 2003)

Safety	The distribution center must be safety which can ensure security and anti-theft measures for cargo storage areas.	Storage	(Barbarosoğlu and Arda 2004)
Traceable	The distribution center must be traceable which can ensure traceability of products in and out of the process for easy monitoring and management.	Product input and output	(Hu, Zhang et al. 2013)
High-quality	The distribution center must be high-quality to ensure the standard of value-added operations.	Value adding operation	(Jacyna-Gołda, Merkisz-Guranowska et al. 2014)
Predictable	The distribution center must be predictable in replenishment process, such as building accurate forecasting models to allow for timely replenishment based on demand.	Replenishment	(Shenhar, Sauser et al. 2009)

Table 4.5: Some additional attributes

Attributes	Explanation	Reference
Accessibility	The distribution center should be well-connected to public transport, allowing employees to easily commute to work using buses or other forms of public transportation.	(Yang and Nguyen 2016)
Connectivity	This distribution center must have good connectivity to nearby highways.	(Bochner, Higgins et al. 2010)
Proximity to customers	The distribution center must be near to all its customers.	(Heizer and Render 2004)
Environmentally friendly	The distribution center must be environmentally friendly to the surrounding community.	(Stevenson, Hojati et al. 2007)

4.5Step 4: Morphological chart

In this chapter, the morphological chart will be introduced as an analysis approach. This is an innovative problem-solving tool, which can be used to generate various alternatives on basis of systematically analyze. In this thesis project, it aims to identify an appropriate new distribution location. Functions and attributes from chapter 4.4 will be used as input in this generalized morphological chart. And some means are generated to form this morphological chart.

4.5.1Functions, attributes, aspects and their means

Functional requirements:

- Receive: Some equipment will be involved in receiving products, such as hand pallet truck, electric pallet truck and forklifts.
- Placement: The distribution center should have various equipment or technology to place products. It can either achieve a certain level of automation to facilitate operation or equip with modern technology. Or place products via conveyor belt or using advanced robotic to handle this kind of job.
- Storage: The distribution center should have different storage equipment such as multi-tier racking, pallet racking, flow racking or cantilever racking.
- Retrieval: The distribution center should have various equipment or technology to search and select products. It can be achieved manually or automatically.
- Shipment: Truck, railway, air and marine transportation can be used in shipment for distribution center.
- Transportation service: For each distribution center it should have sophisticated transportation system to move products. The means include outsource transportation service to third party country and have its own transportation service.
- Specific storage facility: The distribution center should have various storage facility to ensure different demand. The means include hazardous material division for special storage, temperature and humidity control zones for food, pharmaceuticals and cosmetics which need special care.

These functional requirements can be found in Table 4.3, which contains some functions that this system must have. Those functions are taken as a starting point and several means (solutions) to these functions are developed here.

Non-functional requirements:

- Accessibility: Alternatives should have a convenient accessibility. The distance to highway should be taken into consideration and whether it is near to the local harbor for marine transport. And it should also have abundant public transportation and parking area for employees to reach.
- Proximity to customers: The distribution center should be in a place where near high customer density areas, close to key customer bases, close to major markets and commercial zones.
- Environmentally friendly: The distribution center should be environmentally friendly to the surrounding community. And the sustainability measures could be installing energy-saving equipment and technologies, using renewable energy sources, setting green design strategies and optimizing resource utilization.

These non-functional requirements can be found in Table 4.5, which contains some attributes that this system must be. Those attributes are taken as a starting point and several means (solutions) to these attributes are developed here.

Other aspects:

- Land cost: There are three means under this aspect: low-cost areas, medium-cost areas and high-cost areas. They can cover different land cost budgets and consider different geographical locations and investment approaches.
- Site foundation: The region for the new distribution center should be limited. There are three means under this function which are expanding current distribution center, finding new location in the neighbor city or finding location in a new city.

- Distribution center operation strategy: There are four means under this aspect, which are locating the distribution center in empty land or industrial estates, outsourcing to logistics companies, sharing distribution center with other companies or renting temporary distribution center.

These three aspects are out scope of requirements. But they are necessary in siting a new distribution center location and they all meet the constraints.

Based on these 8 functions, 3 attributes, 3 aspects and corresponding 48 means, the morphological chart for a generalized distribution center site selection can be found in Figure 4.2 below. And the explanation of this morphological chart, includes the decision of best, possible and not-allowed means can be found in the next chapter 4.5.2.

	Functions/Attributes	Means			
Functional requirements	Receive	Hand Pallet Truck	Electric Pallet Truck	Forklift	
	Placement	Forklift	Automated Guided Vehicle	Conveyor Belt	
	Storage	Multi-tier Racking	Pallet Racking	Flow Racking	Cantilever Racking
	Retrieval	Manual Picking	Mobile Shelving System	Robotic Picking	Automated storage and retrieval systems
	Shipment	Truck	Railway	Air	Marine
	Information management system	Enterprise resource planning system	Warehouse management system	Customer relationship management system	Cloud computing and Internet of things technology
	Transportation service	Outsource transportation service	Has its own transportation service within the distribution center		
	Specific storage facility	Contain hazardous material division for special storage.	Contain temperature controlled zones	Contain humidity control zones	
Non-functional requirements	Accessibility	Facilitate road transport	Facilitate maritime transport	Easy to reach for employees	Available parking facilities
	Proximity to customers	Locate in high customer density areas	Close to key customer bases	Close to major markets and commercial zones	
	Environmentally friendly	Adopt energy-saving equipment and technologies	Optimize resource utilization and minimize waste	Use renewable energy sources	Green design and green building strategies
Other aspects	Land cost	Low-cost areas	Medium-cost areas	High-cost areas	
	Site foundation	Expand current distribution center	Find new location in the neighbor city	Find new location in a new city	
	Distribution center operation strategy	Locate the distribution center in empty land or industrial estates	Outsource to logistics companies	Share distribution center with other companies	Rental of temporary distribution center

Figure 4.2: Morphological chart for distribution center site selection

4.5.2Possible combinations and not-allowed means

In a morphological chart, combinations can be calculated by multiplying number of means for each function. In our morphological chart shown in Figure 4.2, the total number of combinations is 2239488. But there are many means which are not physically possible and will cause impossible combinations, and some other means which are test with restrictions and will cause not-allowed combinations. By eliminating those invalid or infeasible means, the number of combinations can be limited to an acceptable number. All the combinations can be found in Figure 4.3. In this chart best means are shown in green color. Possible means are shown in yellow color, those means are acceptable but not the best solution for each function. And not-allowed means are shown in red.

	Functions/Attributes	Means			
Functional requirements	Receive	Hand Pallet Truck	Electric Pallet Truck	Forklift	
	Placement	Forklift	Automated Guided Vehicle	Conveyor Belt	
	Storage	Multi-tier Racking	Pallet Racking	Flow Racking	Cantilever Racking
	Retrieval	Manual Picking	Mobile Shelving System	Robotic Picking	Automated storage and retrieval systems
	Shipment	Truck	Railway	Air	Marine
	Information management system	Enterprise resource planning system	Warehouse management system	Customer relationship management system	Cloud computing and Internet of things technology
	Transportation service	Outsource transportation service	Has its own transportation service within the distribution center		
	Specific storage facility	Contain hazardous material division for special storage.	Contain temperature controlled zones	Contain humidity control zones	
Non-functional requirements	Accessibility	Facilitate road transport	Facilitate maritime transport	Easy to reach for employees	Available parking facilities
	Proximity to customers	Locate in high customer density areas	Close to key customer bases	Close to major markets and commercial zones	
	Environmentally friendly	Adopt energy-saving equipment and technologies	Optimize resource utilization and minimize waste	Use renewable energy sources	Green design and green building strategies
Other aspects	Land cost	Low-cost areas	Medium-cost areas	High-cost areas	
	Site foundation	Expand current distribution center	Find new location in the neighbor city	Find new location in a new city	
	Distribution center operation strategy	Locate the distribution center in empty land or industrial estates	Outsource to logistics companies	Share distribution center with other companies	Rental of temporary distribution center

Figure 4.3: Morphological chart for final combinations

4.5.3Evaluation standard for all kinds of means

For non-functional requirements 'Accessibility' and 'Environmentally friendly', all the means in green color are best means and should be contained in the alternative generation on basis of requirements. Because every best means under these two non-functional requirements should be satisfied. The reference of each means can be found below, followed by detail of each means such as advantage and disadvantage and the reason why they are best, possible or not allowed.

1. Receive (Legner and Wende 2006)
    - Hand Pallet Truck
      Advantage: Low cost, easy to operate, low maintenance cost.
      Disadvantage: Not suitable for large scale or long-term use

    - Electric Pallet Truck
      Advantage: Reduce operator's labor intensity and improve transportation efficiency.
      Disadvantage: High cost and maintenance, requires regular recharging. Operators may require some training.

    - Forklifts
      Advantage: High load capacity and very flexible.
      Disadvantage: Higher purchase and maintenance costs, operators may require some training.

Electric pallet truck and forklifts are best means because their load capacity and transport distance are better than hand pallet truck.

2. Placement (Shenhar, Sauser et al. 2009)
    - Forklift
      Advantage: High load capacity and very flexible.
      Disadvantage: Higher purchase and maintenance costs, operators may require some training.

    - Automated guided vehicle
      Advantage: Reduce labor costs and improve efficiency and accuracy.
      Disadvantage: Relatively high purchase and installation costs. It may affect the operation of the entire logistics center if system fails.

    - Conveyor Belt
      Advantage: High efficiency and easy to use.
      Disadvantage: There are certain requirements for the layout and space of the warehouse

These three means are all best means and the selection of these means in a case study should be considered based on the specific needs and environment.

3. Storage (Rouwenhorst, Reuter et al. 2000)
    - Multi-tier Racking
      Advantage: Higher space utilization and increased warehouse capacity.
      Disadvantage: High installation and reconfiguration costs.

- Pallet Racking
  Advantage: Flexible, low cost, easy to install and reconfigure.
  Disadvantage: High dependence on forklifts.

- Flow Racking
  Advantage: Achieve first in, first out inventory management, suitable for items with a high turnover rate.
  Disadvantage: Ramps and rollers are required which may take up some shelf space, higher initial investment costs and regular inspection and maintenance.

- Cantilever racking
  Advantage: Very durable and flexible for easy adjustment to the products.
  Disadvantage: Not suitable for distribution center with limited space.

After evaluating the advantage and disadvantage of these four means, the choice of storage largely depends on what type of products company needs to store, as well as the distribution space and budget. Thus, cantilever racking is the only possible mean here since it may cost slightly more compared to others.

4. Retrieval (Roodbergen and Vis 2009)
   - Manual picking
     Advantage: Low cost and flexible to handle orders of all types and sizes.
     Disadvantage: Extremely inefficient and requires a lot of labor.

   - Mobile shelving system
     Advantage: Efficient use of space and improved picking efficiency.
     Disadvantage: Maintenance costs may be higher than traditional static shelving systems.

   - Robotic picking
     Advantage: Have the capability to work continuously, increase efficiency.
     Disadvantage: Rapid technological change, higher cost.

   - Automated storage system
     Advantage: Improves efficiency of warehouse operations, reduces manual errors, saves space and reduces labor costs.
     Disadvantage: Higher initial investment costs.

Comparing these four means, automated storage systems have advantage in increasing distribution center efficiency, saving more space and reduced labor costs. The important thing is robotic technique is not as mature as automated storage system and it will cost more money in the beginning. And automated storage system has more advanced software such as RFID system compare with mobile shelving system. Therefore, robotic picking and mobile shelving system is selected as possible means. The disadvantages of manual picking greatly outweigh its advantages, so it is not-allowed mean under function retrieval.

5. Shipment

All three means are general shipment tools, so they are all best means and depends on distribution center location or distance to customers.

6. Information management system

Each of the four means has function to meet the needs of distribution center. This includes order processing, inventory management, route optimization, transportation management, etc. In case study company should select these means according to the actual demand and operation, thus all of them are best means.

7. Transportation service (Selviaridis and Spring 2007)
   - Outsource transportation service
     Advantage: Reduce fixed costs and vehicle maintenance costs, company could provide quality transport services.
     Disadvantage: Companies have less control over the transport process. May pose a risk of information leakage and trade secret disclosure.

   - Has its own transportation service within the warehouse
     Advantage: Greater control to ensure transport quality, make customized transport services to suit specific need and increase satisfaction.
     Disadvantage: Higher cost, lower flexibility and difficult to manage transport service.

Here both means are included to 'best mean' in green color on basis of different situation. For example, if the case is to build a new distribution center in an empty land or real estate, normally company should outsource transportation service because the company itself do not have a department to handle product transportation. But if the case is to rent an existing distribution center, then this existing one may have its own transportation service which can be directly used. After considering both situations, both means are included under 'best mean'.

8. Specific storage facility

All three means under this function are best mean, since it depends on the type of product a distribution center will store. For any product which needs special care, the target specific facility should be chosen.

9. Accessibility (Hesse 2002)
   - Facilitate road transport
     Advantage: Easy for road transport and could cover a wide area.
     Disadvantage: May be affected by traffic congestion.

   - Facilitate maritime transport
     Advantage: Easy for marine transport, suitable for long distance and international transport.
     Disadvantage: Possible customs clearance delays.

   - Easy to reach for employees
     Advantage: Improve employee satisfaction, reduce commuting time, attract a wider range of new employees.
     Disadvantage: Land prices and rents are likely to be relatively high, potential for high traffic pressure and congestion.

   - Available parking facilities
     Advantage: Improve employee satisfaction, reduce cargo loading and unloading time and improve logistics efficiency.
     Disadvantage: Occupy a large amount of land which cannot be used for other logistics operation.

10. Proximity to customers

The first two are best means because close to customers will enable the logistics center to serve customers better and faster and increase their satisfaction. The last one is a possible mean which enables logistics center to respond faster to market changes. But not as important as reducing distance to customers.

11. Environmentally friendly (McKinnon, Browne et al. 2015)

Under this function every means will be regarded as a best mean because as a non-functional requirement it is mandatory to have environmentally friendly device no matter it can minimize waste, or it could achieve low carbon emission, or it can increase energy efficiency.

12. Land Cost (Baker and Canessa 2009)

- Low-cost areas:
  Advantage: Land costs are usually lower.
  Disadvantage: Remote, sparsely populated or less developed areas
- Medium-cost areas
  Advantage: Areas with relatively balanced factors such as cost and geographic location.
  Disadvantage: Probably in the far outskirts of the city
- High-cost areas:
  Advantage: The site is well located, easily accessible, densely populated or with high development potential.
  Disadvantage: Land costs are usually higher.

Under this aspect 'High-cost areas' is regarded as a best mean because it has other attributes such as good accessibility and higher population density which are also significant in deciding distribution center location. 'Medium-cost areas' is a possible mean and 'Low-cost areas' is a not-allowed mean since it is normally undeveloped area which requires more money on initial investment.

13. Site foundation

All the three means are best means because searching new distribution center location in the neighbor city or directly expand a current one could reduce employee movement. They do not need to move to another city with new environment, which will increase the satisfaction of employees. Moreover, establishing a distribution center in a completely new city can also cover a new market area and increase brand awareness.

14. Distribution center operation strategy

The first two are best means because firstly, locate in empty land allows company to build a new logistics center according to company needs. And outsource to professional logistics companies can help the company focus on the main business. Share distribution center with other companies is a possible mean which can save costs and increase efficiency. However, some problem might happen when there is insufficient storage space during periods of high demand. Moreover, the complexity of the supply chain will increase and require more coordination and communication efforts. Rental of temporary distribution center is a not-allowed mean because a new distribution center location aims to be stable for long-term use.

4.6Step 5: Distribution center site selection method

Logistics distribution center location selection methods can be divided into qualitative analysis methods and quantitative analysis methods. Qualitative analysis methods focus on non-numerical information, such as observations, descriptions, and interpretations of phenomena. These methods typically rely on expert knowledge, experience, and subjective judgment which require weighing various factors that affect the location selection of distribution centers. Classic qualitative method models include expert review, Delphi method, and SWOT analysis etc. Quantitative analysis methods, on the other hand, involve obtaining relevant cost parameters through historical data or actual measurements, quantifying location factors and objectives, and establishing models that maximize profit or minimize cost. By solving these models, the optimal logistics operation strategy is determined. Classic quantitative method includes analytical method, multi-criteria decision method and mathematical programming. A comparison of the advantages and disadvantages of qualitative analysis methods and quantitative analysis methods, as well as an introduction to their respective models, is shown in Table 4.6.

Multi-criteria decision-making (MCDM) methods are commonly used to decide a series of alternatives on basis of many determining factors associated with alternatives. It has a huge application especially in the domain of 'alternate use selection', 'priority order for rebuilding', 'value assessment', 'service life assessment' and 'contractor selection' (Nadkarni and Puthuvayi 2020). The distribution center site selection problem represents one of the problems which can be solved by MCDM methods. In this decision-making process many stages are included, such as deciding factors, collecting information for decision maker to analysis, generating a series of alternatives which can satisfy constraints and requirements for the target project. And finally utilize a suitable methodology to solve this site problem and find the best alternative (Ehsanifar, Wood et al. 2021). In chapter 2.5 we can find description about different multi-criteria decision methods in detail, those methods include AHP, Choquet integral, TOPSIS, ELECTRE and BWM.

Mathematical programming (MP) is a common method for selecting the location of distribution centers. Based on the actual operating conditions of the distribution center and the objectives of the logistics distribution center location selection, such as minimizing transportation costs and maximizing service levels, a mathematical model is abstracted. By establishing a specific set of constraints, an optimal solution is solved among numerous feasible alternatives. The disadvantage of this method is that the model is often an NP-hard problem, making it difficult to obtain the optimal solution for the constructed model.

Table 4.6: Comparison of qualitative and quantitative analysis

Method	Advantage	Disadvantage	Scope	General model
Qualitative analysis	Based on experience and easy to operate	Tend to have subjective and empirical errors, low reliability of final decisions	Small number of locations, have relevant experience to study	Expert review, Delphi method, SWOT analysis

Quantitative analysis	Analytical method	Simple model with few determining factors	Difficult to solve larger scale problems	Single distribution center location	Center-of-gravity method, Cross median method
	Multi-criteria decision method	Comprehensive consideration of all site selection factors, with the possibility of using both quantitative and qualitative analysis	Difficult modeling and many computational processes	Considering both quantitative and qualitative factors	AHP, Choquet integral, TOPSIS, ELECTRE, BWM
	Mathematical programming	Precise calculation method to obtain the optimal solution	Subjective factors have a significant impact on the results, and have linear decisions	Facility location problem with quantified determining factors	Weber's problem, P-median problem, P-center problem, covering problem

4.6.1Reasons for combining MCDM and MP in solving location problem

In this 5 step of phased method both MCDM and MP are chosen to solve location problem. The first one aims to calculate weights for each determining factor, and the latter one can calculate the score for each alternative. After multiplying factor weight and score together, the rank of all alternatives can be found. There are several significant advantages to the use of this combination methods:

- Comprehensiveness: MCDM allows people to consider multiple determining factors and assign appropriate weights to each factor, thus making the decision process comprehensive. On the other hand, MP methods can solve more specific siting problems, such as minimizing transportation costs, that may be difficult to solve in MCDM.
- Accuracy: In the decision-making process, this combination method can provide accurate quantitative assessments, rather than just subjective or qualitative assessments. This helps improve the accuracy and consistency of decision making.

- Flexibility: This combination method can be adapted to the specific decision environment and needs. For example, people can add or remove decision factors, or adjust the parameters of a MP model as specific case study need.
- Transparency: This combination method can make the decision-making process more transparent. Decision makers can clearly see the weights of each factor and the scores of each alternative on each factor. This helps decision makers understand and accept the decision results.

In general, using a combination of MCDM and MP methods can help the decision maker to get comprehensive, accurate, flexible, transparent and efficient decisions about where to locate the logistics center.

4.6.2MCDM method in distribution center site selection

The main steps of MCDM are as following (Opricovic and Tzeng 2004):

1) Create evaluation factors for the target system.
2) Generating alternatives for the target system to achieve the goal.
3) Using factors to evaluate alternative.
4) Applying a suitable multi-criteria analysis method.
5) Obtaining one of the alternatives as the optimal solution.
6) If the optimal solution is not accepted, reject it and go for another iteration.

Generating evaluation factors and alternatives are the first 3 steps in MCDM. For the fourth step, in chapter 4.6 many distribution center site selection methods are introduced in both quantitative and qualitative ways. One of them is MCDM method. They are commonly used to decide a series of alternatives on basis of many determining factors associated with alternatives. The distribution center site selection problem represents one of the problems which can be solved by MCDM methods. It can be divided into two groups (Nadkarni and Puthuvayi 2020):

1. Method for factor weights assessment
2. Method for alternatives ranking

For some methods such as AHP and BWM (Saaty 2004, Rezaei 2016) they are equipped with both categorizes, which means they have the ability to both evaluate factor weights and rank alternatives. However, other methods such as TOPSIS belongs to only one categorizes. TOPSIS is primarily utilized for ranking and selecting alternative options, and it requires the pre-determination of weights for each factor. Consequently, when employing the TOPSIS method, it is necessary to rely on other methods (such as AHP) to assess criterion weights (Perng, Juan et al. 2007). TOPSIS calculates the distance between each alternative and the positive and negative ideal solutions based on the known weights and the scores of alternatives under each factor, thereby facilitating the ranking and selection of alternatives.

- Weights assessment methods

AHP uses pairwise comparison matrices for factors to compute the score of alternatives according to factor weights. And it is the most dominant MCDM method in the area of weight assessment (Belton and Stewart 2002, Tadeu de Oliveira Lacerda, Ensslin et al. 2011). Another popular method is BWM introduced in the year 2015. Decision maker determines the best and the worst factors and BWM uses pairwise comparison between each of these two factors and other factors. Both these two methods can do factor weights evaluation and alternatives ranking (Rezaei 2015, Yazdi, Adumene et al. 2022). The advantages and disadvantages of them can be found in Table 4.7.

- Alternatives ranking methods

There are many other MCDM methods can only select alternatives ranking list. And they normally need to be combined with another weighting method mentioned before. For example AHP method can be employed to determine factor weights and use TOPSIS to rank alternatives (Perng, Juan et al. 2007). TOPSIS requires the chosen alternative to have the shortest distance to the optimal solution and the farthest distance to the undesirable solution (Chen, Hwang et al. 1992, Opricovic and Tzeng 2004). ELECTRE analyses the outranking relationship between alternatives by using concordance and discordance indexes, which aims to choose the best action from a series of actions (Chen, Hwang et al. 1992, Sevkli 2010). Preference ranking organization method for enrichment evaluation (PROMETHEE) method is one of the outranking methods. Firstly, it construct an outranking relation on factors which presents decision maker preference. In the second phase a leaving and entering flow is considered in the outranking graph for decision maker (Brans, Vincke et al. 1986, Wu, Tao et al. 2020). Multi Attribute Utility Theory (MAUT) uses utility function while considering the preference of decision makers. An index is employed to describe the preference of one factor. Both quantitative and qualitative factors are included in this method (Mustafa and Ryan 1990, Pohekar and Ramachandran 2004). The advantages and disadvantages of them can be found in Table 4.7.

Table 4.7: Comparative assessment of multi-criteria decision-making techniques

Category	MCDM techniques	Principle	Advantage	Disadvantage	Reference
Method for alternatives ranking	PROMETHEE	PROMETHEE method is one of the outranking methods. Firstly it construct an outranking relation on factors which presents decision maker preference. In the second phase a leaving and entering flow is considered in the outranking graph for decision maker.	It is a more simple and stable method, no need for preprocessing raw data and minimal information loss Effectively reflects the characteristics of various factors.	Overlooks the individual behavior of decision-makers.	(Brans, Vincke et al. 1986, Wu, Tao et al. 2020).
	ELECTRE	ELECTRE analyses the outranking relationship between alternatives by using concordance and discordance indexes, which aims to choose the best action from a series of actions.	The information required in the decision matrix can be totally utilized. The trade-off among factors involves compensation.	Computation time grows rapidly as the number of alternatives increase. The computation process is very complex.	(Chen, Hwang et al. 1992, Sevkli 2010)
	MAUT	MAUT uses utility function while considering the preference of decision makers. An index is employed to describe the preference of one factor. Both quantitative and qualitative factors are included in this method.	Helps to fully consider the subjective preferences of decision makers, making the decision-making process more transparent and rational.	Constructing utility functions and determining weights may involve a degree of subjective judgment.	(Mustafa and Ryan 1990, Pohekar and Ramachandran 2004)
	TOPSIS	TOPSIS requires the chosen alternative to have the shortest distance to the optimal solution and the farthest distance to the undesirable solution.	Simple and easy to use and understand. The trade-off among factors involves compensation.	The relative weight of distances between other solutions are not considered. Uses vector normalization which rely on evaluation unit of the factor function. Factors must be numerical and comparable.	(Chen, Hwang et al. 1992, Opricovic and Tzeng 2004)
Method for factor weights evaluation & alternatives ranking	AHP	AHP uses pairwise comparison matrices for factors to compute the score of alternatives according to factor weights.	The factor weights and alternative scores are real numbers. Still a dominant method used for weighting factors.	Lack of reference when weighting factors Assume that it is independent between each factors.	(Belton and Stewart 2002, Tadeu de Oliveira Lacerda, Ensslin et al. 2011)
	BWM	Decision maker determines the best and the worst factors and BWM uses pairwise comparison between each of these two factors and other factors.	Has consistency ratio which can be used to check reliability. A lower number of comparisons can significantly reduce computation time. Decision maker will only use integer numbers 1–9.	BWM is static and difficult to capture dynamic changes. Difficult to measure continuously changing factors.	(Rezaei 2015, Yazdi, Adumene et al. 2022)

4.6.3MP in distribution center site selection

The literature review about facility location problem can be found in chapter 2.6. Owen summarized two mathematical model to solve facility location problem which are static location problem and dynamic location problem (Owen and Daskin 1998). Among static location problem there are four models which can be found in chapter 2.6: Weber's problem, P-median problem, P-center problem and covering problem. The main difference between them is the objective function and the problem-specific constraints (Hale and Moberg 2003).

In order to build the model, in this thesis project Python is used in Jupyter as a modeling language to formulate the model, L-BFGS-B is used as an optimization algorithm in module SciPy. L-BFGS-B is chosen here because the objective function aims to minimize the distance between the target warehouse and all the customers. And as a non-linear problem with constrains, the minimize function will be use with solver limited memory BFGS (L-BFGS-B) (Snyman, Wilke et al. 2018). L-BFGS-B is an algorithm which can solve large-scale constrained optimization problems. The L-BFGS-B algorithm is a modification of the finite-memory BFGS (L-BFGS) algorithm, which is a quasi-Newtonian method for solving unconstrained optimization problems, and the L-BFGS algorithm is a variant of it with finite memory. the L-BFGS-B algorithm adds upper and lower bound constraints on variables to the L-BFGS, making it suitable for solving bounded constrained optimization. This approach has evolved rapidly over the past few decades, providing efficient optimization algorithms for a wide range of applications in machine learning, operations research and other related fields (Zhu, Byrd et al. 1997). In this L-BFGS-B algorithm, the initial guess is needed as the starting point for iterative optimization algorithms (Tsai, Bousse et al. 2017). The quality of the solution will be gradually improved until the convergence criterion is satisfied. With an initial guess it can also help to reach global optimal solution faster. In terms of visualization, this project use “folium” library under python to create interactive maps.

Moreover, in module SciPy, there are many other algorithms which can be used to solve optimize problem, such as TNC (Truncated Newton Conjugate-Gradient), SLSQP (Sequential Least Squares Quadratic Programming) and COBYLA (Constrained Optimization BY Linear Approximations). The advantage and disadvantage of each algorithm can be found in Table 4.8 below.

Table 4.8: Advantage and disadvantage for each algorithm

Algorithm	Advantage	Disadvantage	Reference
TNC	1. More accurate approximation using second order information 2. Fast convergence 3. Suitable for non-linear problems	1. Requires more computational resources 2. May be more memory intensive for large problems	(Nash 2000)
SLSQP	1. Can be used for bounded constraints 2. Linear and non-linear constraints are supported	1. May be slow to converge for large problems 2. Sensitive to initial points	(Boggs and Tolle 1995)
COBYLA	1. Does not require the calculation of gradients 2. Support non-linear constraints.	1. Slower convergence 2. Potentially less efficient for larger problems	(Powell 1994)
BFGS	1. Fast convergence 2. Suitable for non-linear problems 3. Less computational effort	1. Does not directly support boundary constraints 2. Requires the use of projection or penalty methods to handle constraints	(Liu and Nocedal 1989)
L-BFGS-B	1. For bounded constraint problems 2. Fast convergence 3. Suitable for non-linear problems	1. Sensitive to initial points 2. Possible convergence to a local minimum	(Byrd, Lu et al. 1995)

4.7Conclusion

This chapter introduced a structured, stepwise approach in 5 steps to tackle the complex task of distribution center location selection. This method provides a systematic progression through the decision-making process, from identifying key determining factors and constraints, to generating and evaluating location alternatives.

This approach integrates several analytical tools, such as the morphological chart for alternative generation, MCDM and MP for evaluating alternatives. Through this comprehensive process, the approach facilitates robust and objective decision-making, aiding decision makers in identifying an appropriate location for the distribution center.

The conclusion of this chapter includes the answer to sub question 3(a), 3(b), 4(a), 4(b), 5(a) and 5(b) which can be found below:

3. *What are determining factors which can influence the location of distribution center?*
    (a) *How many determining factors can we find in total and what are their sub-factors?*

In this thesis project 8 determining factors are found in total, and there are totally 25 sub-factors can be found from literature, which includes: Distance to customers/consumers, Distance to suppliers/producers, Transport cost, Inventory cost, Warehousing cost, Cargo flow, Delivery time, Delivery responsiveness, Customer support, Packaging density, Value density, Product vulnerability, Motorway network accessibility, Port accessibility, Rail accessibility, Available transport infrastructure, Congestion, Taxes, Zoning policies, Labor market availability, Labor cost, Land cost, Geographical factor, Noise factor and Climate factor.

(b) *How to classify determining factors?*

For factor 'Proximity and flow related factors', 'Logistics cost factors', 'Service level' and 'Product characteristics' they are under categorize 'Supply chain management & Transportation'. For factor 'Accessibility', 'Infrastructure', 'Business environment factors' and 'Natural environmental factors' they are under categorize 'Geography'.

4. *Which methods can be used to solve distribution center site selection problem?*
    (a) *Which multi criteria decision making method can be used and what are the advantages?*

BWM is a useful MCDM method in this thesis project which can be selected. Its advantages can be found below:

1. Has consistency ratio which can be used to check reliability.
2. A lower number of comparisons can significantly reduce computation time. For example the comparison for BWM is 2n−3 but n(n−1)/2 for AHP (Rezaei 2016).
3. Having two anchors since it needs to compare the best factor to others and the worst factor to others, which makes BWM as an excellent candidate in debiasing anchoring bias (Rezaei, Arab et al. 2022).
4. Decision maker will only use integer numbers 1–9.

(b) *Which mathematical programming method can be used and what are the advantages?*

Weber's problem is an efficient MP in this thesis project which can be chosen with L-

BFGS-B as an optimization algorithm. The advantage of using Weber's problem is because of its adaptability. In Weber's problem people can easily add more objectives for different kinds of cost about the distribution center operation, such as fix cost for construction, transport cost, labor cost and so on (Cooper 1963). The advantages of using L-BFGS-B includes: 1. It is useful for bounded constraint problems. 2. It has fast convergence time. 3. It is suitable for non-linear problems (Byrd, Lu et al. 1995).

5. *What alternative and corresponding variants can be generated for distribution center?*
    (a) *What are general constraints and requirements?*

General constraints include zoning policy, land cost, climate factor, labor availability, geographical factor, product vulnerability, transport infrastructure and transport network accessibility.

Functional requirements include receive, shipment, placement, storage, product input and output, retrieval, value adding operation, replenishment and order picking.

    (b) *Which method can be used to generate alternative?*

In this thesis project, the morphological chart, as an innovative problem-solving tool, is used as an analysis approach to generate various alternatives based on requirements.

5. 5 step of phased method description and application

5.1 Introduction

This chapter firstly describes the 5 step of phased method for solving distribution center location problem from chapter 4 in detail. Using a flow diagram to visualize the process of find an appropriate distribution center location from the current state via this 5 step of phased method to the desired state. Secondly, some applications of this method are given in terms of company's specific desired results. The examples focus on exploring possible choices in steps such as determining evaluation factors, alternatives generation and evaluation, which offers a basic foundation for decision maker to solve distribution center location problem by using this 5 step of phased method. Finally sub question 6, 7(a) and 7(b) are answered in this chapter.

5.2 5 step of phased method description

In chapter 4, a 5 step of phased method is proposed to address the distribution center location problem. This approach is designed to ensure a comprehensive and efficient process for location decision-making. The description of each step can be found below:

1. **Determining Factors Identification:**
   Firstly, the approach begins by identifying all the determining factors influencing the distribution center's location. These factors can span multiple dimensions including supply chain management, transportation and geography.

2. **Constraints Selection:**
   Secondly, constraints for the distribution center location are selected from the determining factors. These constraints define the boundaries within which the location decision must follow.

3. **Requirements Outlining:**
   Thirdly, the approach outlines requirements based on the functions of the distribution center. This step ensures that the selected location enables the distribution center to fulfill its intended roles effectively, such as storage, placement, picking and transportation.

4. **Alternative Generation and preselection using Morphological Chart:**
   The fourth step involves using a morphological chart to generate alternatives. This systematic approach facilitates the exploration of various potential solutions, offering a wide array of possibilities for the location decision.

5. **Alternative Evaluation**
   In the fifth step, MCDM can be used to calculate evaluation factor weights and then rank the final alternative list. It ensures an objective and transparent decision-making process, facilitating the selection of an appropriate distribution center location based on the calculated scores. MP is an accurate calculation method which can be applied for quantified factors and directly get the optimal solution.

Overall, this 5 step of phased method provides a way for tackling distribution center location selection. It acted as a bridge between current state to desired state, help decision makers to find an appropriate distribution center location. The flow diagram of the 5 step of phased method can be found in Figure 5.1 below.

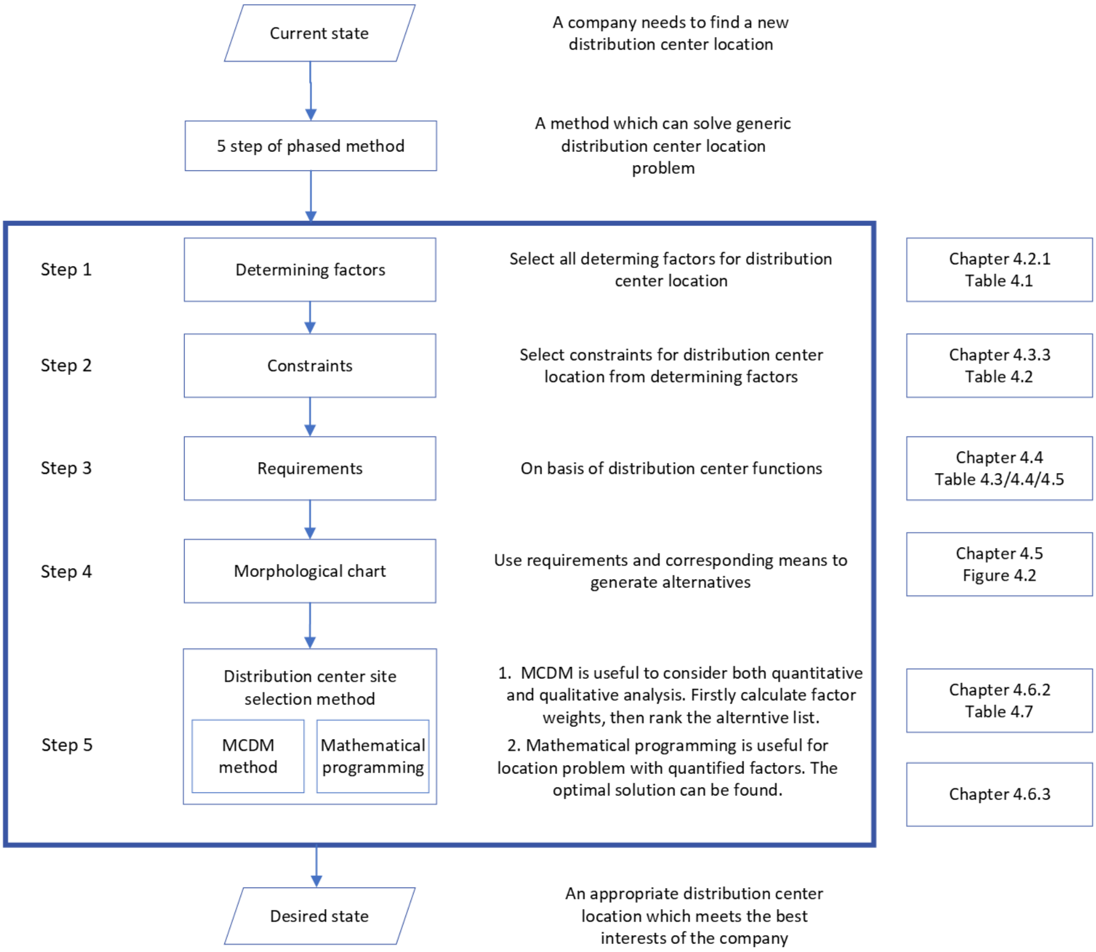

Figure 5.1: Flow diagram of the 5 step of phased method

5.3Application of the 5 step of phased method

In practice, how to apply this 5 step of phased method to specific logistics center location problem is a question we need to explore in depth. Therefore, in this chapter, some examples are used under different situation to illustrate in detail how to apply this 5 step of phased method to site selection. In these examples, the determining factors, alternatives generation and selection are determined on basis of company business model, objectives and strategies.

As a generic method, each of the step in this 5 step of phased method should have several options for decision-makers to choose in order to satisfy different company objectives. Those options in each step can be found in Figure 5.2 below. On top of this figure is the demonstration of different desired state from chapter 3.3 which are the reasons why decision-makers might want to use this 5 step of phased method to solve distribution center location problem. Their choices in each step will also be influenced by the desired state they want to achieve.

- Step 1:
  In the step of determining factors, three desired results are chosen as example for determining factors. However, in the real case, a company may want to achieve multiple desired results which means more determining factors should be considered in that case.

- Step 2:
  In the step of selecting constraints, decision-maker could continue with constraints which are created in this method. Or they can make some changes on basis of specific company preferences or the opinion from other decision-makers.

- Step 3:
  In the step of outlining requirements, the choices may appear like those in step 2. However, these requirements can be modified to fit specific companies based on their type and size.

- Step 4:
  In the step of alternatives generation, the choices are depended on desired result. Two different types of company are chosen as example with different desired results. This result indicates that different type of company with different desired results will cause various location alternatives.

- Step 5:
  In the step of alternative evaluation, the choices are included either using qualitative method with a quick approach or using quantitative analysis with MCDM or MP to evaluate alternative list.

After considering all the options from these 5 steps. Decision-makers could select a series of option which are corresponding to their desired state.

For example, the desired state of decision maker A is to minimize the total cost. So, he should select those relevant factors and generate a morphological chart on basis of that. Then continue with constraints and requirements from literature review. Finally using P-median problem to calculate the optimal solution of the distribution center.

The desired state of decision maker B might be increasing competitiveness. After selecting relevant factors, he could use new constraints and requirements from company's preference. On basis of new requirements, a morphological chart can be generated, and a score card can be directly used to evaluate factors due to time limitation. The final alternative list could be determined by his own preference.

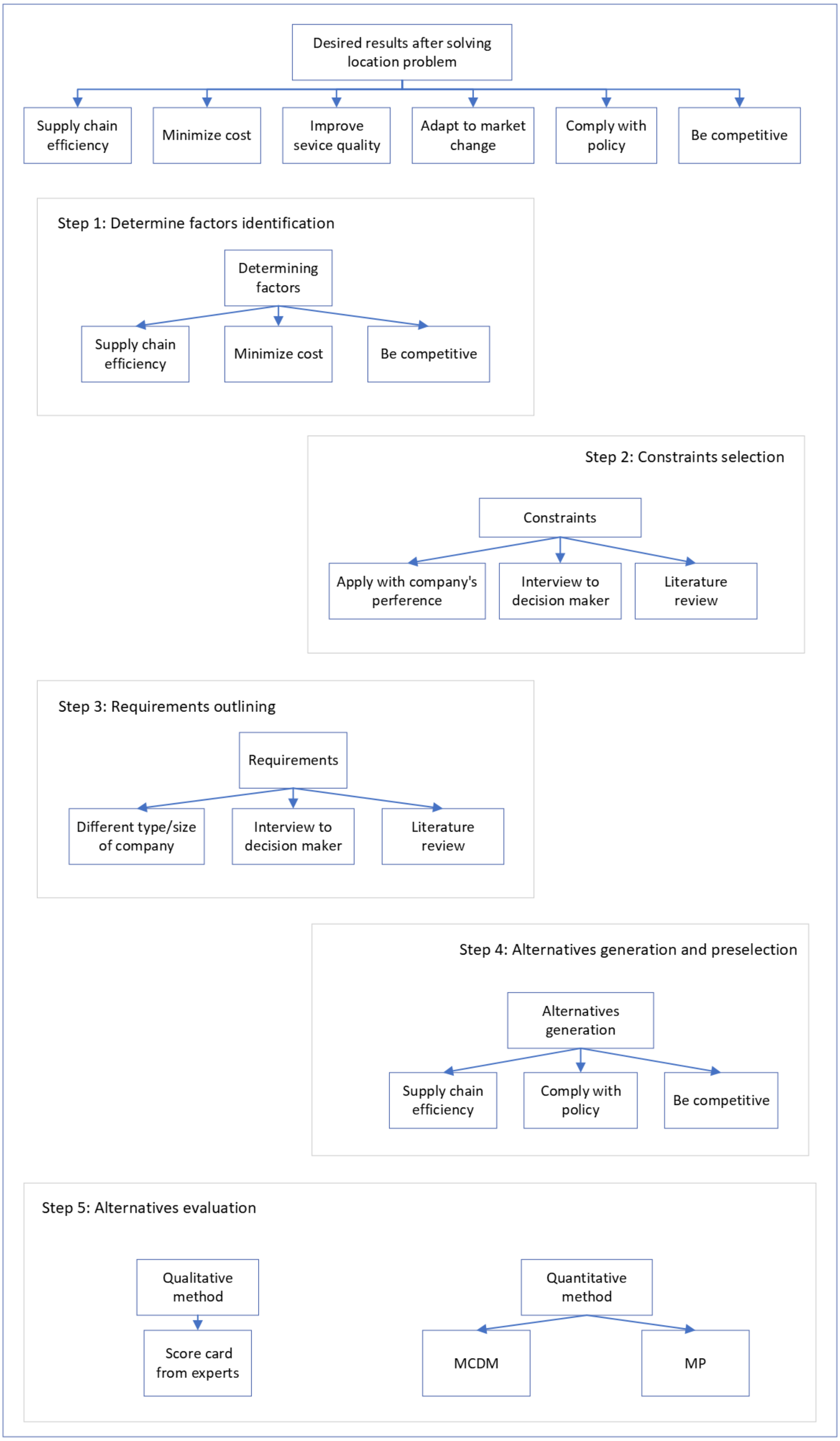

Figure 5.2: Application of this method in 5 steps

5.3.1Determine factors identification

From chapter 3.3, we can find some desired state after solving logistics center location problem. However, in the real application of selecting determine factors from this 5 step of phased method, the company size, type of product, demand urgency and desired state should also be considered.

If a company's goal is to improve supply chain efficiency, it will focus more on those factors that directly affect supply chain management when selecting determine factors. A possible determine factors list for such company can be found in Table 5.1:

Table 5.1: Factors aim to improve supply chain efficiency

Categorize	Main factors	Sub-factors	Description
Supply chain management	Proximity and flow related factors	Distance to customers/consumers	Distance from distribution center to customers of the company or the target consumer markets.
		Distance to suppliers/producers	Distance from distribution center to suppliers of the company or producers owned by company.
	Logistics cost factors	Transport cost	Transport distance, mode and means between distribution center to customers and suppliers
		Inventory cost	Warehouse rent capital, equipment investment, human resources and inventory management
	Service level	Cargo flow	
		Delivery time	Time from placing an order to customer delivery

If a company's goal is to improve its competitiveness and capture market share. Then more consideration needs to be given to those factors that are closely related to adaptability and flexibility. A possible determine factors list for such company can be found in Table 5.2:

Table 5.2: Factors aim to improve competitiveness and market share

Categorize	Main factors	Sub-factors	Description
Supply chain management & Transportation	Proximity and flow related factors	Distance to customers/consumers	Distance from distribution center to customers of the company or the target consumer markets.
	Service level	Cargo flow	
		Customer support	After-sales service, maintenance and technical support
Geography	Accessibility	Motorway network accessibility	
		Port accessibility	
		Rail accessibility	

	Infrastructure	Available transport infrastructure	Various facilities used to support the transportation of products and people
	Business environment factors	Taxes	Corporate income tax or value added tax in the target area
		Zoning policies	Government planning and management of land use and development in the target area
		Labor market availability	The quantity and quality of labor in the target area

If a company's goal is to minimize total cost. Then it is necessary to focus on those factors that are directly related to cost. A possible determine factors list for such company can be found in Table 5.3:

Table 5.3: Factors aim to reduce total cost

Categorize	Main factors	Sub-factors	Description
Supply chain management	Logistics cost factors	Transport cost	Transport distance, mode and means between distribution center to customers and suppliers
		Inventory cost	Warehouse rent capital, equipment investment, human resources and inventory management
		Warehousing cost	Handling cost, storage cost and labor cost
Geography	Business environment factors	Taxes	Corporate income tax or value added tax in the target area
		Labor cost	
		Land cost	Land price per square meter

5.3.2Alternatives generation

The morphological chart in chapter 4.5.2 is the basis for generating alternatives in any case study. Since it covers many general function and attributes that a distribution center should own. Different business goals and strategies in each company may influence the chosen alternative from this morphological chart. For example, if a company aims to minimize costs, then they may be more concerned with how to select locations and whether they can find low-cost land. If the company's goal is to improve supply chain efficiency, then they may be more concerned with how to optimize functions such as receiving, storage, and pickup. Here two examples and final alternatives are given in terms of different business goals and strategies in each company.

Example 1: The objective of a food and beverage company

As a food and beverage company who wants to improve customer satisfaction by increasing supply chain efficiency and responsiveness. In this situation, company probably consider "receive", "storage", "retrieval" and "shipment " as key functional requirements and "proximity to customers" and "accessibility" as non-functional requirements. In addition, "land cost" and "distribution center operation strategy" may also be important considerations as the company wants to reduce operating costs. After selecting function and attributes, the company needs to choose best mean and combine them together as an alternative. Thus, one possible alternative is to use electric pallet trucks for receiving, pallet racking for storage, automated systems for retrieval, locations close to customers, locations with good access, low-cost land, and a self-sustaining logistics center operation strategy. The morphological chart and alternative for this special scenario can be found in Table 5.4.

Table 5.4: One possible alternative for a food and beverage company

	Functions/Attributes	Means			
Functional requirements	Receive	Hand Pallet Truck	**Electric Pallet Truck**	Forklift	
	Storage	Multi-tier Racking	**Pallet Racking**	Flow Racking	Cantilever Racking
	Retrieval	Manual Picking	Mobile Shelving System	Robotic Picking	**Automated storage and retrieval systems**
	Shipment	**Truck**	Railway	Air	Marine
Non-functional requirements	Accessibility	**Facilitate road transport**	Facilitate maritime transport	Easy to reach for employees	Available parking facilities
	Proximity to customers	Locate in high customer density areas	**Close to key customer bases**	Close to major markets and commercial zones	
Other aspects	Land cost	**Low-cost areas**	Medium-cost areas	High-cost areas	
	Distribution center operation strategy	**Locate the distribution center in empty land or industrial estates**	Outsource to logistics companies	Share distribution center with other companies	Rental of temporary distribution center

Example 2: The objective of a cosmetic company

As a cosmetic company who aims to ensure the safe storage and fast distribution of products. Therefore "retrieval", "shipping services" and "specific storage facilities" could be regarded as key functional requirements, "environmentally friendly" as key non-functional requirements. Also, due to the unique nature of the cosmetic industry, site selection may require consideration of " land cost" and "site foundation". The whole morphological chart can be found in Table 5.5 with various combination for alternatives.

Table 5.5: Best means for a cosmetic company

	Functions/Attributes	Means			
Functional requirements	Receive	Hand Pallet Truck	Electric Pallet Truck	Forklift	
	Storage	Multi-tier Racking	Pallet Racking	Flow Racking	Cantilever Racking
	Retrieval	Manual Picking	Mobile Shelving System	Robotic Picking	Automated storage and retrieval systems
	Shipment	Truck	Railway	Air	Marine
	Transportation service	Outsource transportation service	Has its own transportation service within the distribution center		
	Specific storage facility	Contain hazardous material division for special storage.	Contain temperature controlled zones	Contain humidity control zones	
Non-functional requirements	Accessibility	Facilitate road transport	Facilitate maritime transport	Easy to reach for employees	Available parking facilities
	Proximity to customers	Locate in high customer density areas	Close to key customer bases	Close to major markets and commercial zones	
	Environmentally friendly	Adopt energy-saving equipment and technologies	Optimize resource utilization and minimize waste	Use renewable energy sources	Green design and green building strategies
Other aspects	Land cost	Low-cost areas	Medium-cost areas	High-cost areas	
	Site foundation	Expand current distribution center	Find new location in the neighbor city	Find new location in a new city	
	Distribution center operation strategy	Locate the distribution center in empty land or industrial estates	Outsource to logistics companies	Share distribution center with other companies	Rental of temporary distribution center

In this morphological chart, the alternative should satisfy both temperature and humidity control facilities to maintain the stability of cosmetics. And all the four means under attributes “environmentally friendly” should be achieved in each alternative. Therefore, the total number of alternative generated from this morphological chart is 16.

5.3.3Alternatives evaluation

The 5 step of phased method has significant advantages in evaluating alternatives. Firstly, the approach uses MCDM to determine the weights of evaluation factors and rank the alternatives. By obtaining the relative importance of each factor, decision makers can have a better understanding about the relative impact of evaluation factors and maintain focus during the decision-making process. However, in the complex process of selecting a distribution center location, sometimes the decision maker may be under pressure to decide in a short period of time due to time limitation. Such situations may arise from a variety of reasons, such as rapid changes in the market, competitor actions, or urgent needs within the company. Under such pressure, decision makers may not have enough time to conduct this 5 step of phased method thoroughly and need to do a quick approach by shrinking the scale for some steps.

Although this quick approach cannot consider all factors and possibilities as comprehensively as the 5 step of phased method, it can still help to make rational and effective decisions in a limited time frame. Sometime decision maker can just select the most important decision factors by a score card, then generate a limited number of alternatives based on these factors, and finally evaluate the final alternatives by decision maker’s preference.

Table 5.6 is an example of the score card which can be used to determine the most important factor. In this score card a higher score means higher importance.

Table 5.6: The degrees of importance in this score card

The degrees of importance description
1: Extra unimportant
2: Very unimportant
3: Unimportant
4: Slightly unimportant
5: Middle
6: Slightly important
7: High important
8: Very important
9: Extra important

Here the application of using the 5 step of phased method to find a quick solution will be demonstrated. An example will be given about how to make an effective logistics center location decision in a limited time frame.

The key evaluation factors from score card is chosen as: 1. Distance to customers; 2. Transport cost; 3. Labor availability. On basis of these three factors, the two alternatives could be:

1. Choose a location in the center of the city which is very close to the main customer base. Moreover, this location can also attract many employees due to the well-developed public transportation facilities in the city center. However, since land prices and transportation costs can be higher in urban centers, this may increase the operating costs.
2. Choose a location on the outskirts of the city. Although this location is slightly further away from the main customer base, company can save some operation costs due to lower land prices and transportation costs. In addition, if the labor market is also more abundant in the suburbs, then the company can also recruit enough employees.

After generating these two alternatives from morphological chart which has three factors. This final list can be directly handed to final decision maker to make the final choice.

5.4Conclusion

In conclusion, this chapter has shown the versatility and practicality of the 5 step of phased method in addressing distribution center location selection problems. By tailoring the selection of determining factors and generation of alternatives to the company's specific desired results, and offering different approaches for alternatives evaluation, the 5 step of phased method provides a dynamic and adaptable framework for decision-making in this complex issue. The understanding required from this chapter forms a crucial part of the result in chapter conclusion.

The conclusion of this chapter includes the answer to sub question 6, 7(a) and 7(b) which can be found below:

6) *What method has been developed in this thesis project to solve distribution center location problem, and what does it consist of?*

A 5 step of phased method is created to support the process towards selecting a distribution center location. Firstly, many determining factors will be taken into consideration such as logistics cost, service level, accessibility and infrastructure. Those factors will be further divided into qualification factors and evaluation factors. The former will be regarded as general constraints can be used for distribution center site selection. And the latter one can be used as input for MCDM to rank all the alternatives. The second and third step is to outline all the constraints and requirements which are generalized and can be utilized for any distribution center site selection problem. The fourth step is using morphological chart to generate alternatives. In the fifth step, the preference of decision makers is collected to calculate factor weights in MCDM. Quantitative and qualitative analysis are used to calculate factor scores.

7) *How to use this 5 step of phased method while considering different company objectives?*
   (a) How to select determining factors on basis of company objective?

When people apply this 5 step of phased method to select determine factors in real case, the company size, type of product, demand urgency and its desired state should be considered. The desired state includes improve supply chain efficiency or service quality, minimize cost, adapt to market demand or policy changes and be more competitive compare with other companies.

(b) How to generate alternatives on basis of company objective?

When people apply this 5 step of phased method to generate alternatives in real case, different business goals and strategies in each company will influence the chosen alternative from the morphological chart. Because the functions required for a logistics center vary for companies selling different types of products, which will cause different choice of means in the morphological chart.

6. Case study: The merger of two companies in the FMCG industry

6.1 Introduction

In chapter 6, a case study about merging two FMCG companies is given to evaluate the effectiveness of the 5 step of phased method. The detailed description of each method step in chapter 4 and the example of application in chapter 5 are combined in this chapter to solve this distribution center location problem. By using this 5 step of phased method, it aims to find an appropriate distribution center location problem for this merging company, which includes the selection of factors, using a morphological chart to generate alternatives, applying best worst method to provide weights for each factor, and using quantitative and qualitative analysis to rank alternative list. Finally, by validating the alternative which has the highest score, sub-question 8(a), 8(b) and 9(a), 9(b) can be answered. And the effectiveness of this 5 step of phased method can be proved.

6.2 Logistics operation status and demand analysis for the case study

6.2.1 Case introduction

In this case study, Company Alpha and Company Beta plan to merge into a new entity and consolidate their products together. In the landscape of company strategy, the merger of two companies is motivated by mainly four objectives. Firstly, the merged company could improve their production, distribution, and sales capacities, thereby reducing operational costs. This is a persuasion to economies of scale. Secondly, the market presence and competitiveness can be boosted for the merging company. They will have a larger market share and enhance the ability to compete against other companies in the FMCG industry. Thirdly, this merging can offer an opportunity to penetrate new markets. By accessing different geographical areas or market segments, the new company could have a wider market reach. Finally, these two companies can share their resources after merging, such as human resources and technology. The merged company could improve operation efficiency and stimulate innovation. However, currently these two companies have diverse products and fluctuating demand, indicating that the present capacity is insufficient to meet the anticipated needs of the merging company in the future. Therefore, these two companies must decide whether to establish a new distribution center, which would provide the necessary capacity for logistical operations, or to expand one of the current distribution centers to meet the growing demand.

6.2.2 Current distribution center operations

Currently, the distribution centers for both companies dispatch multiple trucks carrying different invoices, each containing only one type of product. Given the dual goals of sustainability and cost-saving, a forthcoming challenge is to consider whether these two distribution centers could be consolidated into one larger center. Since this new distribution center would dispatch multiple trucks for different invoices, each invoice could contain products from both companies. This arrangement means the number of trucks and delivery routes could be significantly reduced.

6.2.2.1Distribution center service overview

The distribution centers for both Company Alpha and Company Beta are in different situations. Company Alpha owns its own distribution center, while Company Beta rents its distribution center from another warehousing company. However, both of their distribution centers employ warehouse 4.0 technologies, which can significantly enhance supply chain performance and ensure optimal customer service.

The distribution center of Company Alpha is located in the western part of Germany, North Rhine-Westphalia. There are many FMCG companies in this region, such as food and beverage company Heinz and Katjes green, beauty product company LVMH, Vegas, Sarem and so on. Company Alpha is a FMCG company in this region with a broad land area. The distribution center of Company Beta located in the southern part of the Netherlands, North Brabant. However, there are many FMCG companies in this region, such as fruit company Den Bosch, meat company Vitelco and PALI, beauty product company MMA, Wicoli, Blezi, Duvado and so on. Company Beta is one of these FMCG companies, its distribution center was designed specifically to provide logistics services. Constructed with future demand growth in mind, this center offers unique supply chain solutions and operates in a way that supports the goal of reducing carbon emissions. The center has easy access to many public transport facilities. The local labor market is easily accessible, ensuring an ample workforce for providing co-packing services. The locations of the distribution centers for Company Alpha and Beta can be found in Figure 6.1.

Figure 6.1: Current distribution center location

6.2.2.2Suppliers’ geographical location analysis

The suppliers for Company Alpha and Beta are different, but the primary suppliers are located in the eastern and southern parts of Europe. For the distribution center of Company Alpha, its suppliers are located in Serbia, Hungary, Spain, Germany and Austria. One of the suppliers for Company Beta is located in Slovenia, and there are another two located in Germany. The locations of the suppliers and the supply chain can be seen in Figure 6.2.

For these two companies, trucks account for 80% of all transportation modes used and 100% of transportation within Europe.

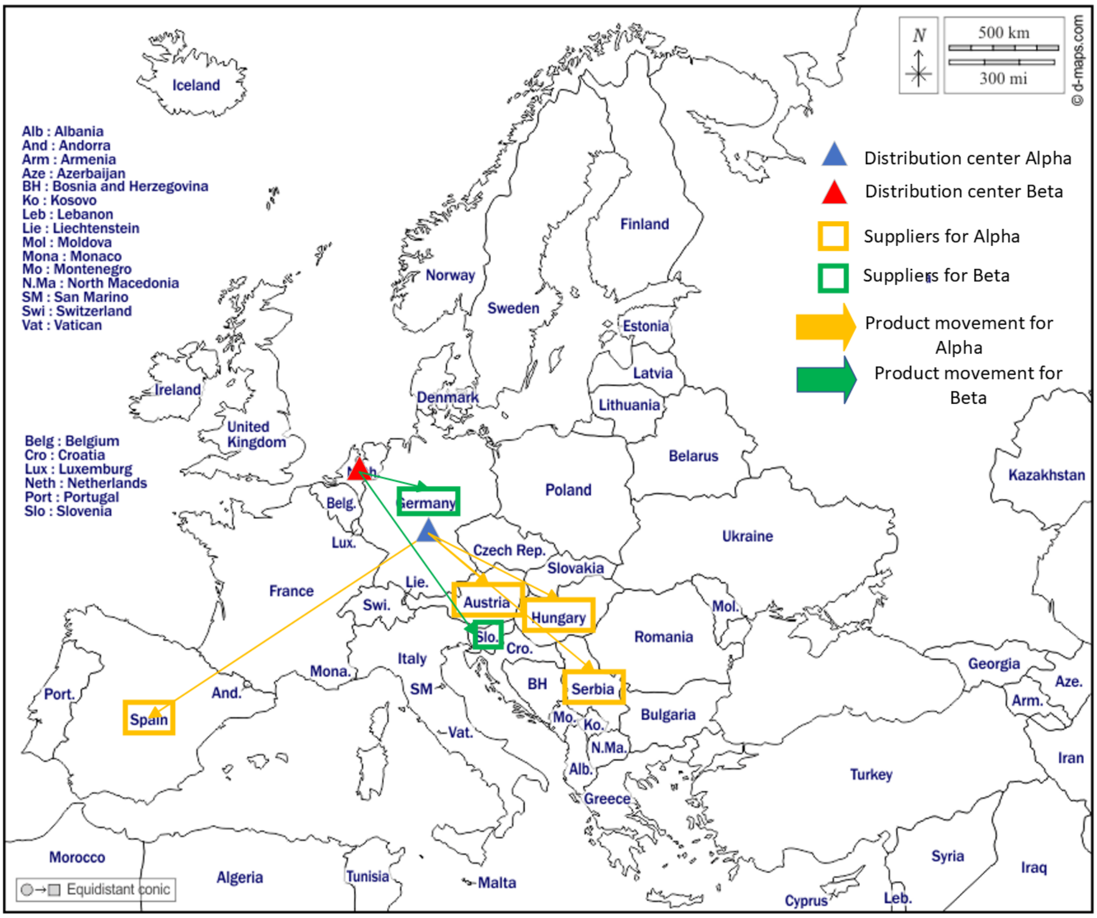

Figure 6.2: Location of suppliers and the supply chain chart

6.2.2.3Geographical analysis of the customer's warehouse

The customers for these two companies are predominantly located in Benelux (187 customers). Products are sent directly from distribution center to the customers' warehouses. In general, the distribution of customer warehouses is as follows:

76 in Belgium, 99 in the Netherlands, 5 in Luxembourg, and 7 in Germany.

6.2.3Desired operation of the new distribution center

In order to find a new distribution center location, the desired outcome for the merging company is to achieve cost minimization, adaptability to market changes, and improvement in supply chain efficiency.

The ideal internal operation of the new distribution center is depicted in Figure 6.3 below. In this operation, inputs are single product pallets from different manufacturing factories, and the outputs are combinations of mixed product pallets delivered to customers. The combination of output depends on customer orders.

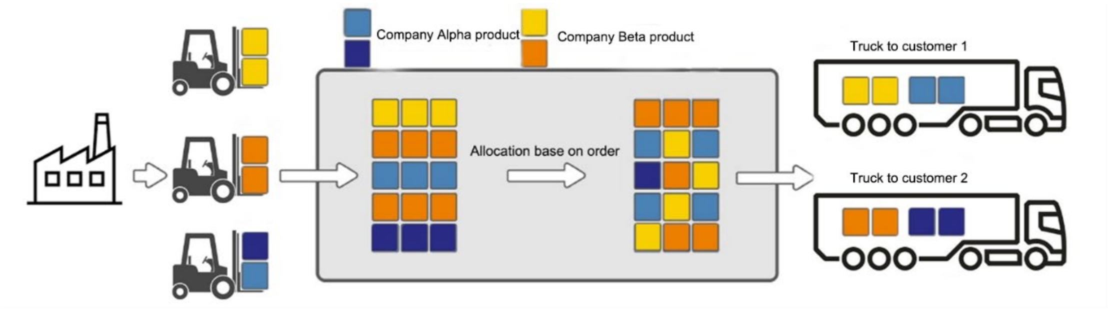

Figure 6.3: Desired internal operation for the new distribution center

6.2.4Scope of the case study research

This thesis project employs a case study of merging Company Alpha and Beta to evaluate the efficacy of the 5 step of phased method. This approach is used with the aim of finding an appropriate location for the new distribution center.

The locations of the current two distribution centers for both companies are known. These centers are responsible for receiving products from manufacturers worldwide, predominantly from the eastern and southern parts of Europe. All products from upstream manufacturers are sent to these distribution centers, where many functions inside the warehouse take place. Products are then dispatched to customers based on order requirements, with shipments typically organized on a pallet basis.

Employee preferences at the current two distribution centers will be factored into the evaluation of the new distribution center location. In addition, many other considerations such as public transport infrastructure, population density, accessibility, attractiveness, and government or provincial policies will be considered.

However, in the process of utilizing the 5 step of phased method, it should be noted that although for the merging company it has other customers in Europe with local distribution centers, these will not be included in the scope of this study. The focus will be solely on customers in the BNL area and Germany.

6.3Application of the 5 step of phased method

The 5 step of phased method used in this case study can be referred to chapter 5, Figure 5.1. By determining evaluation factors, generated alternatives from morphological chart and calculate performance score by MCA, an appropriate distribution center location can be found for this case study.

6.3.1Step 1: Evaluation factor analysis

The evaluation factors used in this section are referred to previous chapter 4, Table 4.1. Totally 7 main factors and 15 sub-factors are chosen as evaluation factors. The explanation of each sub-factors which can be used for ranking alternatives can be found in Table 6.1.

The motivation of choosing these 7 main factors is considered the objective of the merging company, which is minimize cost, be adaptable to market change and improve the supply chain efficiency. This step is referred to previous chapter 5, step 1 in Figure 5.1.

In order to satisfy the objective of minimizing total cost, the evaluation factors include logistics cost factors and business environment factors. In order to satisfy the objective of being adaptable to market change, the evaluation factors include proximity and flow related factors, accessibility and infrastructure. In order to improve the supply chain efficiency, the evaluation factors include proximity and flow related factors and logistics cost factors. For the natural environmental factor, it is derived from the company's need for environmentally friendly.

Table 6.1: Evaluation factors in this case study

Categorize	Main factors	Sub-factors	Factors description
Supply chain management & Transportation	Proximity and flow related factors	Distance to customers/consumers	Distance from distribution center to customers of the company or the target consumer markets.
		Distance to suppliers/producers	Distance from distribution center to suppliers of the company or producers owned by company.
	Logistics cost factors	Transport cost	Transport distance, mode and means between distribution center to customers and suppliers
		Warehousing cost	Handling cost, storage cost and labor cost
	Service level	Delivery responsiveness	Responsiveness after placing an order
Geography	Accessibility	Motorway network accessibility	Distance between distribution center to the nearest highway
	Infrastructure	Available transport infrastructure	Various facilities used to support the transportation of products and people
		Congestion	Traffic congestion between distribution center to customers
	Business environment factors	Land cost	Distribution center land price per square meter
		Taxes	Corporate income tax or value added tax in the target area
		Labor cost	Local average labor cost
		Labor market availability	The quantity and quality of labor in the target area

		Zoning policies	Government planning and management of land use and development in the target area
	Natural environmental factors	Proximity to neighbors	Distance to residential areas
		Climate factor	Local humidity, temperature, wind, salt and rainfall

The hierarchy structure can be found in Figure 6.4 which combined all the main factor and sub-factors.

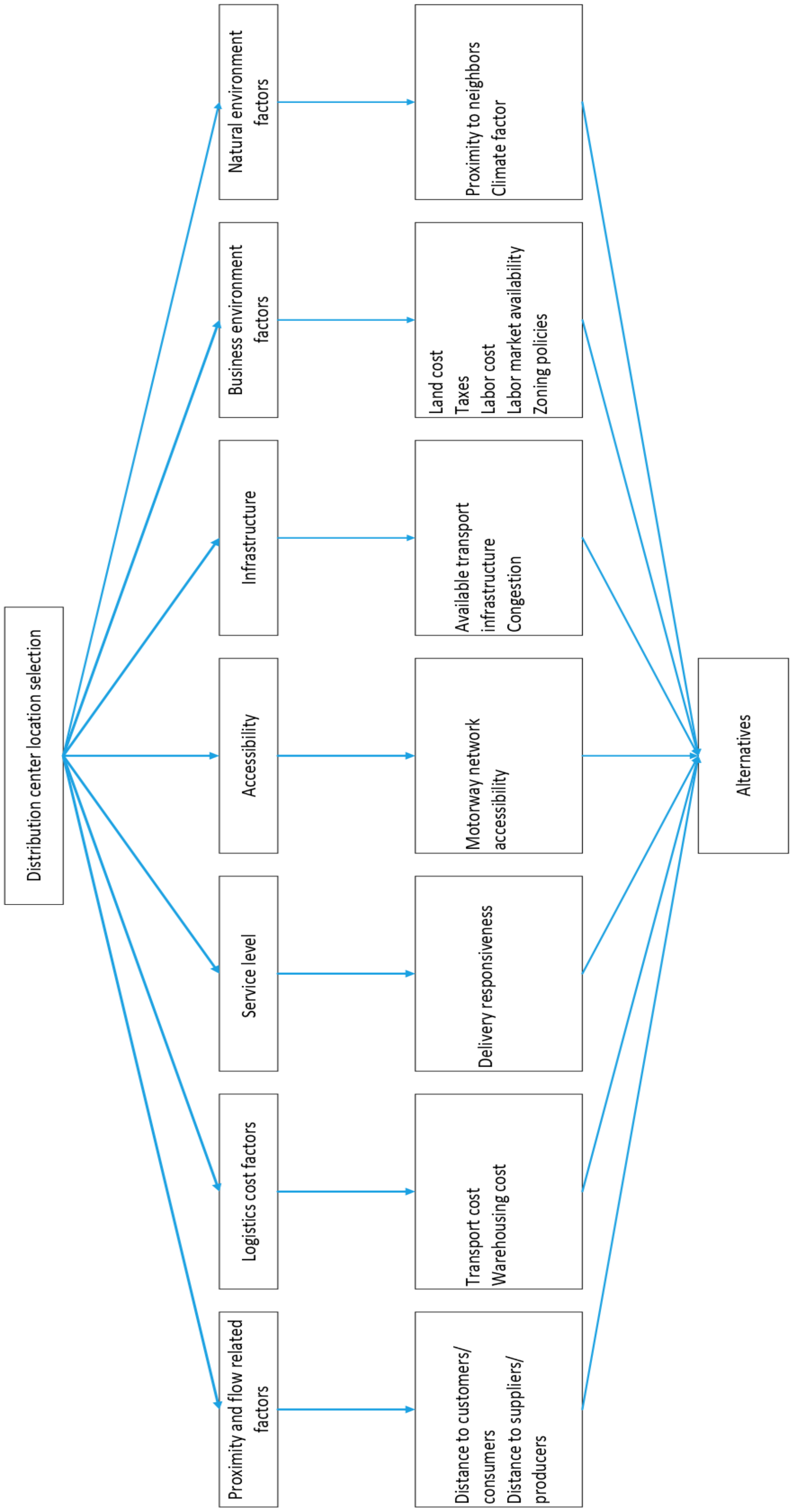

Figure 6.4: Distribution center location selection hierarchy

6.3.2Step 2: Constraints

Constraints are the mandatory requirements that this design must follow:

1. This distribution center must meet the local legislation.
2. This distribution center location must apply with the safety health and environment rules in the company.
3. This distribution center location must consider the natural disaster risk.
4. This distribution center must have good access to the nearest highway.
5. This distribution center must have hazardous material division to storage special products.

Here constraints are based on determining factors which may limit the available options for distribution center location. They are qualification factors that restrict the available options for distribution center location. These constraints are referred to chapter 4, Table 4.2. There are 8 general constraints such as budget, legislation, infrastructure and environmental, which will limit the scope of the available choice set. The motivation of choosing theses 5 constraints from Table 4.2 can be found below:

Constraint 1 and 2 are from zoning policy constraint and climate factor constraint in Table 4.2, which demonstrate this new location must meet local and company rules. They focus on the problem might happen in the constructing process of this new distribution center. They are obvious and general constrains since land use regulation, building standards, environmental permits and fire safety permits are rules that a new distribution center must follow during construction. C1 and C2 are helpful to avoid legal risks, fines and even project failure due to violations of laws and regulations.

Constraint 3 is from geographical factor constraint in Table 4.2, which focus on risk identification and prevention in the location determining process. The choices include building distribution centers in areas of low flood risk or using structural reinforcement to improve the seismic resistance of buildings if the distribution center site is located on a seismic zone.

Constraint 4 is from transport network accessibility constraint in Table 4.2, which can facilitate truck transportation to reduce cost. Constraint 5 is from product vulnerability constraint in Table 4.2, which requires special storage facility for flammable and explosive products. These two constraints are also complied with the decision maker's preference.

6.3.3Step 3: Requirements

6.3.3.1Functional requirements

These functional requirements refer to things that this design need to do.

1. This distribution center must be able to store products.
2. This distribution center must be able to receive and dispatch products.
3. This distribution center must include loading docks which can be used by trucks.
4. The distribution center must have handling equipment and machinery to move goods and materials in and out of the distribution center.
5. The distribution center must have inventory management systems and information system to ensure accurate tracking and timely fulfillment of orders.

These 5 functional requirements are referred to chapter 4, Table 4.3, which contains following 5 typical elements:

- Storage: Functional requirement 1
- Receiving: Functional requirement 2
- Shipment: Functional requirement 3
- Placement: Functional requirement 4
- Product input and output: Functional requirement 5

However, from Table 4.3, there are also other elements such as replenishment, value adding operation are not included in functional requirements which are not relevant processes in this case study.

6.3.3.2Non-functional requirements

The non-functional requirements refer to the characteristics that this design must have.

1. The special storage area of this distribution center must be of high quality.
2. The process of receiving and dispatching products must be fast and synchronisable.
3. The loading dock must be designed to support multiple trucks for simultaneous operation without interfering with each other.
4. The distribution center handling equipment must be automated.
5. The distribution center inventory management and forecast analysis system must be updated.
6. The distribution center should be well-connected to public transport, allowing employees to easily commute to work using buses or other forms of public transportation.
7. This distribution center must be near to all its customers.

There are 7 non-functional requirements in total, the first 5 non-functional requirements are referred to chapter 4, Table 4.4 to describe the relation with functional requirements:

- NF1 – FC1 The attribute about storage function
- NF2 – FC2 The attribute about receive and dispatch function
- NF3 – FC3 The attribute about shipment function
- NF4 – FC4 The attribute about placement function
- NF5 – FC5 The attribute about input and output function

For the rest three non-functional requirements they are referred to chapter 4, Table 4.5 which are some other attributes that a distribution center must have in this case study.

6.3.4Step 4: Morphological chart for alternatives generation

According to the functional and non-functional requirements mentioned before, the morphological chart for this case study is referred to chapter 4, Figure 4.2 and can be found in Figure 6.5 below:

	Functions/Attributes	Means			
Functional requirements	Receive	Hand Pallet Truck	Electric Pallet Truck	Forklift	
	Placement	Forklift	Automated Guided Vehicle	Conveyor Belt	
	Storage	Multi-tier Racking	Pallet Racking	Flow Racking	Cantilever Racking
	Shipment	Truck	Railway	Air	Marine
	Information management system	Enterprise resource planning system	Warehouse management system	Customer relationship management system	Cloud computing and Internet of things technology
Non-functional requirements	Accessibility	Facilitate road transport	Facilitate maritime transport	Easy to reach for employees	Available parking facilities
	Proximity to customers	Locate in high customer density areas	Close to key customer bases	Close to major markets and commercial zones	
Other aspects	Site foundation	Expand current distribution center	Find new location in the neighbor city	Find new location in a new city	
	Distribution center operation strategy	Locate the distribution center in empty land or industrial estates	Outsource to logistics companies	Share distribution center with other companies	

Figure 6.5: Morphological chart for new distribution center solution

6.3.4.1Best and possible combinations

In the morphological chart shown in Figure 6.5, the total number of combinations is 82944. However, by classifying the means to best means and possible means, the number of combinations can be limited to an acceptable number. Since only best means will be used to generate alternatives. After classification, all the combinations can be found in Figure 6.6. In this chart best means are shown in green color and possible means are shown in yellow color.

	Functions/Attributes	Means			
Functional requirements	Receive	Hand Pallet Truck	Electric Pallet Truck	Forklift	
	Placement	Forklift	Automated Guided Vehicle	Conveyor Belt	
	Storage	Multi-tier Racking	Pallet Racking	Flow Racking	Cantilever Racking
	Shipment	Truck	Railway	Air	Marine
	Information management system	Enterprise resource planning system	Warehouse management system	Customer relationship management system	Cloud computing and Internet of things technology
Non-functional requirements	Accessibility	Facilitate road transport	Facilitate maritime transport	Easy to reach for employees	Available parking facilities
	Proximity to customers	Locate in high customer density areas	Close to key customer bases	Close to major markets and commercial zones	
Other aspects	Site foundation	Expand current distribution center	Find new location in the neighbor city	Find new location in a new city	
	Distribution center operation strategy	Locate the distribution center in empty land or industrial estates	Outsource to logistics companies	Share distribution center with other companies	

Figure 6.6: Morphological chart for best and possible combinations

6.3.4.2Motivation of classifying different means

1. Receive

Electric pallet truck is the best mean here because it can provide higher efficiency than hand pallet trucks while being more economical and better suited for smaller and lighter loads than forklift.

2. Placement

Consider cost as a key factor, forklift is the best mean compare with others, although it requires more manual handling.

3. Storage

The choice of storage depends on the shape and size of the products and the amount of storage. Considering that the products in the company after merging are usually in smaller packages, using pallet racking may be the most efficient option since it provides a lot of storage space and is easy to access. Moreover, this is the storage pattern in the current distribution center. Employees are more familiar with this storage pattern.

4. Shipment

Truck is the only best mean under function shipment since for these two company trucks account for 100% of transportation in Europe.

5. Information management system

In this case study the merging company requires sophisticated inventory management system thus warehouse management system is the best mean.

6. Accessibility

In this function, 'facilitate rode transport' is selected as a best mean instead of 'facilitate maritime transport' is because the merging company has a huge percentage in utilizing truck transportation in Europe.

7. Proximity to customers

The interview result demonstrated that it is important to keep the new distribution center location in the area closest to major customers. This is a non-functional requirement, and it is selected as a best mean.

8. Site foundation

This aspect was also determined through interviews. All three means are considered as best mean. For the first and second one it could minimize employee relocation. This means they would not need to move to a completely new city and adjust to a new environment, which would likely increase employee satisfaction. The third mean, establishing a distribution center in a completely new city, has the potential to tap into a new market area and increase brand awareness.

9. Distribution center operation strategy

The first two are best means because firstly, locate in empty land allows company to build a new logistics center according to company needs. And outsource to professional logistics companies can help the company focus on the main business. Share distribution center with other companies is a possible mean which can save costs and increase efficiency.

6.3.4.3Final alternatives list by selecting best means

This final list only includes the best means selected from the morphological chart in Figure 6.6. For each functional and non-functional requirement, there is only a single best mean to be chosen. These best means include:

- Using electric pallet truck to receive products.
- Using forklift to move products inside the distribution center.
- Using pallet racking to storage products.
- Using trucks for transportation.
- Implementing warehouse management system to track and monitor products movement.
- The chosen location should be facilitated to road transport (near to highway).
- The chosen location should be closed to key customers.

But for other aspects in the morphological chart, there are 3 best means in site foundation and 2 best means in distribution center site selection strategy. Thus, the total number of alternatives is calculated by 2*3 = 6. In conclusion, after selecting best means in the morphological chart, the number is reduced to 6 combinations:

1(a). Expand current distribution center for Company Alpha.

1(b). Expand current distribution center for Company Beta.

2. Find new location in the neighbor cities and build it in empty land or industrial estates.

3. Outsource to logistics company in the neighbor cities.

4. Find new location in a new city and build it in empty land or industrial estates.

5. Outsource to logistics company in a new city.

6.3.4.4Specification of final alternatives

Alternative 1, 2, 3 are based on existing distribution center location or searching other possibilities in its neighbor cities. This method has many advantages such as keeping local work force, so employees do not need to move to another new area. Alternative 4 and 5 are based on choosing a new region where can minimize the total travel distance to all the customer warehouses. The mathematical model built in chapter 4.6.3 will be used to find this new region. Here is the demonstration about each alternative:

- Alternative 1: Expand one of the current distribution centers.

Alternative 1(a) is to expand the current distribution center for Company Alpha so that the new one after expanding can be used for the merging company's product storage. In this alternative, Company Alpha has the ownership of this distribution center, and it is located in the western part of Germany, North Rhine-Westphalia. There are many industrial parks in this town and this distribution center is situated near to the highway. This prime geographical location makes it easier to reach major transportation routes in Germany and Europe. This distribution center is well equipped to handle a wide range of products and provide services such as packaging, labeling, and quality control. In terms of automation, this distribution center has many advanced automation technologies which can improve the operation and service level, such as automated storage, retrieval and sorting system.

Alternative 1(b) is to expand the current distribution center for Company Beta so that the new one after expanding can be also used for the merging company's product storage. In this alternative, the new integrated distribution center will be located in the southern part of the Netherlands, North Brabant. There are many industrial parks on the outskirt of this city, this distribution center is exactly one of them. The location of this alternative is near to highways with a few minutes' drive, which will highly improve the truck transport efficiency while transporting products to customers. It also has hazardous material division for products need special care. This hazardous material division is used for flammable liquids and gases. It can provide various logistics services instead of warehousing which includes distribution, packaging, labeling, and assembly. It has forklifts and conveyor systems for product transportation inside the distribution center.

- Alternative 2: Select empty land or industrial estates in neighbor cities

Alternative 2 and 3 aims to search alternatives in the neighbor cities. For Company Alpha there are 4 neighbor cities in the region of North Rhine-Westphalia. The distribution center for Company Beta located in province Noord-Brabant, which has 5 neighbor cities. Figure 6.7 and Figure 6.8 below describes the geographic area in blue to represent possible location for this new distribution center.

Figure 6.7: Map of Province North Rhine-Westphalias showing alternative distribution center locations.

Figure 6.8: Map of Province Noord-Brabant showing alternative distribution center locations.

Alternative 2 is in Duisburg, Germany. The accessibility of this alternative is pretty good since in Duisburg there is an intermodal terminal with many logistics hubs for road and water transport. In terms of road transport, it is adjacent to the A40 highway for 5 minutes driving which can connect to other major cities in the area, such as Essen and Dortmund. It is also near to the intersection of highway A59 and A3, which can directly connect to Düsseldorf. The distance to this intersection is about 4 kilometers which make it as a strategic location. The total area of this warehouse is over 40,000 square meters and can be used for pallet, bulk and shelf storage. Specific storage requirement is also included here for various customer demand. In terms of logistics services, it includes storage, handling and product distribution. Warehouse management system and automated conveyor system are applied in the warehouse to improve operation efficiency. The relative location of alternative 2 on map can be found in Figure 6.9.

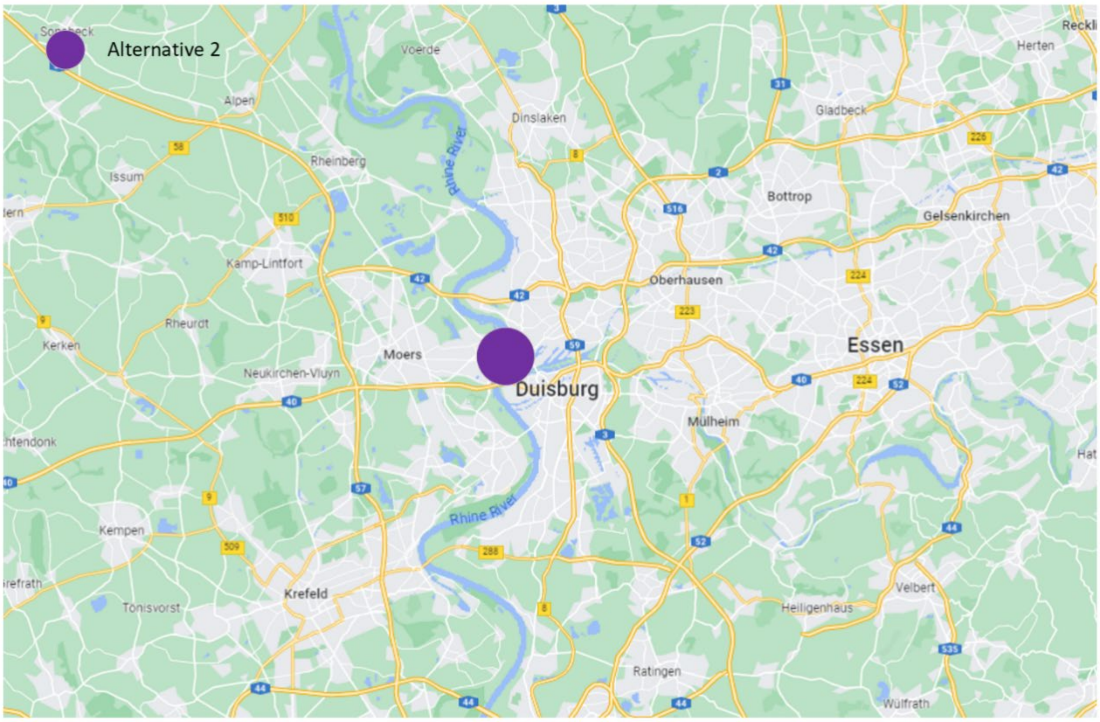

Figure 6.9: Location for distribution center in alternative 2

- Alternative 3: Outsource distribution center in neighbor cities.

In this alternative, the new integrated distribution center will be located in Heerewaarden, a town in the province of Gelderland in the Netherlands. As a leading logistics provider in this area, it can offer various logistics services, including distribution center, transport, and value-added services. For product loading, this distribution center has multiple discharge areas to ensure multiple invoice operation at the same time. Those service focused on promoting efficient operations and minimizing the possibility of damage or loss to stored goods. It also has automated order process system and clients could track its inventory in real-time through the distribution center management system. The important things here is that it could offer temperature-controlled storage solution, which could be useful for the merging company. This distribution center is certified to HACCP (Hazard Analysis and Critical Control Points) to make sure that this distribution center is running under strict quality standards. The capacity of this distribution center is more than 30,000 square meters with modern equipment. Besides that, electric forklifts and conveyor belts are utilized in this distribution center to ensure efficient product handling level is maintained. The relative location of alternative 3 compare with current distribution center on map can be found in Figure 6.10.

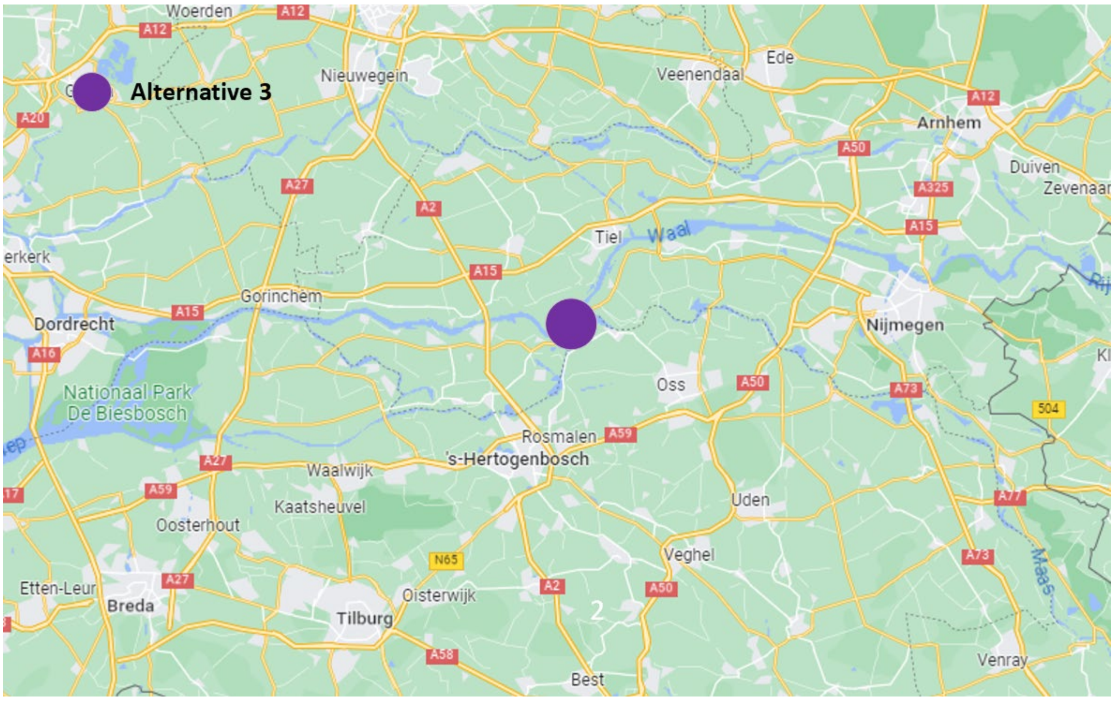

Figure 6.10: Location for distribution center in alternative 3

- Alternative 4 and 5: Select empty land or outsourcing company in a new city

In order to find a region (a new city) that can minimize the total distance to all the major customer's warehouse location, Weber's problem from chapter 4.6.3 is chosen for this case study. Here several attractive points located on a 2D-plane are given as input, which are the location of customers. The objective function is to find the position of a single facility such that the sum of the weighted distances of all points from the single facility is at its global minimum.

$$min \sum_{i \in I} w_i \sqrt{(x - x_i)^2 + (y - y_i)^2} + g(x, y)$$

$$g(x, y) = 0 \ \ if$$

$$x_{min} \leq x \leq x_{max}$$

$$y_{min} \leq y \leq y_{max}$$

$$g(x, y) = +\infty \text{ otherwise}$$

where I is the set of attractive (customers), w_i , $i \in I$ is the weight of the ith attractive point. x, y is the location of potential warehouse. x_{min} , x_{max}, y_{min} , y_{max} are the boundary of potential facility. This constraint was used to limit the scope of the distribution center to avoid the optimum solution located in some impossible area like ocean, thus making the search more efficient and realistic.

However, after running this model for this case study, it can be found that the optimum solution is located at the center of the area enclosed by the boundary restrictions x_{min} , x_{max} , y_{min} and y_{max}. This result raises the speculation that whether the boundary constraint has no impact to the result so that it can be deleted to simplify the model. Another speculation is that since the result of this model will be only used once in this project, whether this model has a lower dependency on time spent is worth exploring.

After deleting this boundary constraint and running model again, the result shows that it has the same optimum solution compare with the old model. And there is no difference in time consuming. Finally, it is improved to a non-constrained model which only has this objective function:

$$min \sum_{i \in I} w_i \sqrt{(x - x_i)^2 + (y - y_i)^2}$$

Where I is the set of attractive (customers), w_i , $i \in I$ is the weight of the ith attractive point. By solving this mathematical model, the optimum location which will reduce the total distance to all the customers can be found in this chapter.

For the merging company it has 187 customer warehouses in total, include 76 customers located in Belgium, 99 in the Netherlands, 5 in Luxemburg and 7 in Germany. However, there is only one best mean in the morphological chart under non-functional requirements, which is ‘close to key customer bases’. In the merging company there are 24 key customers which have the demand above 1000 000 of single products in 2022. Furthermore, the weight w_i for each customer that mentioned before will be determined by the demand quantity for each customer. Thus, the mathematical model can be applied in this situation to calculate the optimum solution on basis of these 24 key customer warehouses’ locations.

After the calculation, the optimum solution is located in city Werkendam, under Noord-Brabant province. The total weighted distance from this location to all the major customers is 5960 kilometers. This weighted distance utilizes Euclidean distance as a measurement. The actual distance travelled by truck is 2720 kilometers, the distance to the nearest customer is 22.1 kilometers away. The distance to the furthest customer is 328 kilometers away. On basis of this optimum solution, a circle can be drawn with the optimal solution as the center and 20 km as the radius. Therefore, inside this region, each distribution center company or empty land could be regarded as a possible solution for alternative 4 and 5. This limited region can be found in Figure 6.11 below and the red icon as center of this circle which is the optimum solution. It is also the location which has the minimum distance to all the customers.

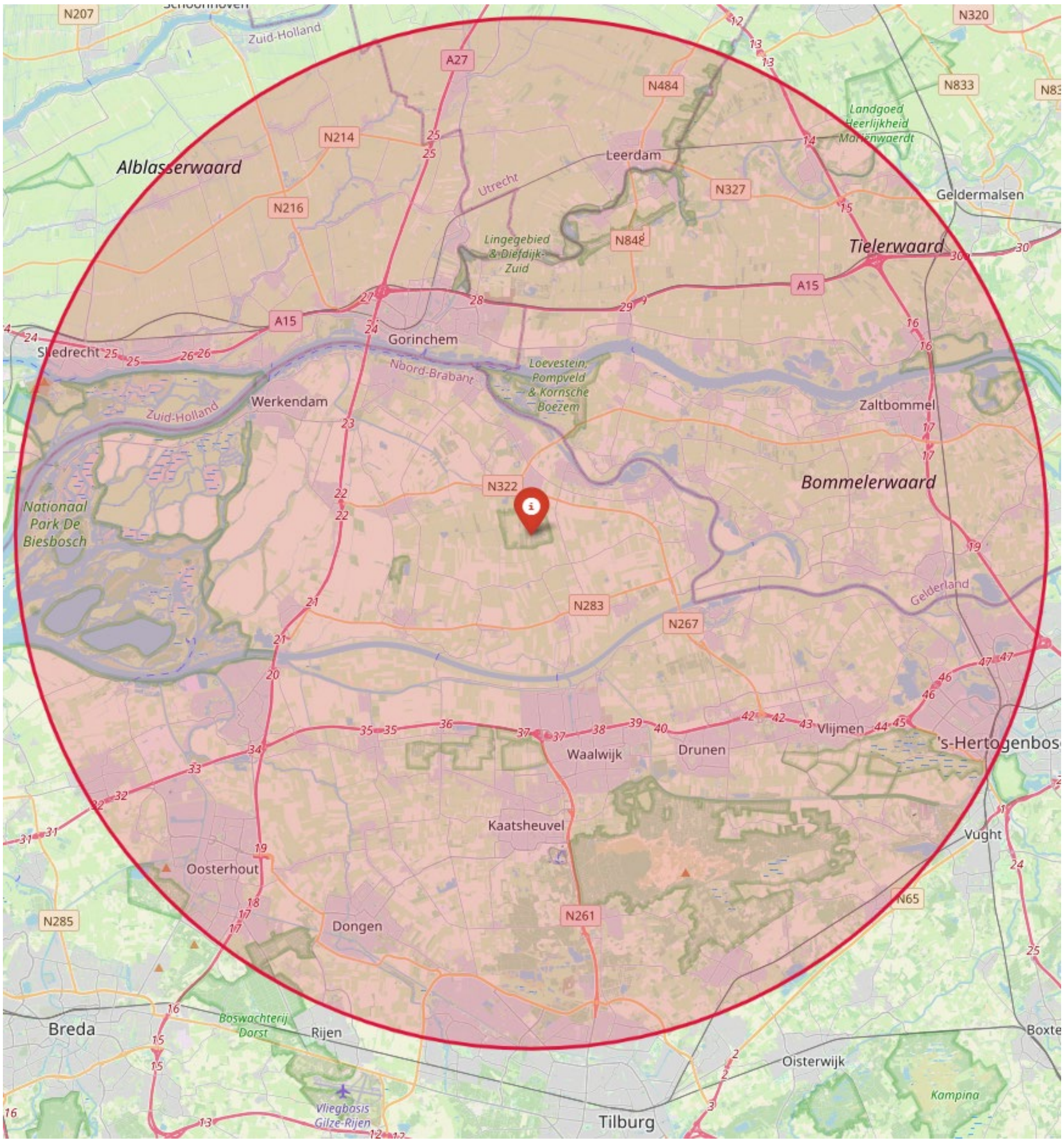

Figure 6.11: Optimum solution and limited region

Here a simple comparison can be made between this optimum solution and the current situation, which is the location of existing distribution center. After calculation we can find that compare with alternative 1(a), the actual distance travelled by truck is 5270 kilometers. Comparing with alternative 1(b), the actual distance travelled by truck is 2830 kilometers. Thus, this optimum solution could help company to save 2550 kilometers and 110 kilometers separately compare with alternative 1.

- Alternative 4: Find an empty land in a new city

This alternative located in the Sluisweg 36 in Waalwijk. In the local area there are many logistics and transportation companies which provide sophisticated infrastructure and labor market. This alternative has an excellent location for road and marine transport. It has connections to major highways including the A59 and A27. For A59 the distance is only 1 minute driving which highly increase the transport efficiency. Moreover, it is also near to local harbor which provide convenient access to inland waterways. The capacity of this warehouse is about 32,000 square meters. The service provide in this warehouse includes storage and order picking. It has warehouse management system and tracking system to improve the operation accuracy and efficiency.

- Alternative 5: Outsource to a logistics company in a new city.

This alternative located in the Edisonweg 44 in Gorinchem. As an existing industrial unit which is waiting for lease, this distribution center has enough industrial space. And could cover most requirements that a company will need such as easy accessibility and an extensive outdoor space. This industrial estate located near A15 highway with the distance of around 500 meters. This great position makes it easier to reach the port of Rotterdam and to other cities in Germany. It is also located in a business park which is surrounded by commercial and office buildings. There are 5 loading docks in this warehouse and can hold loading capacity of maximum 2,500 kilogram per square meters.

The relative location of alternative 4 and 5 can be found in Figure 6.12:

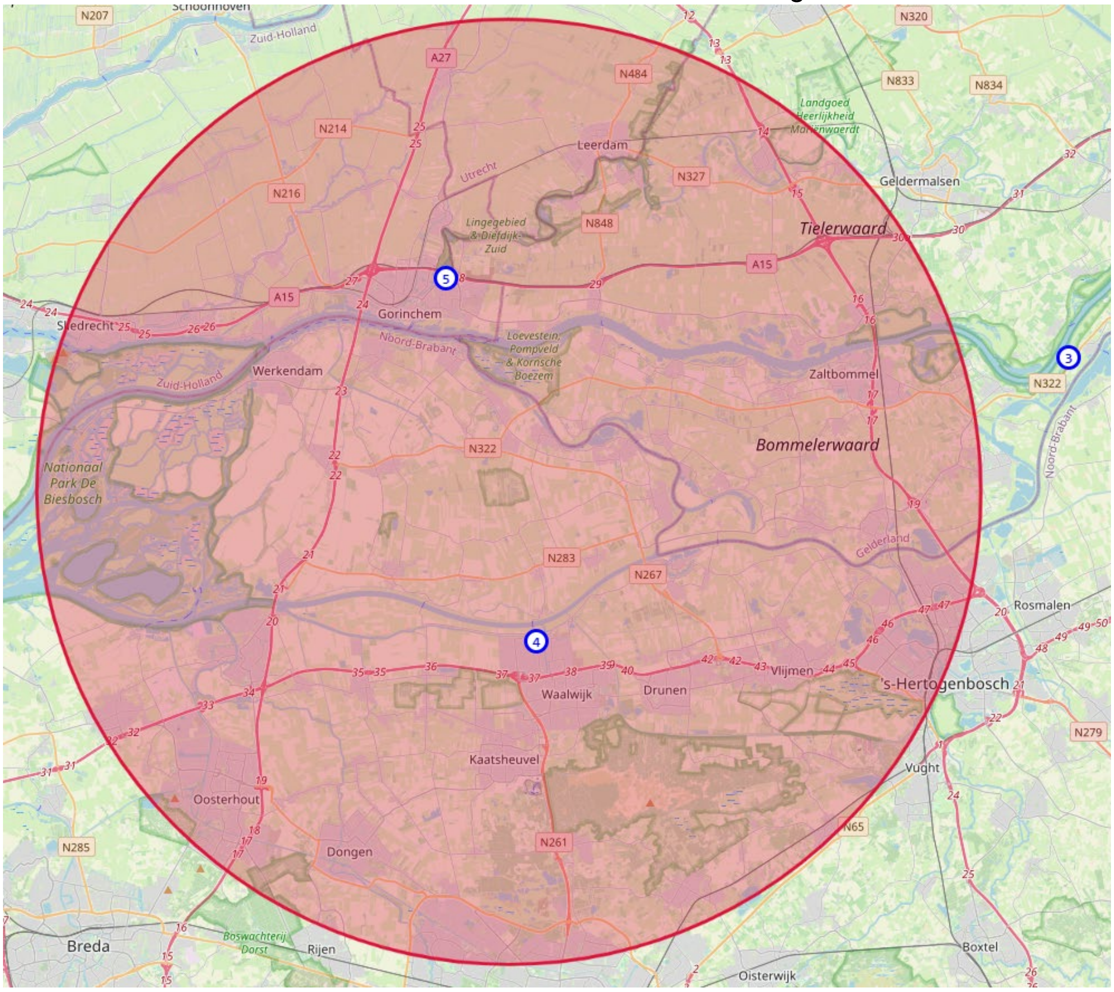

Figure 6.12: Alternative 4 and 5

- Blue icon 3: Outsourcing to a distribution center company in neighbor cities (alternative 3)
- Blue icon 4: Finding an empty land in a new city (alternative 4)
- Blue icon 5: Outsourcing to a distribution center company in a new city (alternative 5)

6.3.5Step 5: Distribution center site selection method

In this case study, the 5 step of phased method used in step 5 consists of four steps:

utilizing BWM to identify the weighting of factors, conducting quantitative analysis to calculate factor scores, applying min-max normalization to normalize factor score to the same range for comparison, and calculating the total performance by a linear-additive function. However, before using BWM to weight evaluation factors, a score card is prepared for all evaluation factors to select the top eight as input for the BWM. This is referred to chapter 5, Table 5.6. In this score card a higher score means higher importance.

After combining the results from two decision makers, eight factors with scores greater than 6 are chosen as the final evaluation factors for the BWM. The results from this score card can be found in Table 6.2 below:

Table 6.2: Score card result

Factors	Score
Distance to customers/consumers	9
Labor cost	7.5
Motorway network accessibility	7.5
Labor market availability	6.5
Proximity to neighbors	6.5
Land cost	6
Taxes	6
Transport cost	6
Distance to suppliers/producers	5
Warehousing cost	4.5
Available transport infrastructure	4.5
Congestion	4
Delivery responsiveness	4
Zoning policies	3.5
Climate factor	2

6.3.5.1Best-Worst Method

Chapter 2.5 and 4.6 introduced some examples of multi-criteria decision-making (MCDM) methods which can be used in the generic 5 step of phased method, such as Analytic Hierarchy Process (AHP), Choquet integral, Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Elimination and Choice Expressing Reality (ELECTRE), and Best Worst Method (BWM). In this case study BWM is used to select final alternatives list as a part of the last step. Ranking alternatives according to the different weights of the determining factors. BWM is a new MCDM method which could calculate the weight of criteria by comparing the best criteria (the most popular) and the worst criteria (the least noticed) to other criteria (Rezaei 2015). Compare with other MCDM methods, BWM has some obvious advantages such as it is simple, intuitive and easy to understand by decision makers. Moreover, BWM has many other advantages that make it stand out among numerous MCDM methods in the case study of this project. However, since BWM can also handle both factor weights evaluation and alternatives selection, which is similar to AHP. Thus, the following comparison is focus on the difference between BWM and AHP to demonstrate the priority of BWM and the reason why it is chosen in this project.

Firstly, BWM as a matrix-based method requires less comparisons compare to AHP. For example, the comparison for BWM is 2n−3 but n(n−1)/2 for AHP (Rezaei 2016). With a lower number of comparisons, the response rate will be raised significantly (Galesic and Bosnjak 2009). Secondly, subjective judgments from decision makers will cause errors (cognitive biases) compare with rational decision-making (Tversky and Kahneman 1974). Among many cognitive biases, anchoring bias is the most important and well-known one (Ünveren and Baycar 2019). Anchoring bias means that the decision makers will put more attention on the initial value. In BWM it has two evaluation factors, the first one compares the best factor and other factors. And the second one compares the worst factor and other factors. Having these two anchors makes BWM as an excellent candidate in debiasing anchoring bias (Rezaei, Arab et al. 2022). Thirdly, the comparison structure in BWM is more logic and robust compare with other MCDM methods. After determining the best and worst factors in BWM, they will be compared with other factors automatically. But during the comparison process in AHP, other factors which have a higher level of importance will be found which lead to repeat comparison. Fourthly, only integer numbers are used in BWM which makes it easier for decision makers to use. But for other MCDM methods such as AHP, both integers and fractional numbers are included (Rezaei 2016).

BWM has six steps to determine the factor weights which are explained in detail below (Rezaei 2015, Rezaei 2016):

- **Step 1**: Determine the set of decision factors $(c_1, c_2, \dots, c_n)$. These determining factors are identified on the basis of literature review.
- **Step 2**: Determine the best (the most important) and the worst (the least important) factors.
- **Step 3**: Execute pairwise comparison between the best factor to all the other factors, using a number from 1 and 9. The result in the best-to-others vector is:

  $$A_B = (a_{B1}, a_{B2}, \dots, a_{Bn})$$

  where a_{Bj} indicates the preference of the best factor B over factor J. And $a_{BB} = 1$.
- **Step 4**: Execute pairwise comparison between all the other factors to the worst factor, using a number from 1 and 9. The result in the others-to-worst vector is:

  $$A_w = (a_{1W}, a_{2W}, \dots, a_{Wn})^T$$

  where a_{jW} indicates the preference of the factor J over the worst factor W. And $a_{WW} = 1$.
- **Step 5**: Find the optimal weights $(\omega_1^*, \omega_2^*, \dots, \omega_n^*)$. It aims to determine the optimal weights of the factor, such that the maximum absolute differences $|\omega_B - a_{Bj}\omega_j|$ and $|\omega_j - a_{jW}\omega_W|$ for all J is minimized, which is translated to this model:

  $$minmax_j\{|\omega_B - a_{Bj}\omega_j|, |\omega_j - a_{jW}\omega_W|\}$$

  such that

$$\sum_j \omega_j = 1,$$

$$\omega_j \geq 0, for\ all\ j$$

This mathematical model is equal to:

$$min\xi$$

such that

$$|\omega_B - a_{Bj}\omega_j| \leq \xi, for\ all\ j$$
$$|\omega_j - a_{jW}\omega_W| \leq \xi, for\ all\ j$$

$$\sum_j \omega_j = 1,$$

$$\omega_j \geq 0, for\ all\ j$$

Solving this model can have results in the optimal weights $(\omega_1^*, \omega_2^*, \ldots, \omega_n^*)$ and ξ^*

- **Step 6**: The input-based consistency ratio is used to indicate the consistency level of a decision maker (Liang, Brunelli et al. 2020).

$$CR = max_j\ CR_j$$

where

$$CR_j = \begin{cases} \dfrac{|a_{Bj} * a_{jW} - a_{BW}|}{a_{BW} * a_{BW} - a_{BW}}, & a_{BW} > 1 \\ 0, & a_{BW} = 1 \end{cases}$$

CR is the global input-based consistency ratio for all factors which can be compared with the threshold values in Table 6.3(Liang, Brunelli et al. 2020):

Table 6.3: Threshold for input-based consistency measurement

	Factors						
Scales	3	4	5	6	7	8	9
3	0.1667	0.1667	0.1667	0.1667	0.1667	0.1667	0.1667
4	0.1121	0.1529	0.1898	0.2206	0.2527	0.2577	0.2683
5	0.1354	0.1994	0.2306	0.2546	0.2716	0.2844	0.2960
6	0.1330	0.1990	0.2643	0.3044	0.3144	0.3221	0.3262
7	0.1294	0.2457	0.2819	0.3029	0.3144	0.3251	0.3403
8	0.1309	0.2521	0.2958	0.3154	0.3408	0.3620	0.3657
9	0.1359	0.2681	0.3062	0.3337	0.3517	0.3620	0.3662

This project uses a BWM-solver in Excel which can directly calculate this model on basis of decision maker's preference. The consistency ratio in Table 6.3 is used to measure the reliability of the result. The result is acceptable if this ratio is lower or equal to the corresponding threshold. Otherwise, the decision-maker should repeat the pairwise comparison until an acceptable ratio is reached.

6.3.5.2BWM application

In the interviews, decision maker first determined best and worst factor, and then finished the pairwise comparison. Based on these comparisons, weights were calculated for each factor via excel file. Table 6.4 shows the final BWM result for each factor.

Table 6.4 shows that for both decision makers, the best factor is Distance to customers. But the worst factor is Land cost for decision maker1 and Taxes for decision maker2. After combining the average weight for both decision makers, Distance to customers (0,3071) is the most important factor while choosing a new distribution center. And the least important factor is Taxes (0.0331). The best and worst factor for each decision maker and other details in this BWM can be found in the Appendix B: BWM

Table 6.4: BWM results factor comparison

Evaluation factors	Decision maker1	Decision maker2	Decision maker3	Average weight
Distance to customers	0.3009	0.3209	0.2995	0.3071
Transport cost	0.1759	0.1302	0.0878	0.1313
Motorway accessibility	0.1759	0.0977	0.1170	0.1302
Labor cost	0.0704	0.1953	0.0585	0.1081
Proximity to neighbors	0.1173	0.0651	0.1756	0.1193
Labor market availability	0.0879	0.0651	0.1756	0.1095
Land cost	0.0278	0.0977	0.0585	0.0613
Taxes	0.0440	0.0279	0.0275	0.0331

A consistency check is used to evaluate the result of these three decision makers. The input-based consistency ratio, for these three comparisons are 0.153, 0.208 and 0.208 separately, which evaluates the reliability of the weights. Based on number of factors which is 8 in this BWM, the corresponding threshold value is 0.3620 by checking Table 6.3. Thus, can conclude that results from these decision makers have an acceptable level of consistency. The input-based consistency ratio can be found in Appendix B: BWM

6.3.5.3Quantitative analysis

The following factors can be evaluated by quantitative analysis, specific figures and statistics can be found to support these factors.

- Distance to customers

In this case study this evaluation factor is quantified in terms of actual distance. The distance matrix API in google maps platform is used to calculate the distance from each alternative to all the key customers. The calculations can be found in Table 6.5 below:

Table 6.5: Distance to customers

Alternatives	Alternative 1(a)	Alternative 1(b)	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Distance to customers	5270 km	2830 km	5302 km	2916 km	2718 km	2698 km

- Transport cost

In this case study this evaluation factor is quantified by total travel time to customers times average truck drivers' cost per hour and average gas cost per hour. The distance matrix API in google maps platform is used to calculate the real travel time from each alternative to all the key customers. The gasoline consume of heavy-duty truck is about 0.8 gallon per hour (Profits 2010). In 2023, the gasoline price in the Netherlands and

Germany is 6.8 EUR/gallon and 6.7 EUR/gallon separately (globalpetrolprices 2023). And the average truck driver's salary is 23 EUR/hour and 22 EUR/hour separately (erieri 2023). By multiplying these factors together, the result of transport cost can be found in Table 6.6 below:

Table 6.6: Transport cost

Alternatives	Alternative 1(a)	Alternative 1(b)	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Transport time	57.62h	32.35h	57.65h	34.07h	32.33h	31.32h
Transport cost	1576Euros	920Euros	1577Euros	969Euros	919Euros	891Euros

- Labor cost

In this case study this evaluation factor is quantified by hourly labor cost in EU in 2022. Hourly labor cost includes the employee's hourly rate and other costs such as social security costs, health insurance etc. It represents the total cost commit by the employer for each hour of work performed by an employee (Eurostat 2022). We can find from Table 6.7 that the hourly labor cost in the Netherlands is 40.5 euros and 39.5 euros in Germany. The labor cost of all EU countries can be found in Appendix C: Quantitative and qualitative analysis.

Table 6.7: Labor cost

Alternatives	Alternative 1(a)	Alternative 1(b)	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Hourly labor costs (EUR)	39. 5Euros	40.5 Euros	39. 5Euros	40.5 Euros	40.5 Euros	40.5 Euros

- Labor market availability

In this case study this evaluation factor is quantified by employment rate from age 20 to 64 in 2022. From one perspective, employment rate connects to economy situation and work environment, a higher employment rate is beneficial for attracting and retaining employees. In addition, employment rate demonstrates the workforce quality. Higher employment rete means more people are participating in the labor market. The employment rate in the Netherlands and Germany can be found in Table 6.8 (Destatis 2022). The employment rate of all EU countries can be found in Appendix C: Quantitative and qualitative analysis.

Table 6.8: Labor market availability

Alternatives	Alternative 1(a)	Alternative 1(b)	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Employment rate	80.7%	82.9%	80.7%	82.9%	82.9%	82.9%

- Taxes

In this case study this evaluation factor is quantified by corporate income tax in 2023. Profit exceeding EUR 200.000 is taxed at 25,8% and 29.8% corporate income tax in the Netherlands and Germany which can be found in Table 6.9 (OECD 2023). The corporate income tax for European OECD countries can be found in Appendix C: Quantitative and qualitative analysis.

Table 6.9: Taxes

Alternatives	Alternative 1(a)	Alternative 1(b)	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Corporate income tax	29.8%	25,8%	29.8%	25,8%	25,8%	25,8%

6.3.5.4Qualitative analysis

Qualitative analysis is used to set a scale for these factors in different levels or intervals. For some of these factors, the actual figures are hard to get. For others the different between each alternative are so small that can be neglect. Thus, use qualitative analysis to set different level is chosen for these factors.

- Motorway network accessibility

In this case study this evaluation factor is qualified by distance to the nearest highway. The scale is divided into 6 levels from extremely convenient (less than 0.5km) to very inconvenient (more than 4km). The result can be found in Table 6.10 and the detail of this scale can be found in Appendix C: Quantitative and qualitative analysis.

Table 6.10: Motorway network accessibility

Alternatives	Alternative 1(a)	Alternative 1(b)	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Nearest highway			A40	N322	A59	A15
Distance to highway	Quite inconvenient	Extremely convenient	Slightly inconvenient	Extremely convenient	Slightly inconvenient	Very convenient

- Proximity to neighbors

In this case study this evaluation factor is qualified by distance to the nearest residential area. The scale is divided into 6 levels from very far to extremely close. The result can be found in Table 6.11 and the detail of this scale can be found in Appendix C: Quantitative and qualitative analysis.

Table 6.11: Proximity to neighbors

Alternatives	Alternative 1(a)	Alternative 1(b)	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Distance to residential area	Very close	Not close	Extremely close	Moderately close	Slightly close	Extremely close

- Land cost

In this case study this evaluation factor is qualified by land area. The scale is divided into 6 levels from small (<10000sqm) to extremely large (>50000sqm). The result can be found in Table 6.12 and the detail of this scale can be found in Appendix C: Quantitative and qualitative analysis.

Table 6.12: Land cost

Alternatives	Alternative 1(a)	Alternative 1(b)	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Land area	Extremely large	Extremely large	Very large	Slightly large	Moderately large	Not large

6.3.5.5Performance score calculation

To evaluate the performance of each alternative on basis of quantitative analysis in each factor, min-max normalization is used to standardize different ranges of data in terms of metrics, allowing them to be ranked (Morholmen 2021). Here alternatives are ranked from 0 to 1, 0 means the worst performance and 1 represents the best performance. By using min-max normalization, each quantified factor can be normalized from 0-1 for total performance calculation. The formula of min-max normalization can be found below (Al Shalabi, Shaaban et al. 2006):

$$X\_normalized = (X - X\_min) / (X\_max - X\_min)$$

In this formula, X is the original value, X_min is the value has worst performance, and X_max is the value has best performance. This normalization method assumes that the worst performance value corresponds to a score of 0 and the best performance value corresponds to a score of 1.

For the factors in chapter 6.3.5.3 which are quantified, this min-max normalization can be used for most of them to obtain the score. For other factors in chapter 6.3.5.4 which are qualified, result is divided into several intervals to give final score. Linear-additive function is used to calculate the final score. Table 6.13 shows the results of the MCA.

Based on the results, it can be seen that alternative 1(b) has the highest score (0.7797). Alternative 3 has the second highest score (0.7493). Alternative 1(a) has the lowest score (0.1760). Meaning that alternative 1(b) is the most appropriate location for this case.

Table 6.13: Multi-criteria analysis of alternatives

	Distance to customers	Transport cost	Motorway network accessibility	Labor cost	Proximity to neighbors	Labor market availability	Land cost	Taxes	Total
Weights	0.3071	0.1313	0.1302	0.1081	0.1193	0.1095	0.0613	0.0331	
Alternative 1(a)	0.0123	0.0015	0.2000	0.2635	0.2000	0.7950	0.0000	0.1988	0.1760
Alternative 1(b)	0.9493	0.9577	1.0000	0.2400	0.8000	0.9050	0.0000	0.3538	0.7797
Alternative 2	0.0000	0.0000	0.4000	0.2635	0.0000	0.7950	0.2000	0.1988	0.1865
Alternative 3	0.9163	0.8863	1.0000	0.2400	0.4000	0.9050	0.6000	0.3538	0.7493
Alternative 4	0.9923	0.9592	0.4000	0.2400	0.6000	0.9050	0.4000	0.3538	0.7157
Alternative 5	1.0000	1.0000	0.0000	0.2400	0.0000	0.9050	0.8000	0.3538	0.6243

6.3.5.6Validation

From the final alternative ranking list, it is evident that alternatives 1(b), 3, 4, and 5 have performance scores exceeding 60%, with 1(b) having the highest score. These top-ranked alternatives share a common characteristic of being geographically close to each other. Alternative 1(b) is the current location, while the others are situated in nearby cities. This geographical proximity to key customers, which holds the highest weight in the evaluation, contributes significantly to their high scores.

Another important factor is the reduced transport cost to all customers, which is the second most important factor according to the BWM calculation. The favorable location of these four alternatives contributes to lower transport costs, further boosting their scores. Alternative 1(b) stands out with the highest scores in the "Motorway network accessibility" and "Proximity to neighbors" factors. This suggests that the location enjoys convenient access to highways, facilitating transportation, while being situated away from residential areas, minimizing disruptions to daily life.

Considering these aspects, it is reasonable to select alternative 1(b) as the most suitable distribution center location. Additionally, as an existing distribution center, alternative 1(b) offers several advantages, such as well-developed infrastructure and operational processes. Leveraging existing resources and facilities reduces the need for additional investments and construction time. The location also benefits from an established local brand reputation and customer relationships.

Considering all these reasons, alternative 1(b) emerges as the appropriate choice for the distribution center location in this case study.

6.4Conclusion

In the case study in chapter 6, the 5 step of phased method is applied for two companies to solve a specific logistics center site selection problem for a merging company. In this case study the 5 step of phased method includes the selection of factors, using a morphological chart to generate alternatives, applying BWM to provide weights for each factor, and finally using quantitative and qualitative analysis to rank alternative list. The goal of this chapter is to evaluate the feasibility and effectiveness of this 5 step of phased method.

This case study firstly identified the logistics operation status in two companies and their core business objectives and strategies. And then selected the important factors that were appropriate for the company needs. Using morphological chart, a series of alternatives that considered functional and non-functional requirements were generated. Then BWM was used to determine weights for each factor to reflect its relative importance. This provided an objective assessment framework to quantitatively evaluate each factor in the next step. Finally, a min-max normalization was used to score alternatives in each factor, and the final score was calculated by a linear-additive function. The result demonstrated that alternative 1(b) had the highest score which was an appropriate distribution center location.

Through the case study in this chapter, the feasibility and effectiveness of the 5 step of phased method in practical applications was validated. This approach provides decision makers with a systematic and structured method for selecting an appropriate distribution center location. By considering company's core business objectives and strategies, decision makers can evaluate alternatives more accurately and provide targeted decision support to the company.

The conclusion of this chapter includes the answer to sub question 8(a), 8(b) and 9(a), 9(b) which can be found below:

8) *How to determine an appropriate location from all the alternatives lists?*
    (a) *What are the evaluation factors used to calculate the weights by MCDM and how to get them?*

In this case study, the evaluation factors are obtained by considering company's desired operation of the new distribution center, which includes minimize cost, adapt market changes and improve supply chain efficiency. The total 15 evaluation factors used in this case study involves: distance to customers/consumers, distance to suppliers/producers, transport cost, warehousing cost, delivery responsiveness, motorway network accessibility, available transport infrastructure, congestion, land cost, taxes, labor cost, labor market availability, zoning policies, proximity to neighbors, climate factor.

(b) Which factor is objective / subjective and how to evaluate it to obtain the score for determining alternative performance?

Firstly, for those 15 evaluation factors, the most important eight factors are used as input to obtain score. For most of these factors they are quite objective which can be evaluated by quantitative analysis. These factors include distance to customers, transport cost, labor cost, labor market availability and taxes. Others are subjective and evaluated by qualitative analysis, which includes motorway network accessibility, proximity to neighbors and land cost. The actual figures are hard to get for these subjective factors.

In quantitative analysis, distance matrix API in google maps platform and some known data from website are used to quantify each factor. Moreover, min-max normalization is used to normalize each factor to scale 0-1 for better calculation and comparison. In qualitative analysis, different scale is given on basis of range 0-1. Alternatives are ranked by this scale in each subjective factor. The final alternative performance score is calculated by using linear-additive function.

9) What is the final alternative list after combining quantitative and qualitative score calculation?

(a) Which alternative has the best performance after the calculation?

Based on the results, alternative 1(b) has the highest score (0.7797). Alternative 3 has the second highest score (0.7493). Alternative 1(a) has the lowest score (0.1760). Alternative 1(b) has the best performance after the calculation.

(b) What are the advantages of this alternative that make it better than others?

There are mainly two advantages of this alternative. Firstly, the geographical of this alternative is proximity to key customers, which holds the highest weight in the evaluation. Secondly, this location could reduce transport cost to all customers, which is the second most important factor according to the BWM calculation. Moreover, alternative 1(b) stands out with the highest scores in the "Motorway network accessibility" and "Proximity to neighbors" factors. This suggests that the location enjoys convenient access to highways, facilitating transportation, while being situated away from residential areas, minimizing disruptions to daily life. Additionally, as an existing distribution center, alternative 1(b) offers several other advantages, such as well-developed infrastructure and operational processes. Leveraging existing resources and facilities reduces the need for additional investments and construction time. The location also benefits from an established local brand reputation and customer relationships.

7. Conclusion and recommendations

This chapter first answers the thesis project objective. Next, the limitations of this thesis and recommendations for further research will be given.

7.1Conclusion

The thesis project objective from chapter 1.2 is answered in this conclusion:

To design an approach for FMCG companies with different business strategic objectives to determine an appropriate distribution center site selection.

In order to achieve the project objective, a 5 step of phased method has been designed as a generic approach. For each step in this method, a company can select several options to satisfy its business objectives. The method can be applied in different ways and may yield different results. A diverse range of options offered by this method enhances its generality. The determining factors in the first step can be chosen to satisfy specific company needs, and multiple MCDM methods are available for selection in step five. In general, the application of this method comprises a series of selections from five steps. In each step, there are several options that decision-makers can choose to satisfy the specific needs of the distribution center.

The different steps in this method are interconnected. They can be divided into four parts, as shown in Figure 7.1 below. The overlapping sections highlighted in yellow demonstrate the relationship between these steps.

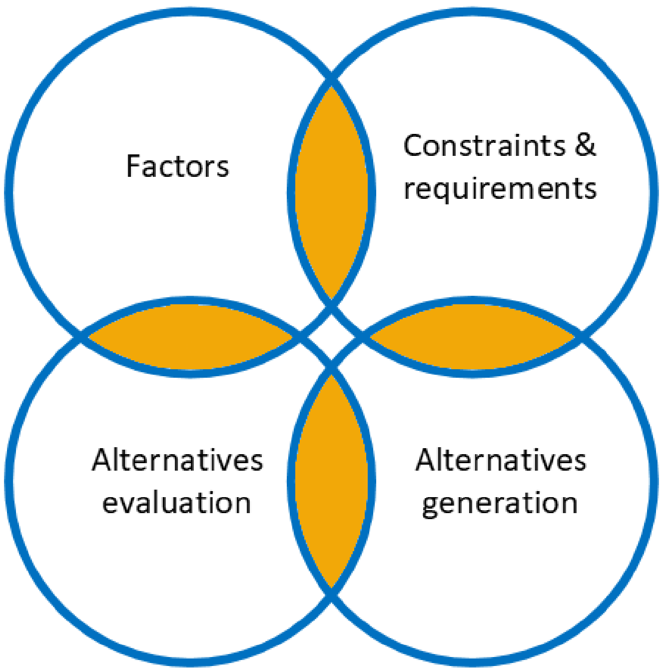

Figure 7.1: Relationship between different steps

- Factors – Constraints & Requirements
  In this method there are two classifications for factors, qualification factors and evaluation factors. The evaluation factors mentioned in the first step are the same compare with constraints in step 2.

- Constraints & Requirements – Alternatives generation
  The constraints and requirements in step 2 and 3 are the primarily input for step 4 alternatives generation. Since in the morphological chart, the functions and attributes are from requirements.
- Alternatives generation – Alternatives evaluation
  Alternatives are generated by morphological chart in step 4. And then the final alternatives list can be further evaluated in the final step.
- Alternatives evaluation – Factors
  There is still a relationship between step 5 and step 1. Because in the process of evaluating alternatives, MCDM is used to calculate evaluation factor weights. And these factors should be quantified or qualified for each alternative to calculate the final performance score.

However, there are certain advantages and disadvantages when comparing this five-step phased method with other methods for solving the distribution center location problem. Numerous papers utilize a hybrid method combining MCDM methods to determine optimal location selection. The advantage of the 5 step of phased method is that it also considers the process of generating alternatives. For many other methods, the list of possible distribution center locations is pre-determined, allowing these methods to be directly used to identify optimal solutions. This advantage of the 5 step of phased method offers a progressive solution for companies. Because finding potential distribution center locations is a prerequisite for a company that wants to determine an optimal one. Furthermore, the universality of the 5 step of phased method is another significant advantage. For instance, the evaluation factors, constraints, and requirements are generic, encompassing most factors and functions relevant to a distribution center. Regarding alternative evaluations, decision-makers can choose from various MCDM tools to address their issues. There is even a streamlined approach for cases constrained by time and requiring immediate decisions. In terms of disadvantages, the factors involved in this method have some limitations, as they cannot fully cover all company needs in reality. For the morphological chart, in real cases the possible means for each function are diverse. However, in this method, only four means are provided, which may limit the choice set. As for alternative evaluation, obtaining some data in real cases can be also challenging or time consuming. These disadvantages need to be addressed in future research.

Overall, this thesis project presents a resolution to the distribution center location problem through the implementation of a 5 step of phased method. This method provides a generic and structured decision-making instrument for decision makers, assisting in identifying an appropriate distribution center location relevant to various scenarios. It is envisaged that this method will contribute to scholarly research and practical applications within affiliated domains, while simultaneously providing decision-making assistance and strategic direction for companies grappling with distribution center location challenges.

7.2Recommendations for future research

In this section during the application of the 5 step of phased method in case study, some recommendations for further research could be made.

1. Number of factors and requirements:
   While the 5 step of phased method employed in this study determines a total of 25

factors, it may not fully encompass all the needs of a company in a real-world context. Future enhancements should consider incorporating additional factors to cater to the increasing demands of companies. Similarly, the same issue applies to requirements. In real scenarios, some companies may encounter specific requirements that are not addressed in this approach. Therefore, it is suggested to increase the number of requirements in the future.

2. Accuracy and availability of data:
   The effectiveness of this approach relies heavily on the calculation of performance score, such as factor weights calculation via MCDM and quantitative and qualitative analysis. In the case study the decision maker who are interviewed to determine factor weights are limited. With more people involved in this process will increase the accuracy of final result. Moreover, in the case study some data are difficult to obtain such as land cost. Thus, in this study it is replaced to land area which is not so accuracy for the final result.
3. Diversity of alternatives generation
   This thesis project uses morphological chart to generate alternative on basis of requirements and other aspects. However, in real life the possible means for each function has many diversities which can highly enrich the available combinations for alternative. Moreover, in case study the chosen alternative also has many options. For example, in a certain area there might be many warehouse companies or empty land which can be chose as a feasible alternative. But in this case study only two of them are considered.

8. Appendix

Appendix A: Scientific paper

The scientific paper can be found on the following pages.

Developing a phased approach for strategic distribution center location selection in FMCG Industries

Chen Hu[a], Jafar Rezaei, Marcel Ludema, Mark Duinkerken

[a]*Delft University of Technology, Transportation, Infrastructure & Logistics, The Netherlands*

Abstract

Fast-Moving Consumer Goods (FMCG) companies face the critical challenge of selecting appropriate locations for their distribution centers to maintain operational efficiency and customer satisfaction. This paper introduces a structured 5 step of phased method to address the distribution center site selection problem, considering various company-specific strategic objectives. The method incorporates determining factors identification, constraints selection, requirements outlining, alternatives generation and alternatives evaluation. A morphological chart is used in the alternative generation phase to create a range of potential locations alternatives. The Multi-Criteria Decision-Making (MCDM) method is applied for the systematic evaluation of the alternatives. The paper suggests that expanding the set of determining factors, incorporating a broader range of stakeholder inputs and further enriching the alternatives through diversified means could enhance the method's applicability and accuracy. This method offers FMCG companies a robust decision-making tool for strategic distribution center location selection, catering to individual business objectives and market dynamics.

Keywords: Distribution Center Site Selection, Multi-Criteria Decision-Making (MCDM), Strategic Decision-Making, FMCG

1. Introduction

Since the 1990s, more and more enterprises have been paying attention to cost control, and the control of logistics costs has the highest priority. In order to control and reduce logistics costs, many regional or national policy have been proposed to support the development of the logistics industry. It caused rapid development of the logistics and distribution industry with more and more diversified service models and improvement in infrastructure. The quality development of logistics is an important part of the quality development of the economy. It is also an important force in promoting high-quality economic development. With the rapid development of the logistics industry and the intensification of market competition, many logistics companies have emerged, but at the same time, more logistics companies are bankruptcy. The study found that inappropriate siting is one of the main factors for the bankruptcy of logistics companies [1]. Facility location problem is a decision problem which aims to determine the best facility location in a given area to obtain certain requirements and objectives. It is a process to reach balance between service demand and the cost for facility operation. Many factors such as geographical location, market demand, transport costs and environmental factors should be taken into consideration in the facility location problem. The facility location problem is a broad field of study that covers a wide range of different types of siting problems, such as retail store location problem, logistics distribution center site selection problem, service facility location problem, landfill location problem and telecommunication base station location problem [2].

Among all kinds of facility location problem mentioned before, the logistics distribution center site selection problem is a specific application of the facility location problem, which is concerned with the siting of a center for logistics distribution. This problem can be generalized as: How to choose the right location for a logistics distribution center? In order to solve this problem, the objective of this paper is to design an approach for FMCG companies with different business strategic objectives to determine an appropriate distribution center site selection. This objective combines factors in many aspects which involves optimal logistics and distribution solutions, service coverage, transportation, environmental factors, market demand and other factors. Finally it aims to reduce logistics costs, improve distribution efficiency and meet customer needs. Currently, distribution center has become a significant part of modern logistics. The issue of choosing the location of logistics and distribution centers is receiving increasing attention. Distribution center is a hub which could connect factories and customers. Finding an appropriate distribution center location could improve local logistics operation service and control distribution costs such as cost of labor, transportation and storage. Therefore, the selection of distribution center location significantly impacts the performance of the logistics system and contributes to the enhancement of the economic efficiency of logistics operations.

In order to address the logistics distribution center site selection problem, various methods can be employed, including both qualitative and quantitative approaches. The former largely depends on subjective judgments and historical experiences, while the latter is typically more accurate and can yield reliable results. However, many qualitative factors often get overlooked in real-world cases by simplifying the complexities involved [3]. Therefore, both qualitative and quantitative methods are combined to enhance distribution center location decisions. This paper introduces a systematic 5 step of phased method, and provides empirical applications to demonstrate its practical applicability and effectiveness in real-world scenarios.

2. Methodologies

This paper presents a 5 step of phased method on the generalized distribution center site selection problem. The foundation of this method is analyzing various determining factors affecting the location selection of distribution centers and employing a morphological chart to generate alternatives. Multi-criteria decision-making (MCDM) is utilized in conjunction with questionnaires directed towards decision makers to calculate the weights of evaluation factors. Ultimately, a blend of quantitative and qualitative analyses is used to rank alternatives, in order to identify an appropriate location for the distribution center. The specific study contains the following points:

1. Basic theoretical research: Study relevant literature and control certain theoretical methods. The literature review focus on finding distribution center site selection method, the main factors involved in distribution center site selection and tools for alternatives generation.
2. Approach design process: On the basis of theoretical research, this paper clarifies the factors, constraints and requirements that influence the location of the distribution center and the procedure for generating alternatives. Creating a 5 step of phased method to solve distribution center location problem.
3. Application of this approach: Summarize possible solutions for this generic approach. The shortcomings of this method is analyzed and discuss the next research direction.

The method used in writing this paper are literature review, interview and combination of qualitative and quantitative method.

1. Literature review: This paper is built upon a wealth of previous research in the field. During the research process, this paper collected and analyzed a variety of books and literature related to facility location problems, serving as the primary theoretical reference for this paper. Other literature studies include topics such as the morphological chart, MCDM method, and factors involved in facility location problems.
2. Combination of qualitative and quantitative method: This paper first analyze the site selection principles, functions and objectives of a logistics distribution center by means of qualitative analysis. And construct a model to solve mathematical programming problem quantitatively. Finally a multi-criteria analysis is used to rank alternatives and arrive at an optimal site.

2.1. FMCG logistics

FMCG logistics companies are companies that produce, procure, store, distribute and sell consumer goods for daily use and play an important role in the production and distribution of consumer goods for daily use. The logistics activities of FMCG logistics companies cover a range of processes from raw material procurement, production and processing, storage of finished products to sales and distribution [4], with the aim of meeting consumer demand for consumer goods. In this process, FMCG logistics companies need to establish an efficient logistics system, including logistics planning, construction and management of logistics facilities, design and optimization of logistics operation processes, as well as construction and application of logistics information systems.

The logistics activities of FMCG companies can be divided into multiple stages, including procurement logistics, production logistics, warehousing logistics, sales logistics, and reverse logistics [5]. The whole process starts from purchasing raw material, goes through manufacture, transportation, warehousing and selling, ends with the final delivery to the end user for consumption.

FMCG companies need to continuously optimize and upgrade their logistics management based on market and consumer demands, in order to improve logistics efficiency and reduce logistics costs, and thus maintain their competitiveness and market position.

2.2. Factors determining distribution center site selection

The classification of factors can be divided into subjective factor which is ambiguous and difficult to measure quantitatively and objective factor which is measurable and can be quantified. Subjective factors are normally described by experience, preferences and feeling. This category is represented by local labor and proximity to suppliers and customers because decision-makers should determine the importance weight on basis of their opinions. Objective factors can be described as exact numbers such as distance, labor and transportation cost, quality of infrastructure and market demand. Ozcan used a game card to decide five criteria which are generated for distribution center site selection. It includes unit price per square meter, stock holding capacity, average distance to market, average distance to suppliers and movement flexibility [6]. Those criteria cover the area of capacity, cost and suppliers. Some experts created five criteria and 16 factors under all the criteria. Those criteria include cost, labor, infrastructure, market and environment [7]. Mangiaracina summarized top 5 factors for distribution network design, the most popular is demand level and followed by cycle time, distance to customers and suppliers, demand volatility and delivery frequency. The number of appearances for factor demand level has the most frequency which is 65% among 160 papers related to distribution network design [8]. Onstein did an literature review about distribution structure decision and proposed three categorizes for factors: supply chain management, transportation and geography [9]. Under supply chain management, the main factors that will facilitate decision maker in the company are demand level such as high product volume, service level such as delivery time and logistics cost includes inventory cost, storage cost and delivery cost. But it is difficult to qualify those factors and the calculation related to cost is normally imprecise. Transportation is about using disaggregate or aggregate model to measure product flow from distribution center to customers in a quantitative way. And geography includes accessibility, labor and taxes.

2.3. MCDM methods for location selection

A MCDM problem is generally used to describe a problem with several alternatives which need the decision maker to analysis. The analysis standard could be based on several criteria which could help decision maker to find the optimal alternative, or to make a list and rank all the alternatives. The process of utilizing MCDM problem could be divided into 5 phases. Firstly, a clear research objective should be formulated with alternatives and criteria. Secondly, MCDM problem include both quantitative and qualitative criteria which have various unit of measure [6]. Based on the criteria each alternatives could be analyzed. Thirdly, the weight of each criteria could be found. Fourthly, the final decision could be made with respect to evaluation result. Finally, the robustness and reliability could be checked for the final decision. In the range of using MCDM methods, Analytic Hierarchy Process (AHP), Choquet integral, Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Elimination and Choice Expressing Reality (ELECTRE), and Best Worst Method (BWM) are more recognized and widely used methodologies. BWM is one of the MCDM methods which uses pairwise comparisons to determine the weight of various criteria and results in multi-optimality [10]. The major utilization of BWM is offering weight to a series of criteria and then ranking all the alternatives. BWM could help decision makers to determine the criteria weight in both direction (qualitative) and strength (quantitative) ways. BWM was applied to a polymer industry to find out its quality dimensions. The optimal solution is derived which will reduce the waste generation in the production process [11].

2.4. Facility location problem

In many fields of science the location selection problem has been researched thoroughly, which includes location science, industrial engineering, computer science, mathematics and economics [12]. This leads to a number of different terms to represent this location selection issue, which includes facility location problem, site selection problem and retail location problem. And there are also many objectives even inside the same term. For example the objective of facility location problem could be minimize the total transport cost such as time, distance and consumed energy among all the customer, and it could also be minimizing the maximum transportation cost between every origin-destination pair [13].

In the 21st century, the logistics industry is becoming a new economic hot-spot. With increasing competition in the market, it is difficult for individual companies to be competitive in all aspects of their business and operations. It is necessary to concentrate on production and outsource non-core activities such as warehousing and distribution to third parties. Whereas the warehouse location problem can be regarded as a precursor of the facility location problem. As the key to the logistics network, there are many literature about solving facility location problem by optimization. Two mathematical model could be summarized based on various studies. They could be divided into (1) Static and deterministic location problem and (2) Dynamic location problem [14]. The difference between these two categories is the complexity of the location selection problem. The latter one has advantage in dealing with uncertain requirements which might happen in the future. So the robustness will be guaranteed with the using of dynamic location problem, the result is more likely to adapt to different changes over time. For static location problem, the objective of such optimization model generally have 3 categories [14]:

- How to minimize the total transportation cost
- How to minimize the maximum distance between each node and the facility
- How to maximize the covered demand

2.5. Alternatives generation

Morphological chart is a useful tool to generate alternatives. General Morphological Analysis (GMA) method is the basis of morphological chart [15]. It can be used in a qualitative way to solve problem by creating functions and a large number of means under each function. Finally combine a series of means as an alternative for the target solution. The benefits of using morphological chart include expanding number of solutions for a problem and using combination to generate novel ideas that cannot be easily thought [16]. In the process of drawing a morphological chart, the functions should be listed first which contains major function that this product should cover and with a brief generalization. The methods used in this process include brainstorming, function analysis and interview experts or customers to have specific requirement for each function. But it is better to have independent functions so that the morphological chart could have the best result [17]. After listing all the functions, the means for each function should be generated. These means include existing knowledge or new ideas. The number of means will also have impact to the result of this morphological chart, it will have the best performance with more means and less functions [18]. Normally, the number of functions between 8-12 is recommended [17]. In terms of means combination, some means might violate with the constraint of the paper so that they could be eliminated by observation. But there are other methods can be used in this process, such as ranking all the functions and based on function to select means which will have the best performance to the solution. Or ranking each means in a row and select the one with highest score [19].

3. Design process of the phased approach

3.1. Determining factors

Ballou in his book divided distribution center location decision method in two levels [20]:

1. Corresponding to all the current warehouses location, how to balance transport cost, inventory cost and handling cost so that a new warehouse could be located.

2. After the decision of geographic region which will be used for a new warehouse location, the area of town or industrial land should be identified. So that the relative location of the new warehouse compare with the town or industrial land should be determined.

Determining factors for distribution center location can be further divided into qualification criteria and evaluation criteria. They play different role in the logistics center site selection problem. Qualification criteria are the basic selection of candidate sites, while evaluation criteria are used to score and rank the candidate sites that meet the qualification criteria to find the best one. Farahani discuss in detail about the role of qualification criteria and evaluation criteria in finding third party logistics company, this concept is also suitable in this distribution center selection issues [2].

- Qualification criteria are required to determine the location of a logistics center and are often considered as binary constraints. The logistics center site either meets these binary conditions or not. If a candidate site does not meet the qualification criteria, it is excluded from the candidate list and is not considered further.
- Evaluation criteria are used to score and rank candidate locations to find the best site for a logistics center. The evaluation criteria are usually a set of quantitative or qualitative indicators that can be used to compare the strengths and weaknesses of different locations.

According to [9] and [39], there are many factors which can be used to help decision makers to choose a place for a distribution center. They can be divided into three categories: Supply chain management, transportation and geography. The following decision factors in Table 1 are factors used in this paper.

Supply chain management: Determining distribution center location is a significant research area in supply chain management. This process involves factors such as service level, logistics cost, product characteristics which are essential aspects of managing a supply chain effectively. These factors contribute to the overall efficiency, cost-effectiveness, and competitiveness of the supply chain.

Transportation: Factors under transportation are matched well with factors under supply chain management. And it aims to build quantitative models to describe freight flow. Proximity and flow-related factors are closely related to transportation. These factors affect the ease of moving goods and services between the distribution center and its customers or suppliers. They also influence the overall transportation costs and the efficiency of the logistics process.

Geography: Business environment factors and natural environmental factors are directly related to the geographical location of the distribution center. Geography focuses on analyzing the impact of spatial location distribution on logistics centers. These factors include local regulations, labor market, climate, and other location-specific aspects that may impact the performance, operational cost, and environmental sustainability of the distribution center.

3.2. Constraints

Constraints and requirements which are needed by this new distribution center location selection has been determined by literature review. In this section all the constraints and requirements could be regarded as general constraints and requirements with universalizing which can be applied for any new distribution center location selection. Robertson authored a paper on the discovery of constraints and requirements, outlining a variety of techniques that can be employed, such as abstraction, brainstorming, interviewing, mind mapping and case workshops [40]. However, specific constraints may vary depending on the case study. When selecting a site for a distribution center, it is important to determine which constraint must be met based on the actual situation and needs. Thus it is quite significant to involve more stakeholders who have their own point of view, standard and experience for each case study. Some constraints mentioned in this paper are followed by a handbook from Rushton and Croucher, which has thoroughly explanation about optimizing and managing supply chain. Constrains about searching new distribution center location is also included in this handbook [41]. The requirements mentioned in this paper are followed by a text book from Sauser and Shenhar, which provide general guidance on how to identify, analyze, and manage requirements and constraints in complex systems [42]. Kotonya and Sommerville also wrote a book about requirements engineering, which includes requirements acquisition, requirements analysis, requirements specification, requirements verification and requirements management. It contains a detailed description of functional requirements, non-functional requirements and constraints [43].

In this paper constraints are based on determining factors in Table 1 which may limit the available options for distribution center location. The constraints are qualification factors that you cannot control and used to restrict the available options for distribution center location. There are many constraints in a distribution center location process, such as budget, legislation, infrastructure, environmental etc. These constraints will limit the scope of your available choice set. For example, if the budget is limited, the company must purchase of rent a warehouse within the limit amount. In this section some general constraints are generated which can be regarded as an example or initial thoughts for any case study. The explanation of these 8 constraints can be found in Table 2.

3.3. Requirements

Functional requirements define the specific capabilities that a warehouse must possess in order to meet its operational needs. They refer to the specific needs and capabilities that a warehouse must possess in order to fulfill its intended purpose effectively and efficiently. Functional requirements in distribution center design can be divided into two types: external factors which will make influence in distribution center surroundings and internal factors which will result technologies inside the distribution center [44]. In this paper some functional requirements focus on internal of distribution center design, which include technologies and devices that a warehousing process will

Table 1: Main decision factors and sub-factors for distribution center location [21, 22, 23, 24, 25, 26, 27, 28, 29] [30, 31, 32, 33, 34, 35, 36, 37, 38]

Categorize	Main factors	Sub-factors	Description	Mention in literature
Supply chain management & Transportation	1. Proximity and flow related factors	1a. Distance to customers/consumers	Distance from distribution center to customers of the company or the target consumer markets.	[21]
		1b. Distance to suppliers/producers	Distance from distribution center to suppliers of the company or producers owned by company.	[21]
	2. Logistics cost factors	2a. Transport cost	Transport distance, mode and means between distribution center to customers and suppliers	[22]
		2b. Inventory cost	Warehouse rent capital, equipment investment, human resources and inventory management	[23]
		2c. Warehousing cost	Handling cost, storage cost and labor cost	[24]
	3. Service level	3a. Cargo flow		[25]
		3b. Delivery time	Time from placing an order to customer delivery	[26]
		3c. Delivery responsiveness	Responsiveness after placing an order	[27]
		3d. Customer support	After-sales service, maintenance and technical support	[27]
	4. Product characteristics	4a. Packaging density	Number of packaged products per unit volume	[26]
		4b. Value density	Value of a product per unit of volume or weight	[26]
		4c. Product vulnerability	Special facility such as moisture resistance to protect product	[28]
Geography	5. Accessibility	5a. Motorway network accessibility		[29]
		5b. Port accessibility		[30]
		5c. Rail accessibility		[31]
	6. Infrastructure	6a. Available transport infrastructure	Various facilities used to support the transportation of products and people	[32]
		6b. Congestion	Traffic congestion between distribution center to customers	[33]
	7. Business environment factors	7a. Taxes	Corporate income tax or value added tax in the target area	[34]
		7b. Zoning policies	Government planning and management of land use and development in the target area	[34]
		7c. Labor market availability	The quantity and quality of labor in the target area	[35]
		7d. Labor cost		[36]
		7e. Land cost	Land price per square meter	[36]
	8. Natural environmental factors	8a. Geographical factor	Terrain topography of the target area	[37]
		8b. Noise factor	Distance to residential areas	[37]
		8c. Climate factor	Local humidity, temperature, wind, salt and rainfall	[38]

Table 2: Constraints in distribution center location selection [28, 29, 32, 34, 35, 36, 37, 38]

Zoning policy constraint: The available options for distribution center location must apply with zoning regulations/ policy.	Land cost constraint: Stakeholder must have a financial restriction in purchasing or renting a new distribution center location.
Climate factor constraint: Environmental regulations, such as restrictions on emissions or waste disposal, must be considered when selecting a distribution center location.	Labor availability constraint: The availability of skilled labor is an important consideration when selecting a distribution center location. The availability of labor in a given area must be considered as a constraint.
Geographical factor constraint: The availability of suitable land for distribution center construction must be limited in certain areas, and therefore needs to be considered when selecting a location.	Product vulnerability constraint: The product characteristics, such as keeping hazardous materials away from other items need to be considered in distribution center location selection.
Transport infrastructure constraint: Infrastructure such as bus stops or train station must meet the daily needs of employees during location selection process.	Transport network accessibility constraint: Location selection must have good access to transportation, such as road, rail, port or airport accessibility.

use. Internal factors will have impact on internal process for each distribution center, the typical elements of warehousing process can be found in Figure 1 below, as a series of order, receive, storage, retrieval, handling and shipment.

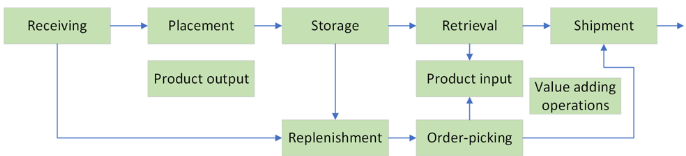

Figure 1: Typical elements of warehousing process [44]

On basis of these typical elements in the process of warehousing, 10 internal elements are found as general items on basis of literature review which can be found in Table 3. Those functional requirements include handling equipment, staff and space for warehousing task, technical performance, physical structure, information system, storage method and packaging operations [42, 44, 45].

Normally non-functional requirements and functional requirements should be one-to-one correspondence since each function that the system possess should have its own attributes. However, some additional attributes of the distribution center are also non-functional requirements such as availability, reliability, safety, environmental friendliness, etc. This section introduces 12 non-functional requirements. 8 of them are followed by typical elements mentioned in Figure 1 which can be found in Table 4. And the rest 4 of them are additional attributes can be found in Table 5 below:

Table 3: Functional requirements in distribution center location selection [42, 44, 45]

Explanation	**Typical elements**
Distribution center should have function to receive products. It needs a receiving area for unloading, inspecting goods and recording receiving information	Receive
Distribution center should have shipment function to load the sorted products onto a transport vehicle and prepare them for shipment. It requires loading and unloading equipment and information system to record shipment information and track the status of the products in transit	Shipment
Distribution center should have function to move products such as handling technologies	Placement
Distribution center should have function to store products and special storage methods such as freezing or air-conditioned	Storage
Distribution center should have function to track and monitor products movement	Product input and output
Distribution center should have retrieval function to select products from the warehouse according to the order requirements. The retrieval process requires efficient goods retrieval equipment and systems, such as automated goods transport system	Retrieval
Distribution center should have value adding operation such as packing picked products to protect them and reduce losses during transportation. This process requires packing materials and packing equipment	Value adding operation
Distribution center should have replenishment function. This function is based on inventory levels and demand forecasts to replenish products from reserve stock to the picking area. It requires an inventory management system to monitor inventory levels, as well as the equipment used to move products	Replenishment
Distribution center should have function to pick products. This function is based on order information, which requires effective picking equipment and technology, such as picking vehicles and picking robots	Order picking

3.4. *Morphological chart*

Functional requirements:

- Receive: Some equipment will be involved in receiving products, such as hand pallet truck, electric pallet truck and forklifts [54].
- Placement: The distribution center should have various equipment or technology to place products. It can either achieve a certain level of automation to facilitate operation or equip with modern technology. Or place products via conveyor belt or using advanced robotic to handle this kind of job [42].
- Storage: The distribution center should have different storage equipment such as multi-tier racking, pallet racking,

Table 4: Some attributes followed by distribution center functions [42, 44, 45, 46, 47, 48, 49]

Attributes	Explanation	Functions
Accurate Efficient	The distribution center must meet accurate and efficient product receiving and retrieval process. And also ensure the accuracy of the order picking process by optimizing the picking process and reduce picking time.	Receive Retrieval Order picking
Reliable	The distribution center must be reliable in shipment process to ensure that the products are not damaged, and also the technical equipment.	Shipment
Flexible	The distribution center must be flexible in placement process to be adaptable for different sizes and shapes of goods.	Placement
Safety	The distribution center must be safety which can ensure security and anti-theft measures for cargo storage areas.	Storage
Traceable	The distribution center must be traceable which can ensure traceability of products in and out of the process for easy monitoring and management.	Product input and output
High-quality	The distribution center must be high-quality to ensure the standard of value-added operations.	Value adding operation
Predictable	The distribution center must be predictable in replenishment process, such as building accurate forecasting models to allow for timely replenishment based on demand.	Replenishment

Table 5: Some additional attributes [50, 51, 52, 53]

Attributes	Explanation
Accessibility	The distribution center should be well-connected to public transport, allowing employees to easily commute to work using buses or other forms of public transportation.
Connectivity	This distribution center must have good connectivity to nearby highways.
Proximity to customers	The distribution center must be near to all its customers.
Environmentally friendly	The distribution center must be environmentally friendly to the surrounding community.

flow racking or cantilever racking [55].

- Retrieval: The distribution center should have various equipment or technology to search and select products. It can be achieved manually or automatically [56].
- Shipment: Truck, railway, air and marine transportation can be used in shipment for distribution center.
- Transportation service: For each distribution center it should have sophisticated transportation system to move products. The means include outsource transportation service to third party country and have its own transportation service [57].
- Specific storage facility: The distribution center should have various storage facility to ensure different demand. The means include hazardous material division for special storage, temperature and humidity control zones for food, pharmaceuticals and cosmetics which need special care.

These functional requirements can be found in Table 3, which contains some functions that this system must have. Those functions are taken as a starting point and a number of means (solutions) to these functions are developed here.
Non-functional requirements:

- Accessibility: Alternatives should have a convenient accessibility. The distance to highway should be taken into consideration and also whether it is near to the local harbor for marine transport. And it should also have abundant public transportation and parking area for employees to reach [25].
- Proximity to customers: The distribution center should be located in a place where near high customer density areas, close to key customer bases, close to major markets and commercial zones.
- Environmentally friendly: The distribution center should be environmentally friendly to the surrounding community. And the sustainability measures could be installing energy-saving equipment and technologies, using renewable energy sources, setting green design strategies and optimizing resource utilization [58].

These non-functional requirements can be found in Table 4, which contains some attributes that this system must be. Those attributes are taken as a starting point and a number of means (solutions) to these attributes are developed here.
Other aspects:

- Land cost: There are three means under this aspect: low-cost areas, medium-cost areas and high-cost areas. They can cover different land cost budgets and consider different geographical locations and investment approaches [59].
- Site foundation: The region for the new distribution center should be limited. There are three means under this function which are expanding current distribution center, finding new location in the neighbor city or finding location in a new city.
- Distribution center operation strategy: There are four means under this aspect, which are locating the distribution center in empty land or industrial estates, outsourcing to logistics companies, sharing distribution center with other companies or renting temporary distribution center.

These three aspects are out scope of requirements. But they are necessary in siting a new distribution center location and they all meet the constraints.

Table 6: Morphological chart for distribution center site selection

	Functions/Attributes	Means			
Functional requirements	Receive	Hand Pallet Truck	Electric Pallet Truck	Forklift	
	Placement	Forklift	Automated Guided Vehicle	Conveyor Belt	
	Storage	Multi-tier Racking	Pallet Racking	Flow Racking	Cantilever Racking
	Retrieval	Manual Picking	Mobile Shelving System	Robotic Picking	Automated storage and retrieval systems
	Shipment	Truck	Railway	Air	Marine
	Information management system	Enterprise resource planning system	Warehouse management system	Customer relationship management system	Cloud computing and Internet of things technology
	Transportation service	Outsource transportation service	Has its own transportation service within the distribution center		
	Specific storage facility	Contain hazardous material division for special storage.	Contain temperature controlled zones	Contain humidity control zones	
Non-functional requirements	Accessibility	Facilitate road transport	Facilitate maritime transport	Easy to reach for employees	Available parking facilities
	Proximity to customers	Locate in high customer density areas	Close to key customer bases	Close to major markets and commercial zones	
	Environmentally friendly	Adopt energy-saving equipment and technologies	Optimize resource utilization and minimize waste	Use renewable energy sources	Green design and green building strategies
Other aspects	Land cost	Low-cost areas	Medium-cost areas	High-cost areas	
	Site foundation	Expand current distribution center	Find new location in the neighbor city	Find new location in a new city	
	Distribution center operation strategy	Locate the distribution center in empty land or industrial estates	Outsource to logistics companies	Share distribution center with other companies	Rental of temporary distribution center

Based on these 8 functions, 3 attributes, 3 aspects and corresponding 48 means, the morphological chart for a generalized distribution center site selection can be found in Table 6 below.

Combinations in the morphological chart can be calculated by multiplying number of means for each function. In this paper, the total number of combinations in Table 6 is 2239488. But there are some means which are not physically possible and will cause impossible combinations, and some other means which are test with restrictions to company objectives and will cause not-allowed combinations. By eliminating those invalid or infeasible means, the number of combinations can be limited to an acceptable number.

3.5. Distribution center site selection method

The 5 step of phased method created in this paper combine both MCDM method and mathematical programming (MP) to solve distribution center site selection problem. The first one aims to calculate weights for each determining factor, and the latter one can calculate the score for each alternative. After multiplying factor weight and score together, the rank of all alternatives can be found. There are several significant advantages to the use of this combination methods:

- Comprehensiveness: MCDM allows people to consider multiple determining factors and assign appropriate weights to each factor, thus making the decision process comprehensive. On the other hand, MP methods can solve more specific siting problems, such as minimizing transportation costs, that may be difficult to solve in MCDM.

- Accuracy: In the decision-making process, this combination method can provide accurate quantitative assessments, rather than just subjective or qualitative assessments. This helps improve the accuracy and consistency of decision making.

- Flexibility: This combination method can be adapted to the specific decision environment and needs. For example, people can add or remove decision factors, or adjust the parameters of a MP model as specific case study need.

- Transparency: This combination method can make the decision-making process more transparent. Decision makers can clearly see the weights of each factor and the scores of each alternative on each factor. This helps decision makers understand and accept the decision results.

In general, using a combination of MCDM and MP methods can help the decision maker to get comprehensive, accurate, flexible, transparent and efficient decisions about where to locate the logistics center.

The main steps of MCDM are as following [60]:

1. Create evaluation factors for the target system.
2. Generating alternatives for the target system to achieve the goal.
3. Using factors to evaluate alternative.
4. Applying a suitable multi-criteria analysis method.
5. Obtaining one of the alternatives as the optimal solution.
6. If the optimal solution is not accepted, reject it and go for another iteration.

Generating evaluation factors and alternatives are the first 3 steps in MCDM. For the fourth step, many distribution center site selection methods are included in both quantitative and qualitative ways. One of them is MCDM method. They are commonly used to decide a series of alternatives on basis of many determining factors associated with alternatives. The distribution center site selection problem represents one of the problems which can be solved by MCDM methods. It can be divided into two groups [61]:

1. Method for factor weights assessment
2. Method for alternatives ranking

For some methods such as AHP and BWM [10, 62] they are equipped with both categorizes, which means they have the ability to both evaluate factor weights and rank alternatives. However, other methods such as TOPSIS belongs to only one categorizes. TOPSIS is primarily utilized for ranking and selecting alternative options, and it requires the pre-determination of weights for each factors. Consequently, when employing the TOPSIS method, it is necessary to rely on other methods (such as AHP) to assess criterion weights [63]. TOPSIS calculates the distance between each alternative and the positive and negative ideal solutions based on the known weights and the scores of alternatives under each factors, thereby facilitating the ranking and selection of alternatives.

- Weights assessment methods

  AHP uses pairwise comparison matrices for factors to compute the score of alternatives according to factor weights. And it is the most dominant MCDM method in the area of weight assessment [64, 65]. Another popular method is BWM introduced in the year 2015. Decision maker determines the best and the worst factors and BWM uses pairwise comparison between each of these two factors and other factors. Both these two methods can do factor weights evaluation and alternatives ranking [66, 67].

- Alternatives ranking methods

  There are many other MCDM methods only have the ability to select alternatives ranking list. And they normally need to be combined with another weighting method mentioned before. For example AHP method can be employed to determine factor weights and use TOPSIS to rank alternatives [63]. TOPSIS requires the chosen alternative to have the shortest distance to the optimal solution and the farthest distance to the undesirable solution [60, 68]. ELECTRE analyses the outranking relationship between alternatives by using concordance and discordance indexes, which aims to choose the best action from a series of actions [68, 69]. Preference ranking organization method for enrichment evaluation (PROMETHEE) method is one of the outranking methods. Firstly it construct an outranking relation on factors which presents decision maker preference. In the second phase a leaving and entering flow is considered in the outranking graph for decision maker [70, 71]. Multi Attribute Utility Theory (MAUT) uses utility function while considering the preference of decision makers. An index is employed to describe the preference of one factor. Both quantitative and qualitative factors are included in this method [72, 73].

4. Application

As a generic method, each of the step in this 5 step of phased method should have several options for decision-makers to choose in order to satisfy different company objectives. Those options in each step can be found in Figure 2. On top of this figure is the demonstration of different desired state which are the reasons why decision-makers might want to use this 5 step of phased method to solve distribution center location problem. Their choices in each step will also be influenced by the desired state they want to achieve.

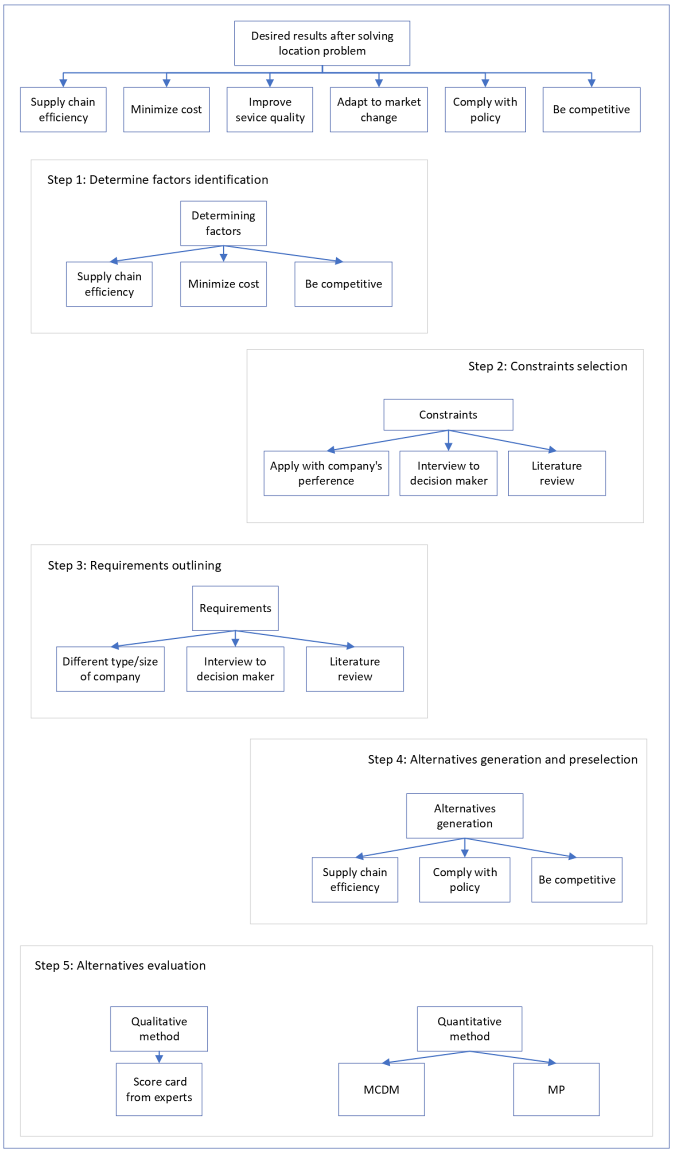

Figure 2: Application of this method in 5 steps

- Step 1: In the step of determining factors, three desired results are chosen as example for determining factors. However, in the real case, a company may want to achieve multiple desired results which means more determining factors should be considered in that case.

- Step 2: In the step of selecting constraints, decision-maker could continue with constraints which are created in this method. Or they can make some changes on basis of

Table 7: The degrees of importance in this score card

The degrees of importance description
1: Extra unimportant
2: Very unimportant
3: Unimportant
4: Slightly unimportant
5: Middle
6: Slightly important
7: High important
8: Very important
9: Extra important

specific company preferences or the opinion from other decision-makers.

- Step 3: In the step of outlining requirements, the choices may appear similar to those in step 2. However, these requirements can be modified to fit specific companies based on their type and size.
- Step 4: In the step of alternatives generation, the choices are depended on desired result. Two different type of company are chosen as example with different desired results. This result indicates that different type of company with different desired results will cause various location alternatives.
- Step 5: In the step of alternative evaluation, the choices are included either using qualitative method with a quick approach or using quantitative analysis with MCDM or MP to evaluate alternative list.

After considering all the options from these 5 steps. Decision-makers could select a series of option which are corresponding to their desired state. For example, one possible application should be regarding minimize total cost as the desired state. In this situation, the decision maker should select relevant factors and generate a morphological chart on basis of this desired state. Then continue with constraints and requirements from literature review. Finally using P-median problem to calculate the optimal solution of the distribution center. Another possible application might be increasing competitiveness. After selecting relevant factors, decision maker could use new constraints and requirements from company's preference. On basis of new requirements, a morphological chart can be generated and a score card can be directly used to evaluate factors due to time limitation. The final alternative list could be determined by decision maker's own preference.

The 5 step of phased method has significant advantages in evaluating alternatives. Firstly, the approach use MCDM to determine the weights of evaluation factors and rank the alternatives. By obtaining the relative importance of each factor, decision makers can have a better understanding about the relative impact of evaluation factors and maintain focus during the decision-making process. However, in the complex process of selecting a distribution center location, sometimes the decision maker may be under pressure to decide in a short period of time due to time limitation. This situations may arise from a variety of reasons, such as rapid changes in the market, competitor actions, or urgent needs within the company. Under such pressure, decision makers may not have enough time to conduct this 5 step of phased method thoroughly and need to do a quick approach by shrinking the scale for some steps. In the second application mentioned before, decision maker used a qualitative method with score card to make a quick decision.

Although this quick approach cannot consider all factors and possibilities as comprehensively as the 5 step of phased method, it can still help to make rational and effective decisions in a limited time frame. Sometime decision maker can just select the most important decision factors by a score card, then generate a limited number of alternatives based on these factors, and finally evaluate the final alternatives by decision maker's preference. Table 7 is an example of the score card which can be used to determine the most important factor. In this score card a higher score means higher importance.

5. Conclusions and recommendations

5.1. Conclusions

In this paper a 5 step of phased method is designed for FMCG companies to determine an appropriate distribution center site selection. For each step in this method, a company can select several options to satisfy its business objectives. The method can be applied in different ways and may yield different results. A diverse range of options offered by this method enhances its generality. The determining factors in the first step can be chosen to satisfy specific company needs, and multiple MCDM methods are available for selection in step five. In general, the application of this method comprises a series of selections from five steps. In each step, there are several options that decision-makers can choose to satisfy the specific needs of the distribution center.

The different steps in this method are interconnected. They can be divided into four parts, as shown in Figure 3. The overlapping sections highlighted in yellow demonstrate the relationship between these steps.

- Factors – Constraints & Requirements

  In this method there are two classification for factors, qualification factors and evaluation factors. The evaluation factors mentioned in the first step are exactly the same compare with constraints in step 2.

- Constraints & Requirements – Alternatives generation

  The constraints and requirements in step 2 and 3 are the primarily input for step 4 alternatives generation. Since in

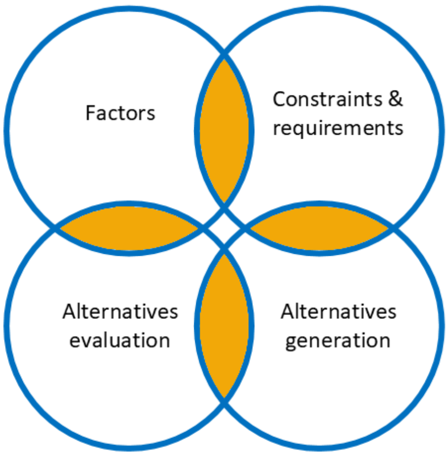

Figure 3: Relationship between different steps

the morphological chart, the functions and attributes are from requirements.

- Alternatives generation – Alternatives evaluation

  Alternatives are generated by morphological chart in step 4. And then the final alternatives list can be further evaluated in the final step.

- Alternatives evaluation – Factors

  There is still a relationship between step 5 and step 1. Because in the process of evaluating alternatives, MCDM is used to calculate evaluation factor weights. And these factors should be quantified or qualified for each alternative to calculate the final performance score.

However, there are certain advantages and disadvantages when comparing this five-step phased method with other methods for solving the distribution center location problem. Numerous papers utilize a hybrid method combining MCDM methods to determine optimal location selection. The advantage of the 5 step of phased method is that it also considers the process of generating alternatives. For many other methods, the list of possible distribution center locations is pre-determined, allowing these methods to be directly used to identify optimal solutions. This advantage of the 5 step of phased method offers a progressive solution for companies. Because finding potential distribution center locations is a prerequisite for a company that wants to determine an optimal one. Furthermore, the universality of the 5 step of phased method is another significant advantage. For instance, the evaluation factors, constraints, and requirements are generic, encompassing most factors and functions relevant to a distribution center. Regarding alternative evaluations, decision-makers can choose from various MCDM tools to address their issues. There is even a streamlined approach for cases constrained by time and requiring immediate decisions. In terms of disadvantages, the factors involved in this method have some limitations, as they cannot fully cover all company needs in reality. For the morphological chart, in real cases the possible means for each function are diverse. However, in this method, only four means are provided, which may limit the choice set. As for alternative evaluation, obtaining some data in real cases can be also challenging or time consuming. These disadvantages need to be addressed in future research.

Overall, this paper presents a resolution to the distribution center location problem through the implementation of a 5 step of phased method. This method provides a generic and structured decision-making instrument for decision makers, assisting in identifying an appropriate distribution center location relevant to various scenarios. It is envisaged that this method will contribute to scholarly research and practical applications within affiliated domains, while simultaneously providing decision-making assistance and strategic direction for companies grappling with distribution center location challenges.

5.2. Recommendations

Some recommendations are made to 5 step of phased method for further research.

1. Application in case study:
   Although in this paper some applications about using this 5 step of phased method are introduced. In the future research this method should be applied in a real case study to verify its effectiveness.
2. Number of factors and requirements:
   While the 5 step of phased method employed in this paper determines a total of 25 factors, it may not fully encompass all the needs of a company in a real-world context. Future enhancements should consider incorporating additional factors to cater to the increasing demands of companies. Similarly, the same issue applies to requirements. In real scenarios, some companies may encounter specific requirements that are not addressed in this approach. Therefore, it is suggested to increase the number of requirements in the future.
3. Accuracy and availability of data:
   The effectiveness of this approach relies heavily on the calculation of performance score, such as factor weights calculation via MCDM and quantitative and qualitative analysis. More decision makers should be interviewed to determine factor weights, which can increase the accuracy of final result.
4. Diversity of alternatives generation
   This paper uses morphological chart to generate alternative on basis of requirements and other aspects. However, in real life the possible means for each function has many diversity which can highly enrich the available combinations for alternative.

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Appendix B: BWM

8	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Criterion 6	Criterion 7	Criterion 8
Names of Criteria	Distance to customers	Transport cost	Motorway network acces	Proximity to neighbors	Labor market	Labor cost	Taxes	Land cost

Select the Best	Distance to customers

Select the Worst	Land cost

Best to Others	Distance to customers	Transport cost	accessibility	Proximity to neighbors	Labor market	Labor cost	Taxes	Land cost
customers	1	2	2	3	4	5	8	9

Worst	Land cost
customers	9
Transport cost	7
accessibility	7
neighbors	6
Labor market	5
Labor cost	4
Taxes	2
Land cost	1

Weights	Distance to customers	Transport cost	accessibility	Proximity to neighbors	Labor market	Labor cost	Taxes	Land cost
	0.300879494	0.175898781	0.175898781	0.117265854	0.087949391	0.070359512	0.043974695	0.027773492

Input-Based CR	0.152777778	The pairwise comparison consistency level is acceptable
Associated Threshold	0.362	

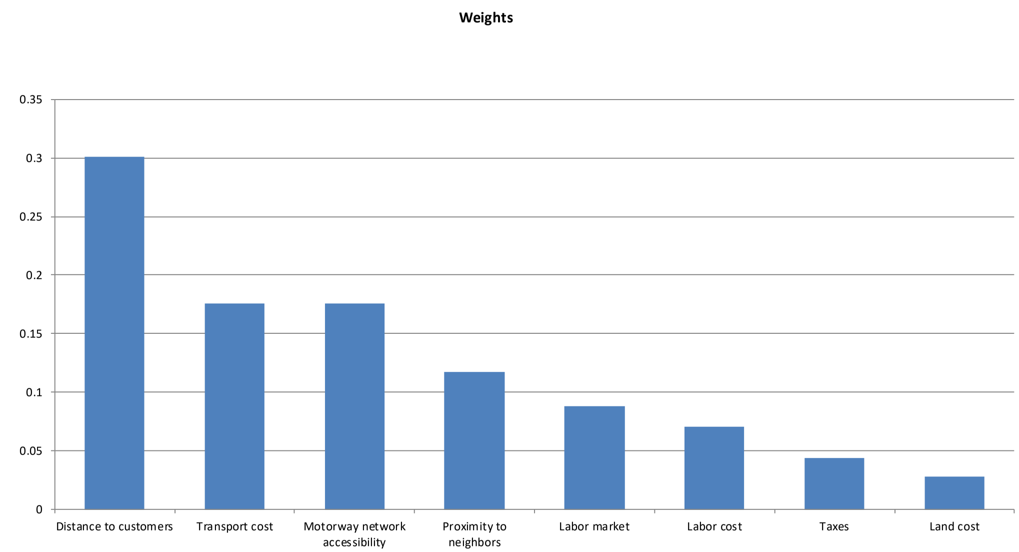

Figure B.1: Best Worst method for decision maker 1

8	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Criterion 6	Criterion 7	Criterion 8
Names of Criteria	Distance to customers	Labor cost	Motorway network acces	Labor market availabil	Proximity to neighbors	Land cost	Taxes	Transport cost

Select the Best	Distance to customers

Select the Worst	Taxes

Best to Others	Distance to customers	Labor cost	accessibility	availability	Proximity to neighbors	Land cost	Taxes	Transport cost
customers	1	2	4	6	6	4	9	3

Worst	Taxes
customers	9
Labor cost	7
accessibility	6
availability	3
neighbors	3
Land cost	5
Taxes	1
Transport cost	7

Weights	Distance to customers	Labor cost	accessibility	availability	Proximity to neighbors	Land cost	Taxes	Transport cost
	0.320930233	0.195348837	0.097674419	0.065116279	0.065116279	0.097674419	0.027906977	0.130232558

Input-Based CR	0.208333333	The pairwise comparison consistency level is acceptable
Associated Threshold	0.362	

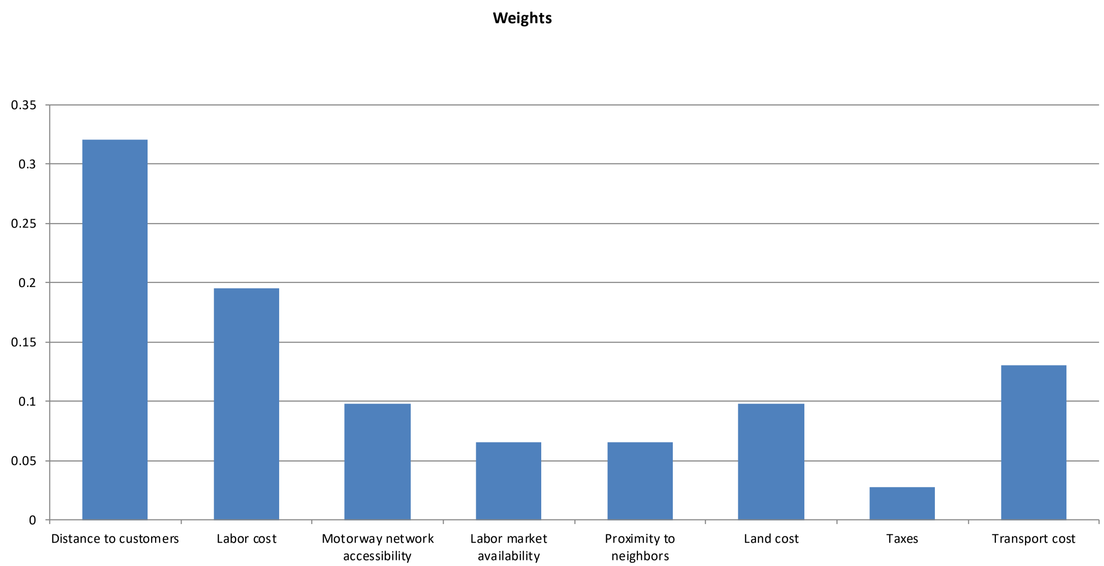

Figure B.2: Best Worst method for decision maker 2

8	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Criterion 6	Criterion 7	Criterion 8
Names of Criteria	Distance to customers	Transport cost	Motorway network acces	Proximity to neighbors	Labor market	Labor cost	Taxes	Land cost

Select the Best	Distance to customers
Select the Worst	Land cost

Best to Others	Distance to customers	Transport cost	accessibility	Proximity to neighbors	Labor market	Labor cost	Taxes	Land cost
customers	1	4	3	6	2	2	6	9

Worst	Land cost
customers	9
Transport cost	5
accessibility	6
neighbors	4
Labor market	6
Labor cost	7
Taxes	2
Land cost	1

Weights	Distance to customers	Transport cost	accessibility	Proximity to neighbors	Labor market	Labor cost	Taxes	Land cost
	0.299483649	0.08777969	0.117039587	0.058519793	0.17555938	0.17555938	0.058519793	0.027538726

Input-Based CR	0.208333333	The pairwise comparison consistency level is acceptable
Associated Threshold	0.362	

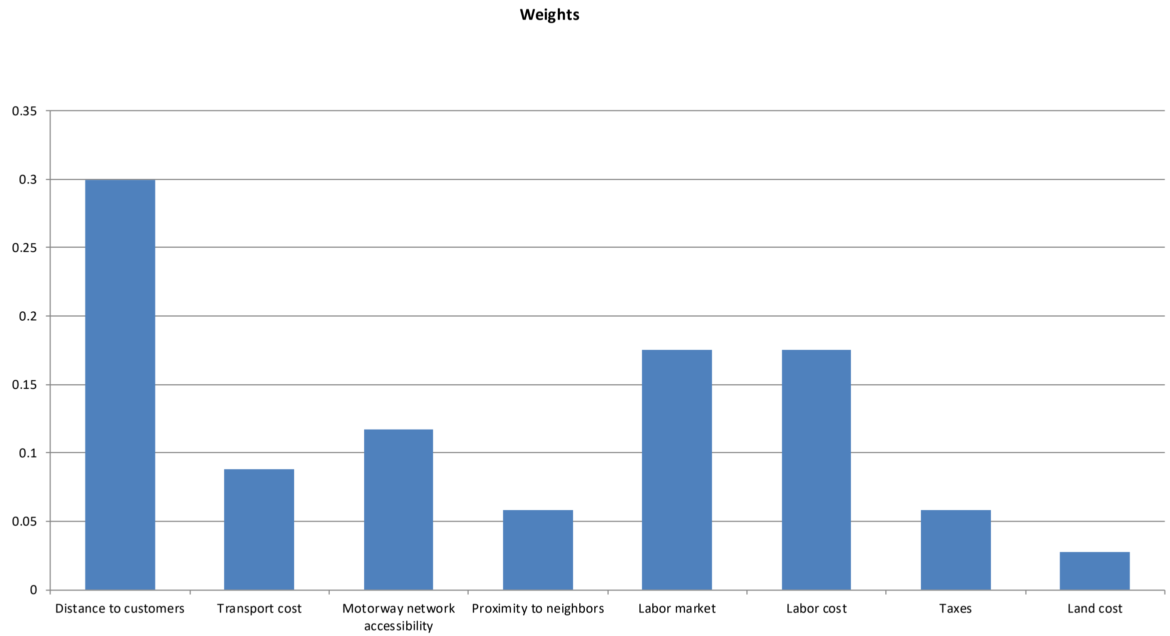

Figure B.3: Best Worst method for decision maker 3

Appendix C: Quantitative and qualitative analysis

- Quantitative analysis

Country	Labor cost (EUR)	Country	Labor cost (EUR)
Luxembourg	50.7	Czechia	16.4
Denmark	46.8	Estonia	16.4
Belgium	43.5	Portugal	16.1
France	40.8	Slovakia	15.6
Netherlands	40.5	Greece	14.5
Sweden	40.1	Malta	14
Germany	39.5	Lithuania	13.1
Ireland	37.9	Poland	12.5
Italy	29.4	Latvia	12.2
Spain	23.5	Croatia	12.1
Slovenia	23.1	Hungary	10.7
Cyprus	19.4	Romania	9.5
		Bulgaria	8.2

Table C.1: Hourly labor cost of all EU countries in 2022

Country	Employment rate %	Country	Employment rate %
Iceland	84.8	Slovenia	77.9
Netherlands	82.9	Portugal	77.5
Sweden	82.2	Austria	77.3
Estonia	81.9	Latvia	77
Switzerland	81.9	Poland	76.7
Czechia	81.3	Slovakia	76.7
Malta	81.1	Bulgaria	75.7
Norway	80.9	Luxembourg	74.8
Germany	80.7	France	74
Hungary	80.2	Belgium	71.9
Denmark	80.1	Croatia	69.7
Lithuania	79	Spain	69.5
Finland	78.4	Serbia	69.3
Ireland	78.2	Romania	68.5
Cyprus	77.9	Greece	66.3
		Italy	64.8

Table C.2: Employment rate (%) of all EU countries

Country	Corporate income tax	Country	Corporate income tax
Colombia	35	Denmark	22
Portugal	31.5	Greece	22
Costa Rica	30	Norway	22
Mexico	30	Slovak Republic	21
Germany	29.83	Sweden	20.6
Japan	29.74	Estonia	20
New Zealand	28	Finland	20
Italy	27.81	Iceland	20
Korea	27.5	Latvia	20
Canada	26.21	Switzerland	19.7
France	25.83	Czech Republic	19
Netherlands	25.8	Poland	19
Belgium	25	Slovenia	19
Spain	25	United Kingdom	19
Austria	25	Lithuania	15
Luxembourg	24.94	Ireland	12.5
Israel	23	Chile	10
Turkey	23	Hungary	9

Table C.3: Corporate income tax (%) 2023 for profit exceeding EUR 200.000

- Qualitative analysis:

Alternatives	Alternative 1(a)	Alternative 1(b)	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Nearest highway			A40	N322	A59	A15
Distance to highway	Quite inconvenient	Extremely convenient	Slightly inconvenient	Extremely convenient	Slightly inconvenient	Very convenient

Score	1	0.8	0.6	0.4	0.2	0
Scale	Extremely convenient (<0.5km)	Very convenient (0.5-1.5km)	Moderately convenient (1.5-2.5km)	Slightly inconvenient (2.5-3.5km)	Quite inconvenient (3.5-4.5km)	Very inconvenient (>4.5km)

Figure C.1: Scale and score for motorway network accessibility

Alternatives	Alternative 1(a)	Alternative 1(b)	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Distance to residential area	Very close	Not close	Extremely close	Moderately close	Slightly close	Extremely close

Score	1	0.8	0.6	0.4	0.2	0
Scale	Very far (>2.5km)	Not close (2-2.5km)	Slightly close (1.5-2km)	Moderately close (1-1.5km)	Very close (0.5-1km)	Extremely close (<0.5km)

Figure C.2: Scale and score for distance to nearby residential area

Alternatives	Alternative 1(a)	Alternative 1(b)	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Land area	Extremely large	Extremely large	Very large	Slightly large	Moderately large	Not large

Score	1	0.8	0.6	0.4	0.2	0
Scale	Small (<10000sqm)	Not large (20000-10000sqm)	Slightly large (30000-20000sqm)	Moderately large (40000-30000sqm)	Very large (50000-40000sqm)	Extremely large (>50000sqm)

Figure C.3: Scale and score for land area

	Alternative 1(a)	Alternative 1(b)	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Motorway network accessibility	0.2	1	0.4	1	0.4	0
Proximity to neighbors	0.2	0.8	0	0.4	0.6	0
Land cost	0	0	0.2	0.6	0.4	0.8

Figure C.4: Final score for each alternative under qualitative analysis

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