GIS-based Multi-Criteria Decision Analysis for Third-party Logistics Provider Selection

Master thesis in partial fulfilment of the requirements for obtaining an MSc degree in Business Administration – specialization Transport & Supply Chain Management

VU Amsterdam
Faculty of Economics and Business Administration

Name: Katja Starzl
Student number: 2603309
Date: August 18, 2017

First supervisor: Dr. Eric Koomen
Second supervisor: Dr. Thomas de Graaff

Abstract

Although the location of a logistics facility is generally considered as an important, strategic decision that affects the company's supply chain (SC) performance, location factors play a minor role in the selection of third-party logistics (3PL) providers nonetheless they exert the company's logistics activities. Based on this contradiction, the paper proposes a Geographic Information System (GIS)-based multi-criteria decision making (MCDM) approach for 3PL selection taking service, cost and location factors into account. The underlying approach consists of six steps including SC-based problem definition, weight generation using the Analytic Hierarchy Process (AHP), establishment of a database, suitability and sensitivity analysis (SA), and recommendations to the decision maker. Moreover, the practicability of the approach is tested in a case study assessing twelve 3PL locations in the Netherlands. The result of this research is that decision makers benefit from incorporating location factors in the selection process because unsuitable locations can be excluded at an early stage.

Key words: Third-party logistics (3PL) provider selection · Geographical Information System (GIS) · Multi-criteria decision-making (MCDM) ·

Table of content

List of figures

Abbreviations and notation

3PL .... Third Party Logistics (provider)
AHP .... Analytic Hierarchy Process
ANP .... Analytic Network Process
CI .... Consistency Index
CR .... Consistency Ratio
GIS .... Geographic Information System
MCDA .... Multi-criteria decision analysis
MCDM .... Multi-criteria decision making
RI .... Random Consistency Index
SC .... Supply Chain
SMCDM .... Spatial multi-criteria decision-making

1 Introduction

Since the 1950s, supply chains (SC) are affected by globalization (Cheong 2003). Thus, they became not only more complex but also less integrated. The former is perceptible in world-spanning supply chains and the increasing spatial division of production and consumption (Verhetsel et al. 2015; Khaled, Kim 2012), while the latter is mainly caused by outsourcing efforts which results in more parties that are involved in the supply chain (Cheong 2003). Following new strategies to stay competitive, companies started to concentrate on their core competencies while outsourcing tasks that are not considered as such (Falsini et al. 2012; Farzipoor Saen 2010). Examples include transport, handling, and storage activities (Cheong 2003). This allows them to achieve greater flexibility, operational efficiency, cost reduction, and improved customer service levels (Aguezzoul 2007; Göl, Çatay 2007; Aghazadeh 2003).

As a response to this trend, third-party logistics (3PL) providers emerged as a new business form in the 1990s (Gürcan et al. 2016). By specializing in providing and managing a variety of logistics services for companies, they became the logistical connection between supplier, manufacturer and end consumer of the products (Verhetsel et al. 2015; Farzipoor Saen 2010; Cheong 2003). Due to this central position in the supply chain, 3PLs rate among the three most important strategic alliances in the logistics value chain (Gürcan et al. 2016).

With a rising number of 3PLs and constantly growing service portfolios covering multiple activities along the supply chain (Gürcan et al. 2016; Alkhatib et al. 2015), companies are facing the challenge of determining the most suitable 3PL provider according to multiple selection criteria; for example service variety, service quality, cost structure, technology usage and location factors (Alkhatib et al. 2015; Aguezzoul 2014, 2007). A large literature is concerned with the 3PL selection process and thereby used selection criteria and multi-criteria decision making (MCDM) methods (Gürcan et al. 2016; Jihene 2014; Bansal, Kumar 2013; Gupta et al. 2011; Farzipoor Saen 2010; Aguezzoul 2007; Göl, Çatay 2007). A close examination shows that location factors belong to the least mentioned criteria group and thus seem to play a minor role for 3PL selection. Aguezzoul (2014) validates this impression in his literature review on the 3PL selection problem.

In literature regarding location and site planning, Rikalovic et al. (2014) and Verhetsel et al. (2015) emphasize the great importance and scope of location decisions for (logistics) operations because of their strategic character. As almost 80% of all logistical processes are related to geographic coordinates (Khaled, Kim 2012), the choice of the right location for logistics facilities greatly impacts the key measures of a company's supply chain performance in terms of lead time, inventory capacity, responsiveness to demand variability, flexibility, quality and average distances or areas covered (Mangalan et al. 2016; Rikalovic et al. 2014).

Since 3PL provider takes over the logistics activities of companies, the lack of involvement of location factors in the 3PL selection is to be criticized and greater attention must be paid on location factors in the selection process. Correspondingly, the objective of this paper is to propose an approach which includes a spatial analysis of several location factors in the 3PL selection process. This is achieved by developing a Geographic Information System (GIS)-based MCDM approach. For this purpose, necessary steps, criteria and MCDM and GIS tools need to be identified. Selecting a GIS approach offers the advantage of reducing conjectures and providing valuable understanding of the business location and its development opportunities (Ringo 2009). Combining GIS and MCDM methods creates a powerful decision making approach that improves the efficiency and quality of spatial analysis by generating a synergistic effect (Rikalovic et al. 2014; Al-Shalabi et al. 2006; Malczewski 2006).

The remainder of this paper is organized as following. In the literature review, previous work that has been conducted on 3PL selection and GIS-based MCDM is described. To provide sufficient basis, relevant publications in the individual areas of GIS and MCDM are reviewed. In the following section, the methodology of a GIS-based MCDA 3PL selection is proposed and further underlined with literature. This approach consists of six steps that include the application of the Analytic Hierarchy Process (AHP) as MCDM method to determine criteria weights, a spatial analysis to evaluate the alternative locations and a sensitivity analysis (SA) determine the impact of a variation in the input weights as well as to assess the robustness of the outcome. In a subsequent case study practicability of the methodology is tested. Lastly, the research findings are discussed and summarized. A conclusion is drawn and guidance for future research is outlined.

2 Literature Review

The literature review focuses on two elements: the parallels of 3PL and site selection and the tools used for it. Further literature will be reviewed in appropriate chapters in the methodology section.

2.1 Parallels in 3PL and site selection, and 3PL selection criteria

3PL selection has many parallels with site selection problems and facility location problems such as similarities in the selection process.

When a company considers working together with a 3PL, a selection process is initiated to determine a suitable 3PL for a long-term cooperation. In his paper, Aghazadeh (2003) presents the five steps of selecting an effective 3PL: once a company decides to use a 3PL, criteria and objectives, the 3PL is supposed to meet, need to be developed. Next, in the weeding out process a list of possible 3PLs is created. Based on this list, the management arranges meetings and facility visits to determine the top prospect. Finally, a new partnership with the chosen 3PL can begin.

The process of site selection is triggered by the recognition of the need to locate a facility (Al-Shalabi et al. 2006; Eldrandaly et al. 2003). Rikalovic et al. (2014) refer to and base their approach on Zelenovic's (2003) steps in a site selection process which are: establishing a set of influential factors relevant to site selection, predicting and analysing the intensity and direction of their effects in time and for given conditions, evaluating possible variants of solutions, and selecting the optimal variant. Van Thai and Grewal (2005) propose in their paper a three-stage hierarchy, namely general geographical area identification, alternative sites identification and specific site selection. While van Thai and Grewal's (2005) stages rather define the scope of actions, Zelenovic (2003) focuses on the tasks that need to be executed in order to find an appropriate site.

Based on these similarities, the existing and broad research in location planning can be explored to support the development of the GIS-based MCDA methodology for 3PL selection by serving as examples. However, operations-research optimization models used in facility location problems are not taken into account in this paper since they mainly deal with the problem to assess the number and location to open a set of preselected alternatives optimizing for example profits, costs, or coverage (Church 1999).

The selection of a 3PL is based on numerous criteria. Aguezzoul (2007, 2014), Gupta et al. (2011), and Jihene (2014) dedicated their collection an own sub chapter. While Gupta et al. (2011) review 3PL selection criteria with attention on the Indian logistics sector, Aguezzoul (2007, 2014) keeps his literature review on a general level. The most extensive collection of criteria is provided by Jihene (2014). However, three of the four papers lack in the definition of the collected criteria.

For this purpose, one can find explanations for 27 criteria in Göl and Çatay's (2007) and 23 criteria in Jharkharia and Shankar's (2007) paper. Jung (2017) proposes to consider social sustainability as an important factor for the customer's recognition of the brand image.

2.2 Site selection tools

The most commonly used tools for solving site selection problems are GIS, MCDA and the combination of both. Before GIS-based MCDM methods are discussed, the single methods will be explained briefly. In doing so, main functionalities, benefits and limitations are described.

2.2.1 Multi-criteria decision analysis

Rikalovic et al. (2014) defines a decision as a choice between alternatives which is based on measurable criteria. Criteria can either be a factor that is measured on a continuous scale or a constraint that quantifies a limit (Rikalovic et al. 2014). If multiple criteria are involved, a multi-criteria decision analysis (MCDA) is performed. It is used to structure decision making, and to compare and evaluate a number of alternatives based on multiple, well-specified criteria (Malczewski 2006). MCDA supports decision making by addressing the common problem of weighting criteria according to their importance (Al-Shalabi et al. 2006). Thereby, decision makers can rely on a rich collection of techniques and procedures (Malczewski 2006). Due to its impact on the final outcome, the selection of the appropriate MCDA method is crucial (Chen et al. 2009; Al-Shalabi et al. 2006). Some methods allow the decision makers to implement preferences for the relative importance of criteria (Malczewski 2006). Pontius and Si (2015) refer to Greene et al. (2011) for a summary of MCDA methods and decision aid for the selection of appropriate methods. Malczewski (2006) distinguishes between two MCDA groups, multi-attribute and multi-objective decision making. While former describes a selection process based on the attributes of a discrete number of alternatives, the best solution in the latter may be found anywhere within a region of feasible solutions. Rikalovic et al. (2014) assume this concept, too.

Due to these various, often conflicting criteria involved in the 3PL selection, the decision-making process is complex. Aguezzoul (2007, 2014) compared four evaluation methods namely: linear weighting models, artificial intelligence, statistical/ probabilistic approaches, and mathematical programming models. The multi-criteria evaluation methods in the reviewed papers on 3PL selection, belong into the groups of linear weighting models (Jung 2017; Gürcan et al. 2016; Jihene 2014; Bansal, Kumar 2013; Göl, Çatay 2007) and mathematical programming models (Farzipoor Saen 2010; Hamdan, Rogers 2007). The distribution of the methods used in the literature review for this paper is in line with Aguezzoul's (2007, 2014) findings: Linear weighting models like the Analytic Hierarchy Process (AHP) are the most utilized approaches. Accordingly, the ranking of criteria in this paper is also conducted using AHP. As an orientation, the ranking conducted in 2003 by the International Warehouse Logistics Association (IWLA) may be considered (see www.iwla.com). However, the importance of criteria varies from company to company depending on factors like company size, demand level and business sector (Aguezzoul 2007).

Site selection as well does not only require the consideration of a wide range of decision criteria, but also the balancing of numerous and possibly conflicting objectives (Rikalovic et al. 2014; Al-Shalabi et al. 2006). Due to the involvement of spatial factors, a site selection is not only a MCDM problem but a spatial MCDM (SMCDM) problem (Rikalovic et al. 2014). Through developments in information technologies, the use of GIS became a common application to determine the suitability of a location and thus for solving SMCDM problems as from 1970s onwards (Boroushaki, Malczewski 2008; Trubint et al. 2006; Church 2002, 1999). This suitability score represents the extent to which a location meets desired conditions that are defined by the selection criteria (Rikalovic et al. 2014). Finally, the site with the highest score of all alternatives is selected.

2.2.2 Geographic Information System

A geographic information system (GIS) is a collection of various powerful tools designed for spatial analysis which provides functionality to manage (acquire, store, collect, access, organize, retrieve), explore and analyse (measure, query, proximity, centrality and service zones functions), manipulate or edit (conversion, aggregation, overlay, interpolation) and visualize (digital map design) information (Bruno, Gianniskos 2015; Murray 2010; Malczewski 2004; Church 2002, 1999).

The central element of a GIS is the location referencing system which allows data to be linked to a specific location and analyse relationships among locations (Church 2002). Empowered by the merger of both spatial and non-spatial attribute data, decision makers are able to display spatial patterns, links or hidden relationships in computerized maps that might not be evident in a non-spatial context by layering multiple sources of information (Aber, Aber 2017). Thus, these maps provide a very powerful message to decision makers and offer the opportunity to answer more complex questions (Comber et al. 2015). Accordingly, there is a huge variety in the fields of GIS applications reaching from site selection problems for production facilities (Zhang et al. 2017; Sahoo et al. 2016; Zhang et al. 2011), storage and retail facilities (Kahraman et al. 2016; Ringo 2009; Trubint et al. 2006; Vlachopoulou et al. 2001; van Ritsema Eck, Jong 1999), public facilities (Ribeiro, Antunes 2002; Yeh 1999; Yeh, Chow 1996) or network and distribution planning issues (Gu et al. 2016; Moreno-Navarro et al. 2015; Irizarry et al. 2013; Sarkar 2007; Miller 1999).

Many authors state that GISs strongly support managers to evaluate placement options and to make informed decisions by visualizing selection criteria the earlier it is applied (Rikalovic et al. 2014; Ringo 2009; Noon, Hankins 2001; Vlachopoulou et al. 2001). Therefore, it is unavoidable when spatial factors are involved in decision-making (Trubint et al. 2006). However, Khaled and Kim (2012) reveal that despite GIS's key strength in spatial suitability analysis, the usage of GIS in facility location analysis is low and not utilizing the program's full potential. Reasons for this may be found in several limitations of GIS that a number of authors are expressing, which are:

1. Availability of data and data structure (Church 2002, 1999; Yeh 1999; Yeh, Chow 1996)
2. Availability of a user-friendly input-output interface (Church 2002; Ribeiro, Antunes 2002)
3. Cost of software and analysis packages (Lei et al. 2015; Ribeiro, Antunes 2002)
4. Availability of analysis and MCDM tools (Lei et al. 2015; Sánchez-Lozano et al. 2013; Murray 2010; Al-Shalabi et al. 2006; Church 2002; Carver 1991)

As indicated by the year of publications of several references, the relevance of limitations mentioned for example in points 1 and 2 decreased and diminished until now due to technological progress. Unlike in 1 and 2, technical developments can also promote the recurring of limitations due to ever advancing possibilities in computing and representation. This applies for example to points 3 and 4. Especially in point 4, authors continue to criticize the limited availability of necessary tools to perform analyses and evaluations since 1991. As main drawbacks are mentioned too generic and unspecialized tools causing a need for manual problem solving, limited possibilities for integrating subjective judgments and limitations to incapability of processing multiple and conflicting criteria. Bruno and Gianniskos (2015) and Malczewski (2004) state that since the mid-1990s the number and variety of available tools as well as the user-friendliness increased while Rikalovic et al. (2014) point out that recent innovations have led to drastic improvements in the mentioned capabilities of GIS.

Of all reviewed papers, only Comber et al. (2015) criticize the lack of critical understanding of the operation in regard to the usage of available analysis and decision-making tools which results in naively generated and/or erroneous maps. GIS does not provide its user with a final solution, but rather allows for a more organized information analysis, which is crucial to making quality decisions (Trubint et al. 2006).

2.2.3 GIS-based multi-criteria decision-making

Location decision problems are complex, data- and time-intensive (Rikalovic et al. 2014; Al-Shalabi et al. 2006; Vlachopoulou et al. 2001). In order to effectively deal with these characteristics, several appropriate modelling, analysis and decision tools need to be employed simultaneously (Al-Shalabi et al. 2006; Vlachopoulou et al. 2001; Carver 1991). Due to technical advances in computing science, GIS and MCDM tools can be combined which leads to a synergistic effect that raises efficiency and quality of the spatial analysis (Rikalovic et al. 2014; Malczewski 2006). The integration of the capabilities of both tools provides better procedures and thus forms one of the most advanced and reliable methods for special decision-making (Feizizadeh, Kienberger 2017; Delgado, Sendra 2004; Carver 1991). Thereby, main GIS functionalities for analysing, managing, storing and visualizing geospatial information are applied in different spatial planning and evaluation processes as well as as they play a vital role in the creation of a comprehensive database (Sánchez-Lozano et al. 2013; Malczewski 2006; Delgado, Sendra 2004). Next, a rich collection of MCDA methods is used to generate judgment values for a set of criteria (Özceylan et al. 2016a; Malczewski 2006). For evaluation reasons, MCDM results can be mapped with the help of GIS in a way that the suitability of sites and areas for a criterion is visualized as a geographical representation of a set of preferences (Chen et al. 2009; Al-Shalabi et al. 2006). Generated criterion maps are overlaid using weights that are established by MCDM methods (Chen et al. 2009; Carver 1991). Based on the thereby calculated suitability levels, alternatives can be compared, ranked and the best result selected in the decision making process (Sánchez-Lozano et al. 2013; Al-Shalabi et al. 2006; Delgado, Sendra 2004).

Comber et al. (2015), Pontius and Si (2015), Rikalovic et al. (2014) and Malczewski (2006) list MCDM methods that are most commonly used in the GIS environment for geo-computation and suitability analysis, which are Boolean Overlay, Analytic Hierarchy Process, Weighted Linear Combination, Ordered Weighted Averaging, outranking methods, and Multiple-Objective Land Allocation. Furthermore, Pontius and Si (2015) provide a brief description of most methods. Chen et al. (2009) identifies the AHP as one of the most popular methods to obtain weights, too. For instance, GIS-AHP integration is used for warehouse site selection (Vlachopoulou et al. 2001), housing area identification (Al-Shalabi et al. 2006) or industrial site selection (Rikalovic et al. 2014). Özceylan et al. (2016b) and Sánchez-Lozano et al. (2013) extended the GIS-AHP approach by assessing the similarity to ideal solutions using the TOPSIS technique for evaluating solar farm locations and freight villages. Özceylan et al. (2016a) offers in their study on logistic performance evaluation of provinces the most extensive use of GIS-based MCDM by comparing five, three-steps approaches using combinations of the MCDA methodologies AHP, ANP, TOPSIS and equal weights. That way, the difference of weighting and ranking based on the relations between criteria (AHP, ANP), the improvement potential of criteria (TOPSIS) and equal weights of criteria is evaluated.

GIS-MCDM literature is reviewed and compared to identify the similarities and differences in the steps that are processed in publications on site selection and evaluation. *Figure 1* displays the outcome of the research. Six steps are identified of which the definition of evaluation criteria, the suitability analysis and recommendation for decision makers are mentioned most frequently. Although the step of establishing a data base is not mentioned in many publications, it is necessary to be able to conduct a suitability analysis. Furthermore, the publications vary in the degree to which problems and goals are defined. The main difference lays in the conduct of a sensitivity analysis (SA). Based on these findings, the methodology of a GIS-based MCDA for 3PL selection is built in the following chapter.

Steps / Publication	Vlachopoulou et al. (2001)	Eldrandaly et al. (2003)	van Thai, Grewal (2005)	Al-Shalabi et al. (2006)	Trubint et al. (2006)	Sánchez-Lozano et al. (2013)	Rikalovic et al. (2014)	Özceylan et al. (2016a)	(Özceylan et al. 2016b)	This paper
Problem and goal definition			x	x	x		x			x
Definition of evaluation criteria	x	x	x	x	x	x	x	x	x	x
Establishment of a data base		x			x	x	x	x	x	x
Suitability analysis	x	x	x	x	x	x	x	x	x	x
Sensitivity analysis	x			x		x			x	x
Recommendation for decision maker	x	x			x	x	x	x	x	x

Figure 1: GIS-based MCDM

3 Methodology

The aim of this paper is to develop an approach that supports decision making in selecting the best 3PL provider based on a set of spatial and non-spatial criteria. The literature review demonstrated that publications on 3PL selection are limited to MCDM methods (see *2.2.1*. Hence, in order to pay more attention to include spatial factors in the analysis, a GIS-based MCDM approach for 3PL selection is proposed hereinafter.

To be able to grant a sufficient robustness of this approach, the three components of a reliable model, verification, validation and SA, are taken into account (Qureshi et al. 1999). By being built based on the literature review in *Figure 1*, it is ensured that the approach accurately implements its specifications (verification) and that it is suitable for the intended purpose (validation). Furthermore, a SA is integrated to examine the robustness of the outcome when input weights are systematically altered within a specific range of interest (Qureshi et al. 1999).

3.1 GIS-based multi-criteria decision-making approach

The suggested GIS-based MCDM approach for 3PL selection is displayed in *Figure 2*. Following the literature review in *Figure 1*, six sequential steps are distinguished.

First of all, a framework needs to be established by defining the problem and goals. Therefore, a supply chain analysis is used to determine the initial situation and performance from which, subsequently, improvement potential can be deducted and constraints be defined.

In the next step, spatial and non-spatial evaluation criteria and sub-criteria for 3PL selection are chosen from existing literature (see *Figure 3*). Their respective, relative weights are computed using the MCDM method AHP and the consistency ratio (CR) of each criteria matrix is calculated to ensure appropriate consistency. This method is a common approach for weight determination and is successfully applied by numerous authors (Jihene 2014; Rikalovic et al. 2014; Al-Shalabi et al. 2006; Vlachopoulou et al. 2001). Therefore, a short chapter explains the process of obtaining weights by applying AHP.

In the third phase, a database must be established. Here, a screening phase in line with Sharma et al. (2017), Rikalovic et al. (2014), Jharkharia and Shankar (2007), and Eldrandaly et al. (2003) is implemented in which possible alternatives are determined that meet the basic criteria. This offers the advantage that the time required for decision making is reduced and the efficiency and quality of the decision-making process is increased. Furthermore, criteria layers are created and prepared for the GIS environment.

Following Sharma et al. (2017), Rikalovic et al. (2014) and Eldrandaly et al. (2003), in the subsequent evaluation phase the most appropriate 3PL provider is determined by comparing the possible alternatives. Therefore, spatial information of the criteria layers is analysed with spatial analysis tools and non-spatial information is evaluated using a rating scheme. To determine the degree of suitability of 3PL providers, the suitability scores of each criterion and 3PL alternative are weighted and summed up.

Afterwards, the robustness of the outcome is determined by changing criteria weights within the scope of a SA and a final ranking of the alternatives is compiled. This is done by following four steps proposed by Chen et al. (2010).

In the last step, the results of both the suitability and sensitivity analyses are summarized and a final decision is proposed to the decision maker. Additionally, the respective improvement against the initial situation can be assessed.

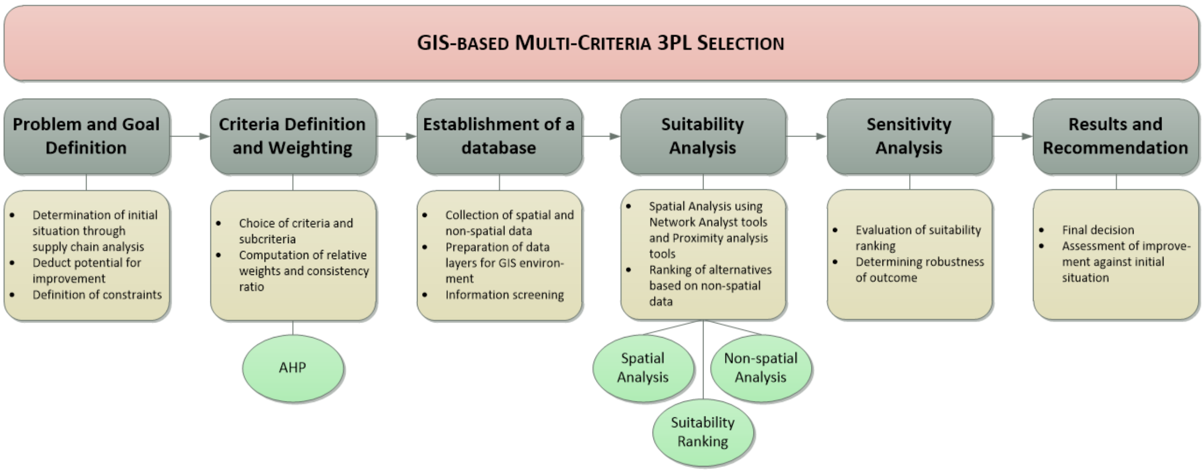

Figure 2: Overall methodology for GIS-based multi-criteria 3PL selection

3.2 Choice of criteria

The definition of selection criteria for the identification of optimal locations is vital (Rikalovic et al. 2014). Criteria can either be described by qualitative or quantitative attributes that define the degree of feasibility or suitability to the company's goals (Vlachopoulou et al. 2001).

This study proposes that the 3PL selection problem can be addressed using nine sub-criteria within the three criteria: service portfolio, logistics costs and location factors. According to Aguezzoul's (2014, p. 75) study, the criterion cost is mentioned most often (13.4%), services rank on place 3 (12.2%) and location scores the penultimate place (4.7%). In their study, Meidutė-Kavaliauskienė et al. (2014) identify service factors as most important followed by costs while location factors are not examined. A summary of the chosen criteria can be seen in *figure Figure* 3.

3.2.1 Service portfolio

Selecting the right 3PL depends on the company's expectations and needs and the 3PL's ability to fulfil these (Aghazadeh 2003). Many authors evaluated and chose 3PL based on their service portfolio (see *Figure 3*). Thus, the service portfolio is considered the most important factor in 3PL selection and is defined by the breadth or specialization of available services (Aguezzoul 2014). In the following, this is summarized under the heading 'available service variety'. While in the beginning, only transportation and distribution functions were offered, the portfolio of today's 3PL also include warehousing, inventory management, order processing, IT services and more value added services (Aguezzoul 2007). Among these services, warehousing is the most often outsourced logistics activity (Moberg, Speh 2004). Following Aguezzoul (2007), for the evaluation the services are categorized in these six groups. The other and more important factor is the service quality because it determines the customer satisfaction and loyalty and hence the business success of the company (Meidutė-Kavaliauskienė et al. 2014).

While the number of available services can easily be quantified by counting, the service quality is hard to measure (Meidutė-Kavaliauskienė et al. 2014). A common approach is it to determine the difference between the provided service level and the customer's expectation (Meidutė-Kavaliauskienė et al. 2014; Abdur Razzaque, Chen Sheng 1998). In order to do so, both Meidutė-Kavaliauskienė et al. (2014) and So et al. (2006) conduct a customer survey using a five-point rating scale. While So et al. (2006) are evaluating the service quality of 3PL providers using the five service quality dimensions tangibles, reliability, responsiveness, assurance and empathy which are proposed as SERVQUAL criteria by Parasuraman, Zeithaml and Berry (1988, 1991); Meidutė-Kavaliauskienė et al. (2014) are examining twelve logistics services, such as transportation and warehousing.

In this paper, the service quality of a 3PL is evaluated based on the information provided on their homepages. This approach is chosen because surveying customers of 3PLs to which a company wants to outsource activities is not considered a common approach from a company's point of view. Furthermore, the internet homepage is regarded as the platform where a company first comes in contact with a 3PL provider and based on which it decides if the 3PL should be considered in the following selection process or not. Following So et al. (2006), the service quality is measured along a five-point rating scale with the dimensions outstanding (5), good (4), average (3), fair (2) and poor (1). Since some services are favored over others, a weight is assigned to each service based on its importance for guaranteeing a smoothly operating supply chain. For that purpose, weights between not important (1) and essential (3) are used.

3.2.2 Logistics costs

In general, the main components of logistics costs are cost of procurement, storage, transportation and warehouse management (Stępień et al. 2016). The supply chain consulting firm Establish assessed the importance of them at approximately 2%, 26%, 50% and 22% (Establish Inc. 2011, p. 19) while another supply chain and economic development consultancy Foremost Quality Logistics identifies shares of approximately 1%, 23%, 63% and 13% (Foremost Quality Logistics 2014, p. 2). These numbers illustrate that major cuts in logistics costs can especially result from minimizing transportation expenses.

With regard to the 3PL selection problem, logistics costs derive from the cost of logistics outsourcing (Aguezzoul 2014). Thus, from a supply chain perspective, they can be divided in inbound, 3PL and outbound costs. Inbound costs refer to procurement, import and transportation costs towards the 3PL, while outbound costs comprise the distribution costs from the 3PL towards the customer. The cost structure of a 3PL differs from the storage and warehousing costs mentioned above. It consists of five elements: the cost of initial set-up, receiving, storage, order fulfilment, and shipping (insightQuote Inc. 2017).

3.2.3 Location factors

The location of a logistics facility ranks among the most crucial strategic decisions (Demirel et al. 2010). Its attractiveness depends in particular on its accessibility which can be expressed by means of distance or transportation cost (Verhetsel et al. 2015). In connection with location factors in 3PL selection, attributes such as distribution/ geographical or market coverage, international scope, shipment destinations, and distance are mentioned most often (Aguezzoul 2014). However, these dimensions rather describe outbound logistics attributes than illustrating the whole supply chain. In their study on location choices of logistics companies in Flanders, Belgium, Verhetsel et al. (2015) identify a ranking of site selection factors based on the outcome of a conducted stated choice experiment. The most important factor is the cost of land rent and the least important factor is a location in a business park. All examined infrastructure characteristics, such as the proximity to a sea port, motorway junction, inland navigation terminal and to a rail terminal, appear to have the same importance. These infrastructure connections should preferably be available within 10 km, 5 min, 15 km and 5 km respectively (Verhetsel et al. 2015). However, Verhetsel et al. (2015) examine companies that are specified in freight transport. Hence, given values do not necessarily apply one-to-one to 3PL providers. Nevertheless, the factors have their justification in the 3PL selection process as they present inbound as well as outbound logistics points. Yet, their use as sub-criteria depends on the structure of the company’s supply chain.

Criteria and sub-criteria		Explanation	Literature on 3PL selection													Literature on logistics location selection				
			(Moberg, Speh 2004)	(Aguezzoul 2007, 2014)	(Göl, Çatay 2007)	(Jharkharia, Shankar 2007)	(Farzipoor Saen 2010)	(Gupta et al. 2011)	(Falsini et al. 2012)	(Ho et al. 2012)	(Bansal, Kumar 2013)	(Jihene 2014)	(Meidutė-Kavaliauskienė et al. 2014)	(Alkhatib et al. 2015)	(Jung 2017)	(van Thai, Grewal 2005)	(Demirel et al. 2010)	(Żak, Węgliński 2014)	(Verhetsel et al. 2015)	(Kahraman et al. 2016)
Service portfolio	Available service variety	Given by the number of available services which are categorized in transportation, warehousing, inventory management, order processing, IT services and value-added services	x	x	x	x		x			x		x	x						
Service portfolio	Quality of services	Given by the degree to which available services fulfil the company's needs measured on a scale from 1 to 5. Certifications are taken into account, too.		x	x	x		x	x	x	x	x	x	x	x					
Logistics cost	Inbound cost [€]	Given by the procurement costs from the factory to 3PL including cost of transportation and import of goods (customs, other fees)															x			
Logistics cost	3PL cost [€]	Given by the cost of initial setup, receiving, storage and order fulfilment	x	x	x	x	x	x	x	x		x	x		x	x	x	x		x
Logistics cost	Outbound cost [€]	Given by the transportation cost to the single customers		x	x				x		x	x				x	x		x	
Location factors	Proximity to inbound logistics points [km]	Given by the distance to production facilities, sea ports or airports used in the supply chain.														x	x		x	x
Location factors	Proximity to major infrastructure [km]	Given by the distance to the road network.									x					x	x	x	x	x
Location factors	Proximity to outbound logistics points [km]	Given by the distance to further SC-partners involved in the distribution process as well as the distance to customers representing the shipment destinations.		x	x	x	x	x			x					x	x	x	x	x

Figure 3: Evaluation criteria

3.3 Determination of weights using the Analytic Hierarchy Process

In order to specify the weights of the previously defined criteria, Saaty's AHP is applied. The procedure is chosen because it weighs each criterion and establishes a total score for each 3PL by summarizing the product of criteria performance and its respective weight (Aguezzoul 2007). Although the method is based on a simple algorithm (Özceylan et al. 2016a), it effectively helps to reduce the complexity of a decision problem by successively examining pairwise comparisons in a hierarchical order (Feizizadeh, Kienberger 2017; Al-Shalabi et al. 2006). By making use of this extensive, logical and structural framework, decision alternatives are easily sorted from the most to the least desirable (Feizizadeh, Kienberger 2017; Al-Shalabi et al. 2006).

AHP consists of three underlying principles: decomposition, comparative judgments and synthesis of priorities. In the decomposition phase, the complex decision problem is broken down into its elements. By arranging these elements in a hierarchical order of criteria, sub-criteria and so on, the problem is structured from the generally applicable to the more specific factors. In the next phase, elements of the same hierarchy level are compared in a nxn matrix A using the pairwise comparison method and the verbal judgments of preferences between alternatives given in *Figure 4*. Thereby, the decision maker's knowledge can be incorporated. Possible values range from $^1/_9$ to 1 and through to 9, representing the least, equal and most important criterion. Since the reciprocal value is automatically entered for the transpose, $n(n-1)/2$ comparisons are made (Saaty 1987).

Verbal judgements of preferences between alternative *i* and alternative *j*	**Numerical rating**
A_i is equally important to A_j	1
A_i is slightly more important than A_j	3
A_i is strongly more important than A_j	5
A_i is very strongly more important than A_j	7
A_i is extremely more important than A_j	9
Intermediate values	2, 4, 6, 8

Figure 4: Verbal judgments of preferences between alternatives (Saaty 1987)

From this point, there are several ways to generate the weights. In the chosen approach, matrix A is normalized by dividing each judgment a_{ij} by the corresponding column sum. The relative weights w_n of the single criterion or sub-criterion are obtained by computing the average of the corresponding row of the normalized matrix A'. Since human judgment can cause inconsistency, the obtained weights need to be verified. Therefore first, the vector x_n is computed by multiplying the normalized matrix A' with the relative weights vector w_n, then the eigenvalue is calculated using the formula $\lambda_{max} = average\{\frac{x_1}{w_1}; \dots; \frac{x_n}{w_n}\}$. Next, the consistency index CI is calculated by the formula $CI = (\lambda_{max} - n)/(n - 1)$ and the result is divided by the corresponding random consistency index RI given in *Figure 5* to obtain the consistency ratio CR. The value of CR has to fall between 0.01 and 0.10 in order to be reliable. In case of a high inconsistency ($CR \geq 0.10$), the judgments can be revised (Saaty 1987).

n	2	3	4	5	6	7	8	9
$RI(n)$	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Figure 5: Random consistency index (Saaty 1987)

After all relative weights w_n are obtained, the global weights w'_n can be calculated by multiplying the relative weights of the criteria with the relative weights of the sub-criteria and so on. This step forms the last phase of the AHP procedure which is called synthesis of priorities (Saaty 1987).

One disadvantage of the AHP is, that it does not take existing interactions among criteria and sub-criteria into account like the Analytic Network Process (ANP) (Özceylan et al. 2016a). However, it is one of the most popular MCDM technique for dealing with complex decision problems because of its reputation as a robust and flexible MCDM tool among the international scientific community (Sánchez-Lozano et al. 2013).

3.4 Establishment of a database

In order to establish the database, spatial and non-spatial data is collected. While spatial data consist of a location or spatial relationship, shape, size and orientation; non-spatial data does not have a specific location in space but can be linked to one in order to provide further information such as region names or population (Surve, Kathane 2014). In a GIS, data is in general organized by separate map layers which can be displayed in the vector or raster model (Bruno, Gianniskos 2015; Rikalovic et al. 2014; Church 2002). In the vector representation, geometric features are displayed as points, lines or polygons and thus ensure a high level of precision (Aber, Aber 2017; Surve, Kathane 2014; Church 2002). The raster representation is characterized by a continuous, regular grid of rectangular cells (Aber, Aber 2017; Surve, Kathane 2014; Church 2002).

3.5 Spatial analysis

While manipulation on vector data comprise transforming and combining basic geographic features, raster data is manipulated by execute mathematical operations and functions through map algebra (Pontius, Si 2015). According to Rikalovic et al. (2014), most commonly, analyses of attributive data, overlapping layers, distances or networks are done. In order to perform the spatial analysis, the industry-standard software ArcGIS 10.4.1 from ESRI is selected (Aber, Aber 2017).

In ArcGIS, four different toolsets are available: extract, overlay, proximity, and statistics (Esri 2017). *Proximity tools* are able to identify features that are closest to one another (Esri 2017). Moreover, they can calculate the distance between or around them (Esri 2017). Although the math tends to be more complex (Aber, Aber 2017), the analysis is conducted on vector data because in this way measurements can be made along roads, streams, or other linear networks (Esri 2017). For these cases, ArcGIS Network Analyst is used to determine the shortest route to a specific location within a given network of transportation routes (*Route tool*), the closest point to a given point or set of points (*Closest Facility tool*), or build areas with equal distances from a centre point along the transportation network (*Service Area tool*) (Esri 2017). In addition to that, network based, shortest distances between multiple points of origin and points of destination can be computed using the *Origin-Destination cost matrix tool*.

For the spatial analysis three tools are applied. The *Origin-Destination cost matrix* is used to compute all distances between possible 3PL providers and inbound logistics points such as production facilities, sea ports or airports, because several origin and destination points are involved. Inbound logistics points are selected as origins, while 3PL locations represent the destinations. In case the shortest distance between two points from different sets of data needs to be determined, the *closest facility tool* is used. This applies for the distance from 3PL locations to major infrastructure and from 3PL locations to outbound logistics points such as downstream SC-partners. In the former, highway conjunctions are used as facilities as suggested by Verhetsel et al. (2015), while in the latter the downstream SC-partners like forwarders or CEP service providers are chosen. For both runs, 3PL locations are selected as incidents, since the closest facility is allocated to an incident. In contrast to these network-based calculations, the distance to customers is measured as Euclidean distances using the *point distance tool*. This approach is chosen because in contrast to the other factors that represent regular transports, customer orders are subject to uncertain order frequencies. Moreover, distribution via forwarder or CEP service provider happens in a separately optimized network.

3.6 Suitability evaluation

The suitability of each alternative is calculated based on the same principle Al-Shalabi et al. (2006) used in his paper:

$$Suitability\ score = \sum subcriteria\ value * AHP\ weight$$

Although all results are measured in the same unit for each criterion, the single sub-criteria result cannot be simply ranked by the respective AHP weights because the value ranges differ strongly among the sub-criteria. Thus, in order to ensure that large values do not dominate small values, the results are first normalized (Feizizadeh, Kienberger 2017). Furthermore, when combining the different criteria to achieve the suitability score, the objective of each criterion needs to be considered: while the values for services are to be maximized, costs and distances need to be minimized. Thus, minimization criteria are converted into maximization criteria in order to achieve a common interpretation of the values by subtracting its value from 1 and subsequently normalizing the obtained result. The converted and normalized value is then used to calculate the final suitability score.

3.7 Sensitivity analysis

Diverse sources of uncertainty such as measurement errors in data acquisition, format conversions or insufficient information in the input data can have considerable impacts on the outputs (Delgado, Sendra 2004). In a spatial environment, a SA is used to examine the response of the model output to weight changes in input parameters by revealing particularly sensitive criteria, so called key determining variables, and to determine the spatial impacts on the model outcomes (Feizizadeh, Kienberger 2017; Chen et al. 2010; Crosetto, Tarantola 2010). Thereby, it can not only help to minimize uncertainty, but it also enables to improve the stability of its outputs (Feizizadeh, Kienberger 2017). The procedure encompasses evaluating changes in the outcome against variations in specific input parameters (Feizizadeh, Kienberger 2017; Chen et al. 2010; Crosetto, Tarantola 2010). Chen et al. (2010) identify three most commonly used SA approaches, namely changing criteria values, changing relative importance of criteria and changing criteria weights.

Delgado and Sendra (2004) reviewed 28 studies of SA application in GIS-based MCDM models concluding, among others, that conducting a SA is not a common practice and that if one is carried out, most of the times it is tested whether variations of the factor weights causes significant changes in the obtained results. Years later, Chen et al. (2010) still mention the same criticisms while emphasizing the importance of sensitivity analyses in GIS-based MCDM as a crucial step for determining the stability of the final outcome of a model, its systematic variation and for understanding the model behaviour and its limitations.

Following Chen et al. (2010), in the SA only criteria weights are altered to examine four specific aspects of interest:

1. ‘investing the stability of an evaluation by introducing a known amount of change to criteria weights;
2. identifying alternatives that are especially sensitive to weight changes;
3. quantifying changes in the rankings of criteria and evaluation; and
4. visualising the spatial change of evaluation results’ (Chen et al. 2010, p. 1585).

In doing so, attention is especially paid to the robustness of evaluation rankings relative to weight changes.

4 Case study

In order to test the proposed GIS-based MCDM approach for 3PL selection, a case study with a Finnish company is conducted. However, due to confidentiality concerns, only the criteria location factors and service portfolio are assessed in the following. Therefore, the aim of the case study is to determine a ranking of alternatives for the company. Based on this, the company can choose which 3PL providers to contact for price details. This section is organized following *Figure 2*.

The company considers product development, brand marketing and business to business (B2B) relationships as their core competence. Therefore, their production and the logistical processes, warehousing and distribution, are outsourced to specialized manufacturers, 3PL and CEP service providers. The company's distribution channels are divided into the three main markets: Europe, Asia and Northern America. Since this case study focuses on the European market only the European supply chain is outlined in *Figure 6*.

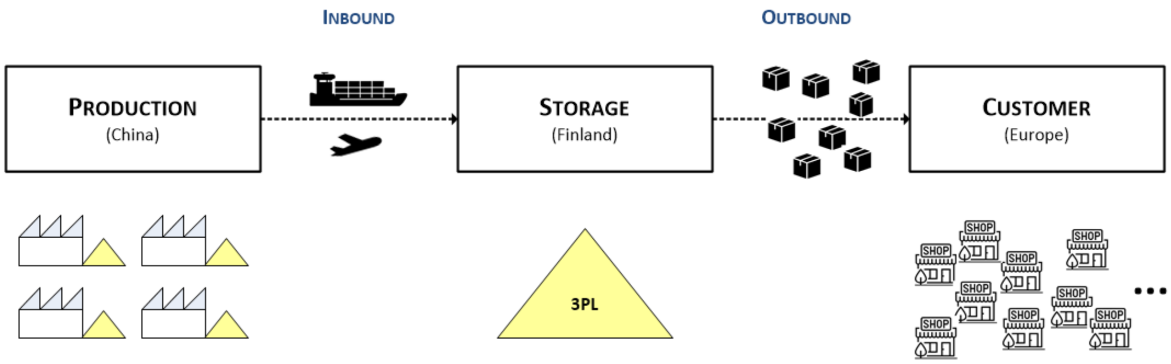

Figure 6: Qualitative outline of company's supply chain

Goods that have been produced in one of the four factories in China are shipped from Hong Kong to the warehousing provider in Finland. For inbound shipments, usually container ships are used but in exceptional cases more expensive airfreights can occur to ensure delivery capability to customers by making use of the significantly shorter lead times. From the Finnish warehousing provider, the goods are distributed by CEP service providers to the company's retail partners in Europe.

4.1 Problem, goal and constraint definition

In an interview with the decision maker, the framework of the project including problems, goals and constraints are identified and discussed. Relevant points are summarized subsequently.

With rising sales, the company recognizes disadvantages of their logistics location in Finland which are:

- High outbound logistics cost resulting from the CEP freight rates
- Long lead times for parcel shipments to customers in Central Europe
- Long waiting time for inbound shipments from Asia due to in port and transhipment times in other European harbours prior to unloading in Helsinki
- Usage of outdated IT interfaces which leads to unnecessary manual work and lower service levels

This suggests a relocation of the company's warehouse location to a Central European country. After some research, the company decided to choose the Netherlands as their logistics location because of its excellent logistics attributes and English skills of 3PL managers and employees. Thus, the study area is limited to the Netherlands. Another constraint is the available storage capacity for rent at the 3PL but due to the company size, too little storage space available is not to be expected. Hence, storage capacity is not considered as a constraint in the case study. Furthermore, the company selected Rotterdam as their port of unloading, Schiphol as their freight airport, and UPS and GLS as their main CEP provider.

The objectives of the 3PL selection can be summarized as following:

- One 3PL location is to be selected from where all, in Europe geographically dispersed customers shall be supplied
- Total logistics costs shall be minimized while customer service quality is to be maximized which is determined e.g. by short lead times and a high rate of on-time deliveries

Tasks that are outsourced by the company because they are not considered to be a part of their core competencies are:

- Activities related to the import of goods into the European Union like organizing shipments via ship or plane and truck, customs clearance and fiscal representation
- Inbound logistics services at the warehouse which include unloading, checking for damages, registration of goods and putting them away to assigned storage locations
- Outbound logistics services at the warehouse which include order management, picking, (customized) kitting, packing and labelling
- Freight management towards the customer which consists of selecting most favourable distribution solution depending on size, weight, destination and client wishes as well as the tack and trace of shipments

The listed tasks represent the minimum requirements on a suitable 3PL provider. Although many 3PL offer further supply chain related services, it is important for the company to handle demand planning and forecasting, inventory management including activities related to ensuring appropriate stock and low back order levels as well as customer service and invoicing internally. Therefore, these activities are not considered in the 3PL selection.

4.2 Define and weight evaluation criteria and sub-criteria

As described in chapter *3.3*, the generation of criteria and sub-criteria weights uses Saaty's AHP technique. *Figure 7* shows the underlying decision hierarchy used in this case study.

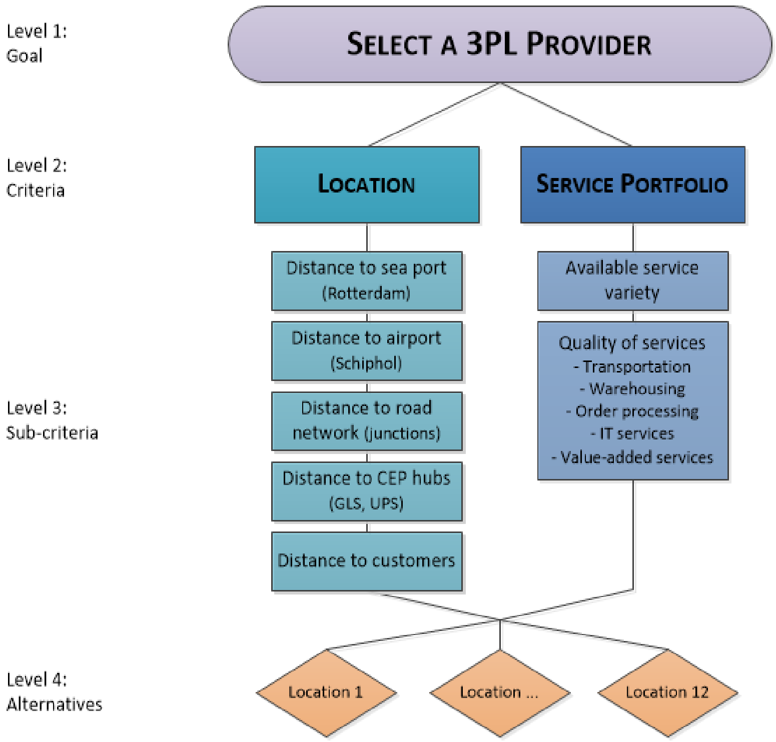

Figure 7: Decision hierarchy for selecting 3PL provider in the case study

Three separate, pairwise comparisons have been done together with the decision maker of the company to obtain the weights using the verbal judgments of preferences between alternatives given in *Figure 4*. In a next step, the consistency of the matrixes is to be verified in order to ensure the reliability of the decision maker. Since a comparison of two elements is always consistent and the critical ratio of the location factor matrix falls between the range of $0.01 < CR < 0.1$ given by Saaty (1987), a reasonable level of consistency is present and the weights can be used in the suitability analysis in *4.4*. The outcome of the AHP procedure is displayed in *Figure 8*. Furthermore, the three pairwise comparison matrices and consistency ratio can be found in appendix B. Next to calculating weights in the AHP procedure, Microsoft Excel is used to do the non-spatial analysis, for the final evaluation as well as the SA.

Criteria	Criteria weight	Sub-criteria	Sub-criteria weight	Global weight
Service portfolio (C1)	80%	Available service variety (C11)	25%	20.0%
		Quality of services (C12)	75%	60.0%
Location factors (C2)	20%	Distance to sea port (C21)	19%	3.8%
		Distance to airport (C22)	7%	1.4%
		Distance to road network (C23)	17%	3.5%
		Distance to CEP hubs (C24)	23%	4.6%
		Distance to customers (C25)	33%	6.6%

Figure 8: Criteria and sub-criteria weightings using AHP

4.3 Establishment of data base

The company provided data from November 2016 for analysis. November usually represents a time period with a high demand and thus serves as an appropriate starting point that already includes expectable market growth.

4.3.1 Spatial Data

The spatial data consists of seven data layers which are summarized in *Figure 9*. Location information is downloaded or collected online at given sources as well as provided by the company like customer data or locations of unloading. As CEP providers, the current standard providers of the company General Logistics Systems B.V. (GLS) or United Parcel Service of America Inc. (UPS) are used. After a brief online research, 18 hub locations in the Netherlands are identified. Suitable 3PL provider are identified using the search engine *Google* with the following search criteria: 'Third-party logistics provider' or 'warehousing provider' or 'supply chain solutions' and 'Netherlands'. Initially, ten companies with 26 possible location alternatives are selected. In the next step, the 3PL screening, their services are roughly compared, and the providers that do not offer price advantages at parcel shipments due to their large buying power are excluded. Finally, six companies with 12 possible location alternatives remain for the analysis. All available addresses are geocoded by converting them into their latitude and longitude coordinates using an online tool (available at *www.latlong.net*).

Data	Metadata	Type	Source
Netherlands	Layer shows the area of the Netherlands.	Vector: Polygon	www.gadm.org/download
European Road Network	Layer shows the highways in Europe.	Vector: Line	www.gadm.org/download
Customer Location	Layer shows the location of 58 customers which are considered as most important.	Vector: Point	Company data
CEP Hub Locations	Layer shows the location of 18 CEP hub locations in the Netherlands of which 12 are operated by GLS and six by UPS.	Vector: Point	www.gls-info.nl/dp/All www.ups.com/dropoff#
Sea port	Layer shows the location of the port of unloading, Rotterdam.	Vector: Point	Google maps
Airport	Layer shows the location of the freight airport Schiphol.	Vector: Point	Google maps
3PL locations	Layer shows the 12 alternative locations which are ranked according to their suitability.	Vector: Point	www.janssen1877.com/ www.glgbv.com/ www.vcklogistics.com/ www.bas.eu/ www.nl.dsv.com/ www.b-logicservices.com/

Figure 9: Spatial data

4.3.2 Non-spatial Data

The non-spatial data consists of the service attributes of the six 3PL providers. Available services are assigned to one of the five headings transportation, warehousing, order processing, IT services and value-added services given in Aguezzoul's (2007) research. This differs slightly from *chapter 3.2* because the company is not interested in services regarding demand planning and forecasting, inventory management and customer services like invoicing as specified in *chapter 4.1*. Thus, they are not considered in the evaluation. Next, related tasks are assigned to each heading and the importance of the task is defined on a scale from 1 (less important) to 3 (very important).

In order to complete the list, the 3PL's homepage is scanned for descriptions of services. The provided service information is evaluated on a scale from 1 (poor) to 5 (outstanding) as described in *3.2* in order to differentiate between the single 3PLs. The thereby generated list can be found in appendix C.

4.4 Suitability Analysis

The analysis in ArcGIS starts with geocoding the spatial information described in *4.3.1*. Thereby, the study area is visualized in a map which is shown in *Figure 10.*

Figure 10: Study area

The following suitability analysis consists of three elements: a non-spatial analysis, a spatial analysis, and the subsequent combination of both to evaluate the suitability of each alternative. The sequence in which the analyses are done depends on the hierarchy of the criteria and its weight in the final suitability evaluation. After each analysis has been carried out, a map is created which visualized the ranking of alternatives by using a colour code that ranges from dark green (best location) to red (worst location). Thus, following for example Rikalovic et al. (2014) or Al-Shalabi et al. (2006), both criteria are represented by a map.

4.4.1 Service portfolio

The service portfolio of a 3PL is evaluated in MS Excel based the non-spatial database created in *4.3.2*. Since some services are more important than others, the availability and quality scores are multiplied by the importance weight to further differentiate the 3PL's service portfolio. For each alternative, the weighted availability (C11) and quality (C12) scores are summed up, normalized and further weighted according to the formula:

$$C1 = 0.25 * C11 + 0.75 * C12$$

The result gives the service portfolio score C1 for each 3PL. Since it is a maximization criterion, the largest value (0.0895, A6) is ranked on place 1 while the lowest value (0.0700, A11) obtained rank 12. *Figure 11* shows the spatial distribution of service portfolio analysis. While four of the five alternatives that ranked highest, are located in the East to South-east of the Netherlands (A6, A1, A7, A5), one can be found in the South-west of the country (A3). The alternative with the weakest service portfolio, A11, is located in the North-west at the Markermeer.

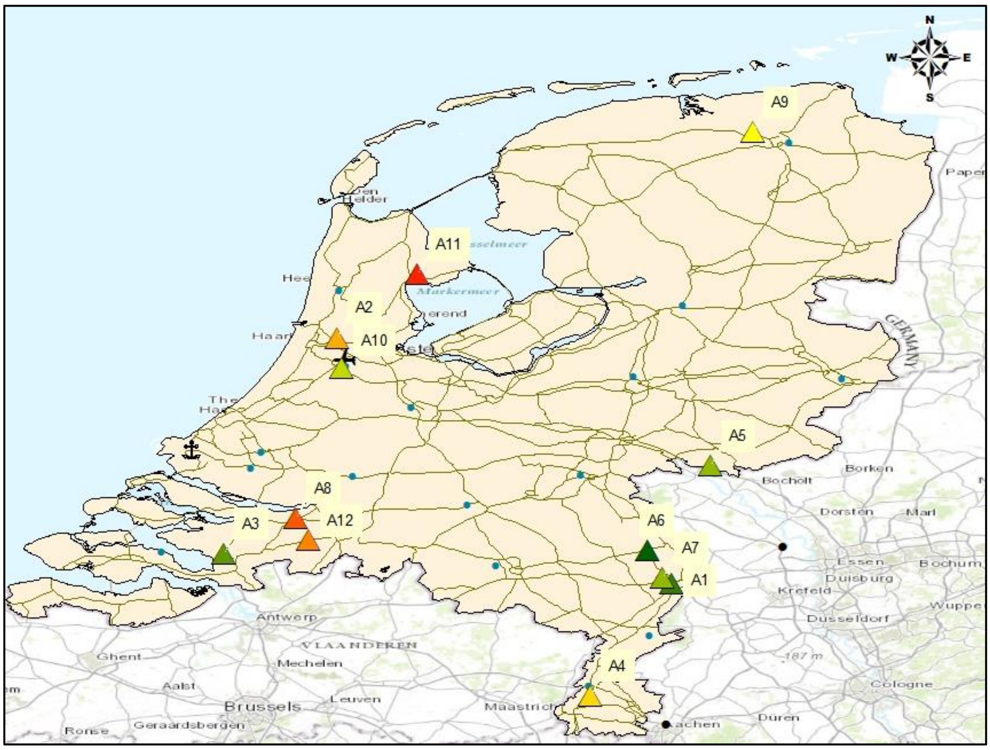

Figure 11: Service ranking (map)

4.4.2 Location factors

The location factors are evaluated using spatial analysis tools in ArcGIS. The goal of the spatial analysis is to determine the distances of a 3PL location to the sea port in Rotterdam, the airport Schiphol, to the highway network and to the CEP hub network as measures of accessibility. In order to do so, the two tools *origin-destination cost matrix* and closest facility from the network analyst extension are used as described in *0*. Further analysis of the outputs takes places after they have been exported to MS Excel. The average distances are 144.5 km, 117.2 km, 3.1 km and 25.4 km respectively measured on the actual road network. Next, the distance to the customers is measured by the Euclidean distance between the 3PL location and the customers by using the point distance tool. All distances can be seen in *Figure 17*.

The value of C2 determines the suitability of each alternative in regard to their location attributes. It is calculated using the following formula:

$$C2 = 0.19 * C21 + 0.07 * C22 + 0.18 * C23 + 0.23 * C24 + 0.33 * C25$$

Since shorter distances are preferred, C2 is a minimization criterion. Thus, the lowest value (0.0489, A10) is ranked on place 1 while the larges value (0.1451, A5) obtains rank 12. In *Figure 12*, the outcome of the spatial analysis is visualized in a map. The best and second-best alternatives, A10 and A2, are located close to Amsterdam. Alternatives that are ranked on the third and fourth place, can be found in Venlo (A1, A7). These four sites offer the best values for C1. The four worst locations are in the North (A9), South-West (A3, A12) and East (A5).

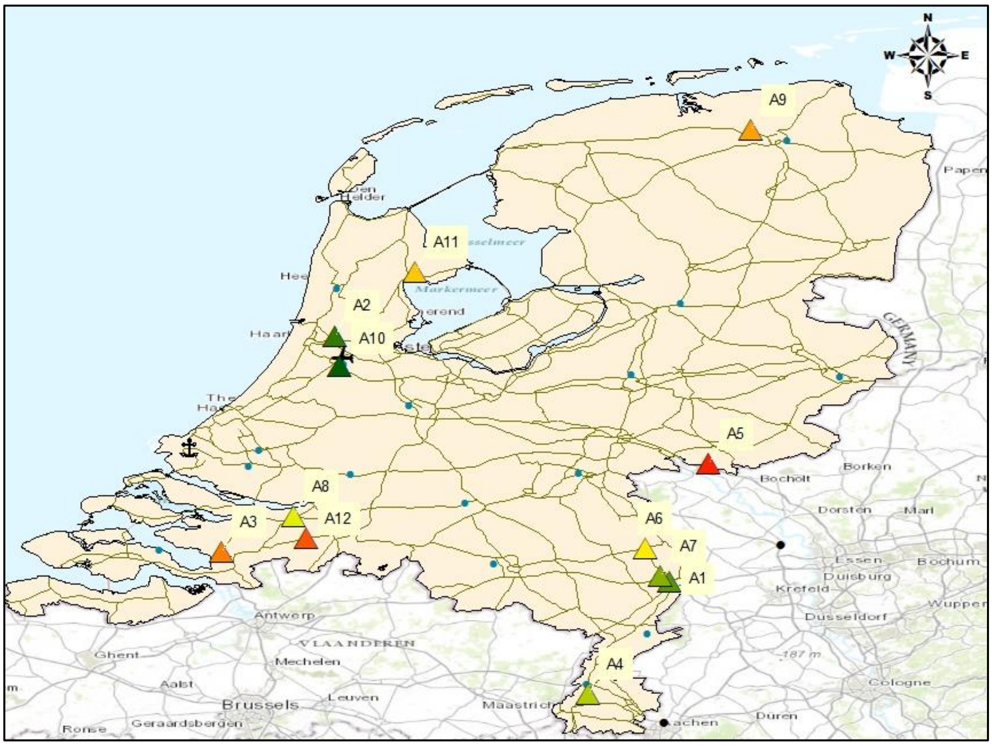

Figure 12: Location factors (map)

4.4.3 Suitability evaluation

In the suitability evaluation, the results of both previously done analyses are combined using their weights. As C1 is a maximization and C2 a minimization criterion, C2 is converted in a maximization criterion to achieve a common interpretation of the values. Therefore, the value of C2 is subtracted from 1 and then normalized to generate C2'. The suitability of a 3PL can then be calculated used the formula

$$Suitability = 0.8 * C1 + 0.2 * C2'$$

The final outcome is shown in *Figure 13*. Five alternatives are suitable and marked in green (A6, A1, A7, A3, A10), the three yellow alternatives (A4, A9, A5) have a fair suitability score and four are displayed in orange to red (A2, A8, A12, A11), which hints for a low suitability.

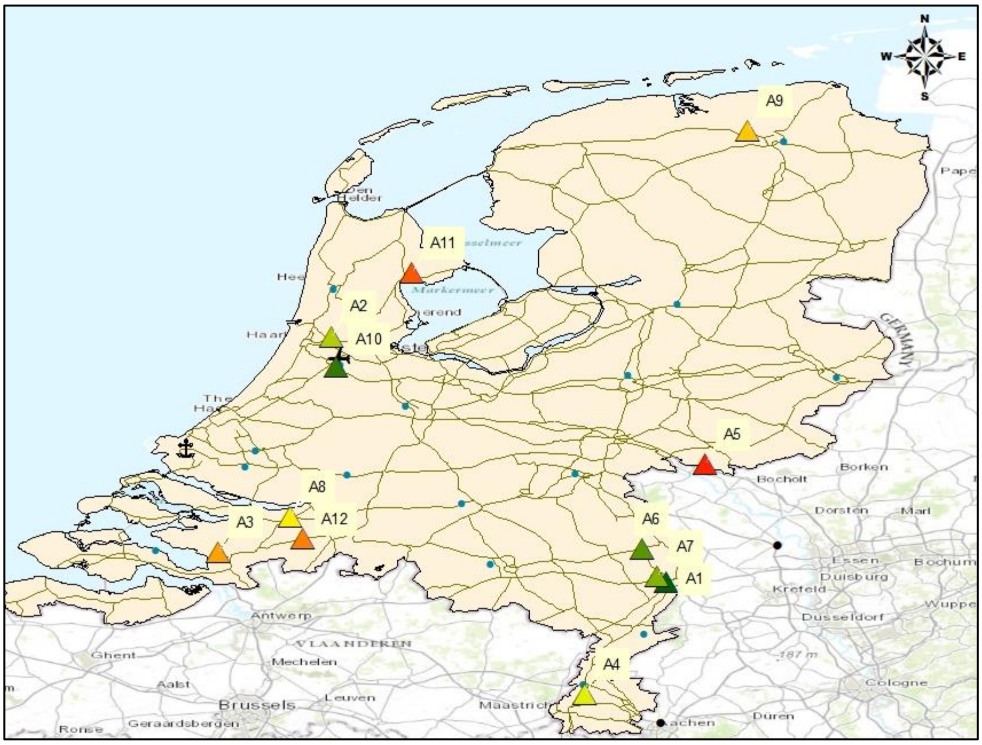

Figure 13: Suitability ranking (map)

4.5 Sensitivity analysis

In order to evaluate the robustness of the outcome a SA is conducted. Thereby, it is examined how a 5% change in the weighting ratio of location and service factors affects the final ranking of the alternatives. The output is tested within a range of ± 10% around the weighting in the suitability evaluation, because the decision maker pointed out in the interview that service factors are more important than location factors. In appendix E, *Figure 19* displays the result of the SA and spatial changes within scenario 1, 3 and 5 are visualized in *Figure 20*.

In all five test scenarios, four alternatives (A6, A1, A9, A11) keep their ranking which includes the best and second-best rank. As the influence of location factors rises, one alternative loses one rank (A12) while four alternatives improve their rating by one rank (A7, A10, A2, A8). In two cases, the change accounts for two ranks (A3, A4) and only once, an alternative loses three positions (A5). In general, the smaller the effect of a change in the input weights or values, the more robust is the output. Thus, A6, A1, A9 and A11 are considered very robust while A5 is the most sensitive alternative to changes in the final weighting.

4.6 Results and recommendation for the decision maker

In this section, the findings of the suitability and sensitivity analysis are discussed. Starting with the individual analyses of potential explanations for the results are presented. Next, conclusions based on the conducted SA are drawn and finally a recommendation for the decision maker is given.

In the non-spatial analysis, the service attributes of the 3PL providers are compared based on the information given on their homepages. Five out of twelve 3PL alternatives are regarded as convincing alternatives and most of them are located in the East of the Netherlands with focus on the area around Venlo.

The spatial analysis of the 3PL locations reveals two areas of interest: around Amsterdam and Venlo. When looking at the data of the top 4 in *Figure 17*, the major differences between the alternatives in these areas and the other alternatives becomes apparent. All four alternatives have similar values for outbound related activities like distance to the road network and CEP network. While the alternatives close to Amsterdam (A10, A2) are characterized by short distances to the unloading points for inbound shipments at the harbour of Rotterdam and the main benefit of the alternatives close to Venlo (A1, A7) lies in the proximity to the customers.
Since the distance to customers is one of the company's reasons for the relocation of the warehousing activities, it has the largest weight and can outweigh greater distances in the inbound process. However, this is only possible to a certain degree (see A4, A6 and A9 which offer a similar structure). The main disadvantages of alternatives A3, A12 and A5 are bad connections to the road and CEP hub network.

When combining both analyses by using a weight of 80% for the service portfolio and 20% for the location factors, only the area around Venlo with the alternatives A6, A1 and A7 remain of interest. Furthermore, the outcome of the SA confirms the robustness of the ranking regarding the top 5 and last 4 alternatives. Noticeable changes are only expected for alternatives A4 and A5. Thus, it is advisable to choose the top three alternatives A6, A1 and A7.

5 Discussion

Rikalovic et al. (2014) find that location decisions greatly impact the key measures of a company's supply chain performance. Nevertheless, literature on 3PL selection does not include location factors to a great extent (see *Figure 3*).

This paper contributes to the existing literature by proposing a GIS-based MCDM approach for 3PL selection consisting of six sequentially processed steps in which 3PL provider are evaluated based on the three criteria: service portfolio, logistics costs and location factors. Trustworthy results are achieved by combining weight determination using AHP with spatial analysis capabilities of GIS and a subsequent SA. Based on the generated ranking of alternatives, the decision maker can purposively select 3PL providers. A conducted case study proves that the proposed approach helps to find the best alternative and thus that the approach offers the anticipated performance. Even if data is missing for some the sub-criteria, the proposed approach can still be successfully applied to reduce the number of alternatives to a manageable amount that ensures better clarity in further activities.

The main difference to other papers is the fact that 3PL selection is conducted in form of a spatial MCDA instead of a common MCDA like Jharkharia and Shankar (2007), Jihene (2014) or Gürcan et al. (2016) did. Hence, location factors are considered as a main criterion itself and can be differentiated in the three general sub-criteria proximity to inbound logistics points, major infrastructure, and outbound logistics points. The major advantage of conducting a spatial MCDA in GIS is that 3PL provider in unsuitable areas can be identified and excluded from the analysis right from the start. This is important to ensure a cost-effective flow and storage of goods within the SC (Żak, Węgliński 2014).

Furthermore, criteria are set in line with supply chain processes around the 3PL. This way, the central position of a 3PL in the SC is emphasized and sub-criteria are differentiated between inbound and outbound related factors. Given this framework, decision makers can add related sub-criteria and assign weights established using the AHP when necessary. Thus, the approach can be easily adjusted for the practical needs of a company. Moreover, that way, Al-Shalabi et al.'s (2006) call for more systematic frameworks for handling MCDM problems while considering suitability concerns is fulfilled.

6 Conclusions, limitations and future research

In this paper, the process of developing a GIS-based MCDM approach for 3PL selection is demonstrated and the final model is presented and successfully applied. Nine sub-criteria within the three criteria, service portfolio, logistics costs and location factors, are chosen based on a literature review and considered in the model. The AHP method is used for defining the criteria weights applied in the suitability analysis. Finally, the robustness of the results is examined in a SA and recommendations are derived. This six-steps model is tested in a case study on twelve alternative 3PL locations in the Netherlands. Based on the results, it is concluded that although the importance of location criteria cannot compete with service criteria, the incorporation of spatial factors helps to determine areas of interest and thus to reduce the number of alternatives to a manageable amount. Hence, decision makers benefit from incorporating location factors in the selection process because unsuitable locations and areas can be excluded at an early stage. Another advantage of the proposed methodology is the holistic and supply chain oriented view.

The approach is limited by the little number of criteria considered as well as by the available data in the case study. However, the approach can easily be extended by adding more criteria and sub-criteria into the analysis as well as corresponding data. In addition to this, further improvement can be achieved by using the Analytic Network Process (ANP) for the weight generation which takes interactions among different criteria into account as indicated by Özceylan et al. (2016a). Since the current approach determines the best 3PL based on the given criteria, ranking can alternatively be based on the ideal solution using TOPSIS. Moreover, one can use the proposed methodology to develop a spatial decision support system for 3PL selection which integrated GIS, MCDM and operations research tools on one interface (Pontius, Si 2015). Thereby, building blocks and other add-ons needed for the implementation of e.g. AHP are provided at ESRI's ArcGIS suite of products (Rikalovic et al. 2014).

This paper highlights the lack of inclusion of spatial factors in the 3PL selection problem while demonstrating the benefits by developing and successfully applying a GIS-based MCDM approach which not only takes spatial but also structural considerations of the underlying supply chain into account.

Publication bibliography

Abdur Razzaque, Mohammed; Chen Sheng, Chang (1998): Outsourcing of logistics functions. A literature survey. In *Int Jnl Phys Dist & Log Manage* 28 (2), pp. 89–107. DOI: 10.1108/09600039810221667.

Aber, Susan Elizabeth Ward; Aber, Jeremy Ward (2017): Geographic Information Systems and Remote Sensing. In *Map Librarianship Elsevier*, pp. 71–85. DOI: 10.1016/B978-0-08-100021-2.00004-3.

Abidi, Hella; Leeuw, Sander de; Klumpp, Matthias (2014): Humanitarian supply chain performance management. A systematic literature review. In *Supp Chain Mnagmnt* 19 (5/6), pp. 592–608. DOI: 10.1108/SCM-09-2013-0349.

Aghazadeh, Seyed-Mahmoud (2003): How to choose an effective third party logistics provider. In *Management Research News* 26 (7), pp. 50–58. DOI: 10.1108/01409170310783583.

Aguezzoul, Aicha (2007): Third-party logistics selection: A Review of Literature. In *International Logistics and Supply Chain Congress* Nov 2007. DOI: 10.1016/j.omega.2014.05.009.

Aguezzoul, Aicha (2014): Third-party logistics selection problem: A literature review on criteria and methods. In *Omega* (49), pp. 68–78.

Alkhatib, Saleh Fahed; Darlington, Robert; Yang, Zaili; Nguyen, Trung Thanh (2015): A novel technique for evaluating and selecting logistics service providers based on the logistics resource view. In *Expert Systems with Applications* 42 (20), pp. 6976–6989. DOI: 10.1016/j.eswa.2015.05.010.

Al-Shalabi, Mohamed; Mansor, Shattri; Ahmed, Nordin; Shiriff, Rashid (2006): GIS Based Multicriteria Approaches to Housing Site Suitability Assessment. In *GIS Applications – Planning Issues - Shaping the Change* 10.

Bansal, Ankit; Kumar, Pravin (2013): 3PL Selection: a Multi-criteria Decision Making Approach. IEEE International Conference on Industrial Engineering and Engineering Management (IEEM),10 - 13 Dec. 2013, Bangkok, Thailand 2013. Piscataway, NJ: IEEE. Available online at http://ieeexplore.ieee.org/servlet/opac?punumber=6945926.

Boroushaki, Soheil; Malczewski, Jacek (2008): Implementing an extension of the analytical hierarchy process using ordered weighted averaging operators with fuzzy quantifiers in ArcGIS. In *Computers & Geosciences* 34 (4), pp. 399–410. DOI: 10.1016/j.cageo.2007.04.003.

Bruno, Giuseppe; Gianniskos, Ioannis (2015): Location and GIS. In Gilbert Laporte, Stefan Nickel, Francisco Saldanha da Gama (Eds.): Location science. Cham: Springer, pp. 509–536.

Carver, Stephen J. (1991): Integrating multi-criteria evaluation with geographical information systems. In *International journal of geographical information systems* 5 (3), pp. 321–339. DOI: 10.1080/02693799108927858.

Chen, Y.; Shahbaz, K.; Xevi, E. (2009): A GIS-Based Sensitivity Analysis of Multi-Critieria Weights. In *18th World IMACS/ MODSIM Congress, Carns, Australia*, pp. 3137–3143.

Chen, Y.; Yu, J.; Khan, S. (2010): Spatial sensitivity analysis of multi-criteria weights in GIS-based land suitability evaluation. In *Environmental Modelling & Software* 25 (12), pp. 1582–1591. DOI: 10.1016/j.envsoft.2010.06.001.

Cheong, Michelle L. F. (2003): Logistics Outsourcing and 3PL Challenges. Available online at https://dspace.mit.edu/bitstream/handle/1721.1/3908/IMST011.pdf.

Church, Richard L. (1999): Location modelling and GIS. In *Geographical information systems*, pp. 293–303. Available online at http://www.geos.ed.ac.uk/~gis-teac/gis_book_abridged/files/ch20.pdf.

Church, Richard L. (2002): Geographical information systems and location science. In *Computers & Operations Research* (29), pp. 541–562.

Comber, Alexis; Dickie, Jennifer; Jarvis, Claire; Phillips, Martin; Tansey, Kevin (2015): Locating bioenergy facilities using a modified GIS-based location–allocation-algorithm. Considering the spatial distribution of resource supply. In *Applied Energy* 154, pp. 309–316. DOI: 10.1016/j.apenergy.2015.04.128.

Crosetto, Michele; Tarantola, Stefano (2010): Uncertainty and sensitivity analysis. Tools for GIS-based model implementation. In *International Journal of Geographical Information Science* 15 (5), pp. 415–437. DOI: 10.1080/13658810110053125.

Delgado, Montserrat Gómez; Sendra, Joaquín Bosque (2004): Sensitivity Analysis in Multicriteria Spatial Decision-Making. A Review. In *Human and Ecological Risk Assessment: An International Journal* 10 (6), pp. 1173–1187. DOI: 10.1080/10807030490887221.

Demirel, Tufan; Demirel, Nihan Çetin; Kahraman, Cengiz (2010): Multi-criteria warehouse location selection using Choquet integral. In *Expert Systems with Applications* 37 (5), pp. 3943–3952. DOI: 10.1016/j.eswa.2009.11.022.

Eldrandaly, Khalid; Eldin, Neil; Sui, Dan (2003): A COM-based Spatial Decision Support System for Industrial Site Selection. In *Journal of Geographic Information and Decision Analysis* 7 (2), pp. 72–92.

Esri (2017): ArcMap. Edited by Esri. Available online at http://desktop.arcgis.com/en/arcmap/.

Establish Inc. (2011): Logistic Trends and Network Strategies. Presentation at the Chief Supply Chain Officer Summit in Chicago. With assistance of HWD & Grubb & Ellis Global Logistics. Edited by Establish Inc. Chicago. Available online at https://www.slideshare.net/tsfeemster/csco-summit-v1.

Falsini, Diego; Fondi, Federico; Schiraldi, Massimiliano M. (2012): A logistics provider evaluation and selection methodology based on AHP, DEA and linear programming integration. In *International Journal of Production Research* 50 (17), pp. 4822–4829. DOI: 10.1080/00207543.2012.657969.

Farzipoor Saen, Reza (2010): A New Look at Selecting Third-Party Reverse Logistics Providers. In *International Journal of Information Systems and Supply Chain Management* 3 (1), pp. 58–67. DOI: 10.4018/jisscm.2010092904.

Feizizadeh, Bakhtiar; Kienberger, Stefan (2017): Spatially explicit sensitivity and uncertainty analysis for multicriteria-based vulnerability assessment. In *Journal of Environmental Planning and Management* 59 (2), pp. 1–23. DOI: 10.1080/09640568.2016.1269643.

Foremost Quality Logistics (2014): Macro and Micro Economic and Industry Trends Impacting the Site Selection Decision. With assistance of Institute for Supply Management. Edited by Foremost Quality Logistics. Available online at https://www.slideshare.net/tsfeemster/macromicro-economics-logistrics-market-trends-impacting-site-selection-ism-apics-2014.

Göl, Hakan; Çatay, Bülent (2007): Logistics outsourcing and 3PL selection: A Case study in an automotive supply chain. In *Sabanci University, Istanbul*.

Greene, R.; Devillers, R.; Luther, J. E.; Eddy, B. G. (2011): GIS-based multiple-criteria decision analysis. In *Geography Compass* (5), pp. 412–432.

Gu, Wei; Foster, Krista; Shang, Jennifer (2016): Enhancing market service and enterprise operations through a large-scale GIS-based distribution system. In *Expert Systems with Applications* 55, pp. 157–171. DOI: 10.1016/j.eswa.2016.02.015.

Gupta, Rajesh; Sachdeva, Anish; Bhardwaj, Arvind (2011): Criteria of Selecting 3PL Provider: A Literature Review. In *International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering* 5 (11) 2011 (5 - 11), pp. 2345–2349. Available online at http://waset.org/publications/10355/criteria-of-selecting-3pl-provider-a-literature-review.

Gürcan, Ömer Faruk; Yazıcı, İbrahim; Beyca, Ömer Faruk; Arslan, Çiğdem Yavuz; Eldemir, Fahrettin (2016): Third Party Logistics (3PL) Provider Selection with AHP Application. In *Procedia - Social and Behavioral Sciences* 235, pp. 226–234. DOI: 10.1016/j.sbspro.2016.11.018.

Hamdan, Amer; Rogers, K. J. (2007): Evaluating the efficiency of 3PL logistics operations. In *International Journal of Production Economics* 113 (1), pp. 235–244. DOI: 10.1016/j.ijpe.2007.05.019.

Ho, William; He, Ting; Lee, Carman Ka Man; Emrouznejad, Ali (2012): Strategic logistics outsourcing. An integrated QFD and fuzzy AHP approach. In *Expert Systems with Applications* 39 (12), pp. 10841–10850. DOI: 10.1016/j.eswa.2012.03.009.

insightQuote Inc. (2017): Cost of 3PL services. Available online at http://www.3plcompanies.net/what-is-the-cost-of-3pl-services/.

Irizarry, Javier; Karan, Ebrahim P.; Jalaei, Farzad (2013): Integrating BIM and GIS to improve the visual monitoring of construction supply chain management. In *Automation in Construction* 31, pp. 241–254. DOI: 10.1016/j.autcon.2012.12.005.

Jharkharia, Sanjay; Shankar, Ravi (2007): Selection of logistics service provider. An analytic network process (ANP) approach. In *Omega* 35 (3), pp. 274–289. DOI: 10.1016/j.omega.2005.06.005.

Jihene, Jlassi (2014): AHP Method for Selecting Third Party Logistics Provider: Application in Emergency Department. In *International Journal of Inventions* 3-2014 (3). Available online at http://www.ijeijournal.com/papers/Vol.3-Iss.7/H0375662.pdf.

Jung, Hosang (2017): Evaluation of Third Party Logistics Providers Considering Social Sustainability. In *Sustainability* 9 (5), p. 777. DOI: 10.3390/su9050777.

Kahraman, Cengiz; Öztasysi, Basar; Boltürk, Eda; Goztepe, Kerim (2016): Multi-attribute warehouse location selection in humanitarian logistics using hesitant fuzzy AHP. In *IJAHP* 8 (2), pp. 271–298. DOI: 10.13033/ijahp.v8i2.387.

Khaled, Afzal Mohammad; Kim, Yong Jin (2012): GIS Exploitation for New Facility Location Decisions- A Logistics Perspective. In *Journal of International Logistics and Trade* (10), pp. 43–59.

Lei, Ting L.; Church, Richard L.; Lei, Zhen (2015): A unified approach for location-allocation analysis. Integrating GIS, distributed computing and spatial optimization. In *International Journal of Geographical Information Science* 30 (3), pp. 515–534. DOI: 10.1080/13658816.2015.1041959.

Malczewski, Jacek (2004): GIS-based land-use suitability analysis. A critical overview. In *Progress in Planning* 62 (1), pp. 3–65. DOI: 10.1016/j.progress.2003.09.002.

Malczewski, Jacek (2006): GIS-based multicriteria decision analysis. A survey of the literature. In *International Journal of Geographical Information Science* 20 (7), pp. 703–726. DOI: 10.1080/13658810600661508.

Mangalan, Anil Varghese; Kuriakose, Sandeep; Mohamed, Hashim (2016): Optimal Location of Warehous Using Weighted MOORA Approach. Piscataway, NJ: IEEE. Available online at http://ieeexplore.ieee.org/servlet/opac?punumber=7731602.

Meidutė-Kavaliauskienė, Ieva; Aranskis, Artūras; Litvinenko, Michail (2014): Consumer Satisfaction with the Quality of Logistics Services. In *Procedia - Social and Behavioral Sciences* 110, pp. 330–340. DOI: 10.1016/j.sbspro.2013.12.877.

Miller, Harvey J. (1999): Potential Contributions of Spatial Analysis to Geographic Information Systems for Transportation (GIS-T). In *Geographical Analysis* 31 (4), pp. 373–399. DOI: 10.1111/j.1538-4632.1999.tb00991.x.

Moberg, Christopher R.; Speh, Thomas W. (2004): Third-Party Warehousing Selection. A Comparison of National and Regional Firms. In *American Journal of Business* 19 (2), pp. 71–76. DOI: 10.1108/19355181200400013.

Moreno-Navarro, J. G.; Medianero-Coza, A.; Hilal, I. (2015): GIS modelling of intermodal networks. A comparison of two methods. In *Urban Transport WIT Transactions on The Built Environment*, pp. 475–483. DOI: 10.2495/UT150381.

Murray, Alan T. (2010): Advances in location modeling. GIS linkages and contributions. In *J Geogr Syst* 12 (3), pp. 335–354. DOI: 10.1007/s10109-009-0105-9.

Noon, C. E.; Hankins, C. T. (2001): Spatial data visualization in healthcare: supporting a facility location decision via GIS-based market analysis. In *Hawaii International Conference on System Sciences. HICSS-34 Maui, HI, USA 3-6 Jan. 2001*, p. 10. DOI: 10.1109/HICSS.2001.926573.

Özceylan, Eren; Çetinkaya, Cihan; Erbaş, Mehmet; Kabak, Mehmet (2016a): Logistic performance evaluation of provinces in Turkey. A GIS-based multi-criteria decision analysis. In *Transportation Research Part A: Policy and Practice* 94, pp. 323–337. DOI: 10.1016/j.tra.2016.09.020.

Özceylan, Eren; Erbaş, Mehmet; Tolon, Mert; Kabak, Mehmet; Durğut, Temel (2016b): Evaluation of freight villages. A GIS-based multi-criteria decision analysis. In *Computers in Industry* 76, pp. 38–52. DOI: 10.1016/j.compind.2015.12.003.

Pontius, Robert G.; Si, Kangping (2015): Spatial Decision Support Systems. In *International Encyclopedia of the Social & Behavioral Sciences*, pp. 136–141. DOI: 10.1016/B978-0-08-097086-8.72060-5.

Qureshi, M. E.; Harrison, S. R.; Wegener, M. K. (1999): Validation of multicriteria analysis models. In *Agricultural Systems* (62), pp. 105–116.

Ribeiro, Alexandra; Antunes, António Pais (2002): A GIS-Based Decision-Support Tool for Public Facility Planning. In *Environ Plann B Plann Des* 29 (4), pp. 553–569. DOI: 10.1068/b1281.

Rikalovic, Aleksandar; Cosic, Ilija; Lazarevic, Djordje (2014): GIS Based Multi-criteria Analysis for Industrial Site Selection. In *Procedia Engineering* 69, pp. 1054–1063. DOI: 10.1016/j.proeng.2014.03.090.

Ringo, Lindner G. (2009): Utilizing GIS-Based Site Selection Analysis for Potential Customer Segmentation and Location Suitability Modeling to Determine a Suitable Location to Establish a Dunn Bros Coffee Franchise in the Twin Cities Metro, Minnesota. Resource Analysis. Saint Mary's University of Minnesota, Winona, MN.

Saaty, R. W. (1987): The Analytic Hierarchy Process. What it is and how it is used. In *Mathematical Modelling* 9 (3-5), pp. 161–176.

Sahoo, K.; Hawkins, G. L.; Yao, X. A.; Samples, K.; Mani, S. (2016): GIS-based biomass assessment and supply logistics system for a sustainable biorefinery. A case study with cotton stalks in the Southeastern US. In *Applied Energy* 182, pp. 260–273. DOI: 10.1016/j.apenergy.2016.08.114.

Sánchez-Lozano, Juan M.; Teruel-Solano, Jerónimo; Soto-Elvira, Pedro L.; Socorro García-Cascales, M. (2013): Geographical Information Systems (GIS) and Multi-Criteria Decision Making (MCDM) methods for the evaluation of solar farms locations. Case study in south-eastern Spain. In *Renewable and Sustainable Energy Reviews* 24, pp. 544–556. DOI: 10.1016/j.rser.2013.03.019.

Sarkar, Avijit (2007): GIS Applications in Logistics: A Literature Review. University of Redlands, Redlands, CA, USA. School of Business.

Sharma, B.; Birrell, S.; Miguez, F. E. (2017): Spatial modeling framework for bioethanol plant siting and biofuel production potential in the U.S. In *Applied Energy* 191, pp. 75–86. DOI: 10.1016/j.apenergy.2017.01.015.

So, Soon-hoo; Kim, JaeJon; Cheong, KiJu; Cho, Geon (2006): Evaluating the Service Quality of Third-Party Logistics Service Providers using the Analytic Hierarchy Process. In *Journal of Information Systems and Technology Management* 3 (3), pp. 261–270. Available online at http://www.scielo.br/pdf/jistm/v3n3/01.pdf.

Stępień, Marcin; Łęgowik-Świącik, Sylwia; Skibińska, Wioletta; Turek, Izabela (2016): Identification and Measurement of Logistics Cost Parameters in the Company. In *Transportation Research Procedia* 16, pp. 490–497. DOI: 10.1016/j.trpro.2016.11.046.

Surve, Rupali B.; Kathane, Bhaskar Y. (2014): Disparity of Spatial and Non-Spatial Data. In *International Journal of Advance Foundation and Research in Computer (IJAFRC)* 1 (8), pp. 50–55.

Trubint, Nikola; Ostojic, Ljubomir; Bojovic, Nebojsa (2006): Determining an optimal retail location by using GIS. In *Yugosl. j. oper. res.* 16 (2), pp. 253–264. DOI: 10.2298/YJOR0602253T.

van Ritsema Eck, J.R; Jong, T. de (1999): Accessibility analysis and spatial competition effects in the context of GIS-supported service location planning. In *Computers, Environment and Urban Systems* 23 (2), pp. 75–89. DOI: 10.1016/S0198-9715(99)00016-2.

van Thai, Vinh; Grewal, Devinder (2005): Selecting the location of distribution centre in logistics operations. A conceptual framework and case study. In *Asia Pac Jnl of Mrkting & Log* 17 (3), pp. 3–24. DOI: 10.1108/13555850510672359.

Verhetsel, Ann; Kessels, Roselinde; Goos, Peter; Zijlstra, Toon; Blomme, Nele; Cant, Jeroen (2015): Location of logistics companies. A stated preference study to disentangle the impact of accessibility. In *Journal of Transport Geography* 42, pp. 110–121. DOI: 10.1016/j.jtrangeo.2014.12.002.

Vlachopoulou, Maro; Silleos, George; Manthou, Vassiliki (2001): Geographic information systems in warehouse site selection decisions. In *International Journal of Production Economics* 71 (1-3), pp. 205–212. DOI: 10.1016/S0925-5273(00)00119-5.

Yeh, Anthony Gar-On; Chow, Man Hong (1996): An integrated GIS and location-allocation approach to public facilities planning—An example of open space planning. In *Computers, Environment and Urban Systems* 20 (4-5), pp. 339–350. DOI: 10.1016/S0198-9715(97)00010-0.

Yeh, Anthony G-O (1999): Urban Planning and GIS. In *Geographical Information Systems: Principles, Techniques, Applications, and Management 2nd edition, Eds PA Longley, M Goodchild, D Maguire, D Rhind (John Wiley, New York)*, pp. 877–888. Available online at http://www.geos.ed.ac.uk/~gisteac/gis_book_abridged/files/ch62.pdf.

Żak, Jacek; Węgliński, Szymon (2014): The Selection of the Logistics Center Location Based on MCDM/A Methodology. In *Transportation Research Procedia* 3, pp. 555–564. DOI: 10.1016/j.trpro.2014.10.034.

Zelenovic, D. (2003): The design of production systems. Novi Sad.

Zhang, Fengli; Johnson, Dana M.; Sutherland, John W. (2011): A GIS-based method for identifying the optimal location for a facility to convert forest biomass to biofuel. In *Biomass and Bioenergy. DOI:* 10.1016/j.biombioe.2011.06.006.

Zhang, Fengli; Wang, Jinjiang; Liu, Shuhai; Zhang, Shimin; Sutherland, John W. (2017): Integrating GIS with optimization method for a biofuel feedstock supply chain. In *Biomass and Bioenergy* 98, pp. 194–205. DOI: 10.1016/j.biombioe.2017.01.004.

Appendix

A Literature review methodology

For the search for publications several web-based scientific search engines, electronic libraries, and databases are used. Relevant literature published within the last two decades is identified using the Boolean search string given in *Figure 14* is examined.

Database	Search String	Number of publications
VU library	("Third-party logistics provider selection" OR "Warehouse site selection") AND ("GIS-based multi-criteria approach")	25
Elsevier/ Science Direct	("Third-party logistics provider selection" OR "Warehouse site selection") AND ("GIS-based multi-criteria approach")	20
Research gate	("Third-party logistics provider selection" OR "Warehouse site selection") AND ("GIS-based multi-criteria approach")	22
Web of knowledge/ science	("Third-party logistics provider selection" OR "Warehouse site selection") AND ("GIS-based multi-criteria approach")	66
Google scholar	("Third-party logistics provider selection" OR "Warehouse site selection") AND ("GIS-based multi-criteria approach")	79
Total		212

Figure 14: Outcome of the automated search

More than relevant 200 articles are discovered. Elimination of duplicated and further screening yields 75 useful sources. To supplement the automated search, the reference sections of main sources are skimmed and when necessary a manual research for certain topics like the sensitivity analysis or AHP is done. Inclusion aspects for the review are research concerning GIS-based MCDM approaches and 3PL selection. Papers that are not relevant for the paper but still identified in the automated search are skipped from further consideration, leaving 29 items that are reviewed thoroughly.

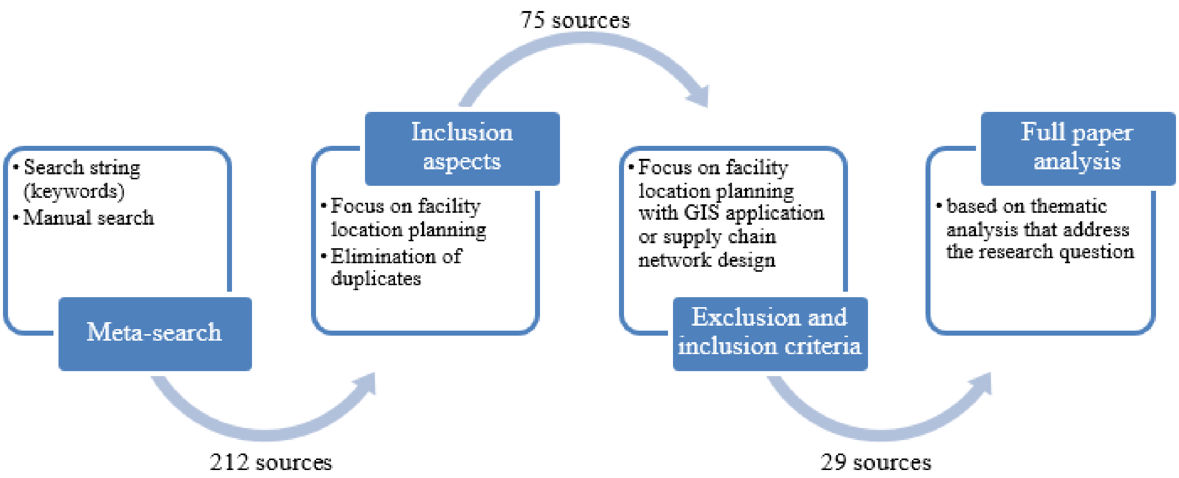

Figure 15: Literature screening approach (Design following Abidi et al. 2014)

B Analytic Hierarchy process

Criteria	Service portfolio	Location factors	Weights
Service portfolio	1	4	0.8
Location factors	0.25	1	0.2

Service portfolio	Available service variety	Quality of services	Weights
Available service variety	1	0.33	0.25
Quality of services	3	1	0.75

Location factors	Harbour	Airport	Roads	CEP hub	Customer	Weights
Harbour	1	5	1	0.5	0.5	0.1916
Airport	0.2	1	0.5	0.25	0.33	0.0720
Roads	1	2	1	1	0.5	0.1727
CEP hub	2	4	1	1	0.5	0.2316
Customer	2	3	2	2	1	0.3320

average $\lambda_{max} = 5.234$; $RI = 1.12$, $CR = 0.05$

C Non-Spatial Analysis

A1						
	Im-portance	Service	Availability rating	Weighted availability	Quality rating	Weighted Quality
Transportation						
Consignee manage-ment, brokering	2	The company is your single point of contact to efficiently handle all your International shipments	1	**2**	4	**8**
Fiscal representation	2	yes	1	**2**	2	**4**
Organize outbound shipments	3	software chooses most cost-efficient transport for each country collaboration with CEP providers daily deliveries to Berlin	1	**3**	4	**12**
Warehousing						
Receiving	3	x	1	**3**	2	**6**
Checking for dam-ages/ quality	3	x	1	**3**	2	**6**
Registration of goods	3	x	1	**3**	2	**6**
Storage	3	Important information in your sup-ply chain is always accessible via the web;	1	**3**	4	**12**
Return goods	3	return handling	1	**3**	3	**9**
Order processing						
Order entry/ fulfil-ment	3	online order entry	1	**3**	3	**9**
Picking	3	innovative automation systems	1	**3**	4	**12**
Customized kitting	3	x	1	**3**	2	**6**
Packing	3	x	1	**3**	2	**6**
Marking/ labelling	3	x	1	**3**	2	**6**
IT services						
IT systems	3	use of current technology	1	**3**	3	**9**
Tracking and tracing	3	innovative automation systems for freight movement overview	1	**3**	4	**12**
Value-added services						
Designing and recy-cling of packaging	1	Sharing packaging knowledge → savings (material costs and environ-mental taxes)	**1**	**1**	**4**	**4**
Billing (Payment con-trol)	2	x	1	**2**	2	**4**
Certification	2	DEKRA, AEO, UL, Lean & green	1	**2**	4	**8**
Other	2	knowledge to use unique opportuni-ties for tax benefits and tariff duties in NL	1	**2**	4	**8**
	50		**19**	**50**	**57**	**147**

A2						
	Im-portance	Service	Availability rating	Weighted availability	Quality rating	Weighted Quality
Transportation						
Consignee management, brokering	2	x	1	**2**	2	**4**
Fiscal representation	2	x	1	**2**	2	**4**
Organize outbound shipments	3	Selecting the most favourable distribution solution depending on size, weight and destination parcels, courier and rush delivery shipments, pallet / groupage freight	1	**3**	4	**12**
Warehousing						
Receiving	3	x	1	**3**	2	**6**
Checking for damages/ quality	3	x	1	**3**	2	**6**
Registration of goods	3	x	1	**3**	2	**6**
Storage	3	x	1	**3**	2	**6**
Return goods	3	x	1	**3**	2	**6**
Order processing						
Order entry/ fulfilment	3	Daily order management (agreed format and timing)	1	**3**	3	**9**
Picking	3	x	1	**3**	2	**6**
Customized kitting	3	Kitting/ Configuration/Customisation	1	3	3	9
Packing	3	Packaging/Repackaging	1	3	3	9
Marking/ labelling	3	x	1	**3**	2	**6**
IT services						
IT systems	3	seamlessly integration of IT systems with customers and carriers	1	**3**	4	**12**
Tracking and tracing	3	Freight execution and monitoring (track and trace) Exception reporting and Proof of Delivery	1	**3**	4	**12**
Value-added services						
Designing and recycling of packaging	1					
Billing (Payment control)	2	Freight settlement (incl. freight invoice audit & client billing)	1	**2**	3	**6**
Certification	2	ISO 9001:2000, AEO	1	2	4	8
Other	2	Performance reporting	1	**2**	3	**6**
	50		**18**	**49**	**49**	**133**

A3						
	Importance	Service	Availability rating	Weighted availability	Quality rating	Weighted Quality
Transportation						
Consignee management, brokering	2	operational provider sites have dedicated customs teams + Air freight, sea freight, road transport	1	**2**	4	**8**
Fiscal representation	2	x	1	**2**	2	**4**
Organize outbound shipments	3	Selecting the most favourable distribution solution depending on size, weight and destination parcels, courier and rush delivery shipments, pallet / groupage freight	1	**3**	4	**12**
Warehousing						
Receiving	3	x	1	**3**	2	**6**
Checking for damages/ quality	3	x	1	**3**	2	**6**
Registration of goods	3	x	1	**3**	2	**6**
Storage	3	x	1	**3**	2	**6**
Return goods	3	x	1	**3**	2	**6**
Order processing						
Order entry/ fulfilment	3	Daily order management (agreed format and timing)	1	**3**	3	**9**
Picking	3	outbound logistic picking principles: FEFO, LIFO, FIFO	1	**3**	3	**9**
Customized kitting	3	Kitting/ Configuration/Customisation	1	**3**	3	**9**
Packing	3	Packaging/Repackaging	1	**3**	3	**9**
Marking/ labelling	3	x	1	**3**	2	**6**
IT services						
IT systems	3	seamlessly integration of IT systems with customers and carriers	1	**3**	4	**12**
Tracking and tracing	3	Freight execution and monitoring (track and trace) Exception reporting and Proof of Delivery	1	**3**	4	**12**
Value-added services						
Designing and recycling of packaging	1					
Billing (Payment control)	2	Freight settlement (incl. freight invoice audit & client billing)	1	**2**	3	**6**
Certification	2	ISO 9001:2000, VCA	1	**2**	4	**8**
Other	2	Performance reporting	1	**2**	3	**6**
	50		**18**	**49**	**52**	**140**

A4						
	Importance	Service	Availability rating	Weighted availability	Quality rating	Weighted Quality
Transportation						
Consignee management, brokering	2	x	1	**2**	2	**4**
Fiscal representation	2	x	1	**2**	2	**4**
Organize outbound shipments	3	Selecting the most favourable distribution solution depending on size, weight and destination parcels, courier and rush delivery shipments, pallet / groupage freight	1	**3**	4	**12**
Warehousing						
Receiving	3	x	1	**3**	2	**6**
Checking for damages/ quality	3	x	1	**3**	2	**6**
Registration of goods	3	x	1	**3**	2	**6**
Storage	3	x	1	**3**	2	**6**
Return goods	3	x	1	**3**	2	**6**
Order processing						
Order entry/ fulfilment	3	Daily order management (agreed format and timing)	1	**3**	3	**9**
Picking	3	outbound logistic picking principles: FEFO, LIFO, FIFO	1	**3**	3	**9**
Customized kitting	3	Kitting/ Configuration/Customisation	1	**3**	3	**9**
Packing	3	Packaging/Repackaging	1	**3**	3	**9**
Marking/ labelling	3	x	1	**3**	2	**6**
IT services						
IT systems	3	seamlessly integration of IT systems with customers and carriers	1	**3**	4	**12**
Tracking and tracing	3	Freight execution and monitoring (track and trace) Exception reporting and Proof of Delivery	1	**3**	4	**12**
Value-added services						
Designing and recycling of packaging	1					
Billing (Payment control)	2	Freight settlement (incl. freight invoice audit & client billing)	1	**2**	3	**6**
Certification	2	ISO 9001:2000	1	**2**	4	**8**
Other	2	Performance reporting	1	**2**	3	**6**
	50		**18**	**49**	**50**	**136**

A5						
	Im-portance	Service	Availability rating	Weighted availability	Quality rating	Weighted Quality
Transportation						
Consignee management, brokering	2	operational provider sites have dedicated customs teams + Air freight, sea freight, road transport	1	**2**	4	**8**
Fiscal representation	2	available	1	**2**	3	**6**
Organize outbound shipments	3	Selecting the most favourable distribution solution depending on size, weight and destination parcels, courier and rush delivery shipments, pallet / groupage freight	1	**3**	4	**12**
Warehousing						
Receiving	3	x	1	**3**	2	**6**
Checking for damages/ quality	3	x	1	**3**	2	**6**
Registration of goods	3	x	1	**3**	2	**6**
Storage	3	x	1	**3**	2	**6**
Return goods	3	x	1	**3**	2	**6**
Order processing						
Order entry/ fulfilment	3	Daily order management (agreed format and timing)	1	**3**	3	**9**
Picking	3	x	1	**3**	2	**6**
Customized kitting	3	Kitting/ Configuration/Customisation	1	**3**	3	**9**
Packing	3	x	1	**3**	2	**6**
Marking/ labelling	3	Labelling	1	**3**	3	**9**
IT services						
IT systems	3	seamlessly integration of IT systems with customers and carriers	1	**3**	4	**12**
Tracking and tracing	3	Freight execution and monitoring (track and trace) Exception reporting and Proof of Delivery	1	**3**	4	**12**
Value-added services						
Designing and recycling of packaging	1					
Billing (Payment control)	2	Freight settlement (incl. freight invoice audit & client billing)	1	**2**	3	**6**
Certification	2	ISO 9001:2000, AEO	1	**2**	4	**8**
Other	2	Performance reporting	1	**2**	3	**6**
	50		**18**	**49**	**52**	**139**

A6						
	Importance	Service	Availability rating	Weighted availability	Quality rating	Weighted Quality
Transportation						
Consignee management, brokering	2	operational provider sites have dedicated customs teams + Air freight, sea freight, road transport	1	**2**	4	**8**
Fiscal representation	2	x	1	**2**	2	**4**
Organize outbound shipments	3	Selecting the most favourable distribution solution depending on size, weight and destination parcels, courier and rush delivery shipments, pallet / groupage freight	1	**3**	4	**12**
Warehousing						
Receiving	3	unloading and palletizing	1	**3**	3	**9**
Checking for damages/ quality	3	x	1	**3**	2	**6**
Registration of goods	3	registration of serial numbers or items	1	**3**	3	**9**
Storage	3	x	1	**3**	2	**6**
Return goods	3	x	1	**3**	2	**6**
Order processing						
Order entry/ fulfilment	3	Daily order management (agreed format and timing)	1	**3**	3	**9**
Picking	3	outbound logistic picking principles: FEFO, LIFO, FIFO	1	**3**	3	**9**
Customized kitting	3	Kitting/ Configuration/ Customisation	1	**3**	3	**9**
Packing	3	Packaging/Repackaging	1	**3**	3	**9**
Marking/ labelling	3	Labelling	1	**3**	3	**9**
IT services						
IT systems	3	seamlessly integration of IT systems with customers and carriers	1	**3**	4	**12**
Tracking and tracing	3	Freight execution and monitoring (track and trace) Exception reporting and Proof of Delivery	1	**3**	4	**12**
Value-added services						
Designing and recycling of packaging	1					
Billing (Payment control)	2	Freight settlement (incl. freight invoice audit & client billing)	1	**2**	3	**6**
Certification	2	AEO, ISO 9001-2008, TAPA-A	1	**2**	4	**8**
Other	2	Performance reporting	1	**2**	3	**6**
	50		**18**	**49**	**55**	**149**

A7						
	Importance	Service	Availability rating	Weighted availability	Quality rating	Weighted Quality
Transportation						
Consignee management, brokering	2	x	1	**2**	2	**4**
Fiscal representation	2	x	1	**2**	2	**4**
Organize outbound shipments	3	Selecting the most favourable distribution solution depending on size, weight and destination parcels, courier and rush delivery shipments, pallet / groupage freight	1	**3**	4	**12**
Warehousing						
Receiving	3	x	1	**3**	2	**6**
Checking for damages/ quality	3	checking the goods for defects and damage	1	**3**	3	**9**
Registration of goods	3	x	1	**3**	2	**6**
Storage	3	x	1	**3**	2	**6**
Return goods	3	x	1	**3**	2	**6**
Order processing						
Order entry/ fulfilment	3	Daily order management (agreed format and timing)	1	**3**	3	**9**
Picking	3	x	1	**3**	2	**6**
Customized kitting	3	Kitting/ Configuration/ Customisation	1	**3**	3	**9**
Packing	3	Packaging/Repackaging	1	**3**	3	**9**
Marking/ labelling	3	Labelling	1	**3**	3	**9**
IT services						
IT systems	3	seamlessly integration of IT systems with customers and carriers	1	**3**	4	**12**
Tracking and tracing	3	Freight execution and monitoring (track and trace) Exception reporting and Proof of Delivery	1	**3**	4	**12**
Value-added services						
Designing and recycling of packaging	1					
Billing (Payment control)	2	Freight settlement (incl. freight invoice audit & client billing)	1	**2**	3	**6**
Certification	2	ISO 9001:2000, TAPA-A, AEO	1	**2**	4	**8**
Other	2	Performance reporting	1	**2**	3	**6**
	50		**18**	**49**	**51**	**139**

A8						
	Importance	Service	Availability rating	Weighted availability	Quality rating	Weighted Quality
Transportation						
Consignee management, brokering	2	x	1	**2**	2	**4**
Fiscal representation	2	x	1	**2**	2	**4**
Organize outbound shipments	3	Selecting the most favourable distribution solution depending on size, weight and destination parcels, courier and rush delivery shipments, pallet / groupage freight	1	**3**	4	**12**
Warehousing						
Receiving	3	x	1	**3**	2	**6**
Checking for damages/ quality	3	x	1	**3**	2	**6**
Registration of goods	3	x	1	**3**	2	**6**
Storage	3	x	1	**3**	2	**6**
Return goods	3	x	1	**3**	2	**6**
Order processing						
Order entry/ fulfilment	3	Daily order management (agreed format and timing)	1	**3**	3	**9**
Picking	3	x	1	**3**	2	**6**
Customized kitting	3	x	1	**3**	2	**6**
Packing	3	Packaging/Repackaging	1	**3**	3	**9**
Marking/ labelling	3	x	1	**3**	2	**6**
IT services						
IT systems	3	seamlessly integration of IT systems with customers and carriers	1	**3**	4	**12**
Tracking and tracing	3	Freight execution and monitoring (track and trace) Exception reporting and Proof of Delivery	1	**3**	4	**12**
Value-added services						
Designing and recycling of packaging	1					
Billing (Payment control)	2	Freight settlement (incl. freight invoice audit & client billing)	1	**2**	3	**6**
Certification	2	ISO 9001:2000, TAPA-A, AEO	1	**2**	4	**8**
Other	2	Performance reporting	1	**2**	3	**6**
	50		**18**	**49**	**48**	**130**

A9						
	Im-portance	Service	Availability rating	Weighted availability	Quality rating	Weighted Quality
Transportation						
Consignee management, brokering	2					
Fiscal representation	2					
Organize outbound shipments	3	special Over Night Service. Highly experienced in parcel handling (national + international) Direct line hauls to central hubs, Cooperation with postal authorities	1	**3**	4	**12**
Warehousing						
Receiving	3	x	1	**3**	2	**6**
Checking for damages/ quality	3	x	1	**3**	2	**6**
Registration of goods	3	x	1	**3**	2	**6**
Storage	3	central warehouse, Storage of any size of products most up to date storage options	1	**3**	4	**12**
Return goods	3	Reverse logistics	1	**3**	3	**9**
Order processing						
Order entry/ fulfilment	3	order fulfilment service	1	**3**	3	**9**
Picking	3	Effective picking methods	1	**3**	3	**9**
Customized kitting	3	kitting	1	**3**	3	**9**
Packing	3	(Re)packing of goods	1	**3**	3	**9**
Marking/ labelling	3	labelling	1	**3**	3	**9**
IT services						
IT systems	3	x	1	**3**	2	**6**
Tracking and tracing	3	Informing your client per personalized email in order of your company about the status of the parcel by using a track & trace system.	1	**3**	4	**12**
Value-added services						
Designing and recycling of packaging	1	recycling of waste (paper, plastic, card-board)	**1**	**1**	**4**	**4**
Billing (Payment control)	2	Accounting	1	**2**	4	**8**
Certification	2	AEO, FENEX, DAS	1	**2**	4	**8**
Other	2	one standard contact person	1	**2**	3	**6**
	50		**17**	**46**	**53**	**140**

A10						
	Importance	Service	Availability rating	Weighted availability	Quality rating	Weighted Quality
Transportation						
Consignee management, brokering	2	experts will handle your import and export shipments + customs procedures for you comprehensive license for storage in transit Bonded and non-bonded warehouses	1	**2**	4	**8**
Fiscal representation	2					
Organize outbound shipments	3	provide transport services Collaboration with UPS, TNT, DHL, DPD, Dachser, parcel and pallet experts day & night delivery.	1	**3**	4	**12**
Warehousing						
Receiving	3	x	1	**3**	2	**6**
Checking for damages/ quality	3	x	1	**3**	2	**6**
Registration of goods	3	scan and register the goods	1	**3**	3	**9**
Storage	3	centralized warehouses, secure storage	1	**3**	3	**9**
Return goods	3	return logistics	1	**3**	3	**9**
Order processing						
Order entry/ fulfilment	3	x	1	**3**	2	**6**
Picking	3	Our picking and packing processes are completely separate to enhance quality	1	**3**	3	**9**
Customized kitting	3	customization	1	**3**	3	**9**
Packing	3	Our picking and packing processes are completely separate to enhance quality	1	**3**	4	**12**
Marking/ labelling	3	generate new barcodes and apply special labels.	1	**3**	4	**12**
IT services						
IT systems	3	Systems are seamlessly aligned	1	**3**	4	**12**
Tracking and tracing	3	x	1	**3**	2	**6**
Value-added services						
Designing and recycling of packaging	1					
Billing (Payment control)	2	track the status of transactions	1	**2**	4	**8**
Certification	2	FENEX, AEO, DNV-GL, IATA, TAPA	1	**2**	4	**8**
Other	2		0	**0**	0	**0**
	50		**16**	**45**	**51**	**141**

A11						
	Im-portance	Service	Availability rating	Weighted availability	Quality rating	Weighted Quality
Transportation						
Consignee management, brokering	2					
Fiscal representation	2					
Organize outbound shipments	3	negotiating shipping or postal rates + network of postal services provide the most economical shipping option	1	**3**	4	**12**
Warehousing						
Receiving	3	x	1	**3**	2	**6**
Checking for damages/ quality	3	From intake to dispatch, several measurements are taken, either physical or system-based to meet the high-quality standards.	1	**3**	3	**9**
Registration of goods	3	x	1	**3**	2	**6**
Storage	3	real-time access to warehousing and distribution information	1	**3**	4	**12**
Return goods	3	Returns management	1	**3**	3	**9**
Order processing						
Order entry/ fulfilment	3	order files/ pick waves can be received throughout the day.	1	**3**	4	**12**
Picking	3	warehouse management system optimizes the orders received for effective order picking	1	**3**	4	**12**
Customized kitting	3	x	1	**3**	2	**6**
Packing	3	(re)packing	1	**3**	3	**9**
Marking/ labelling	3	x	1	**3**	2	**6**
IT services						
IT systems	3	x	1	**3**	2	**6**
Tracking and tracing	3	x	1	**3**	2	**6**
Value-added services						
Designing and recycling of packaging	1	select the most suitable packaging material for your products	**1**	**1**	**4**	**4**
Billing (Payment control)	2					
Certification	2					
Other	2					
	50		**14**	**40**	**41**	**115**

A12						
	Importance	Service	Availability rating	Weighted availability	Quality rating	Weighted Quality
Transportation						
Consignee management, brokering	2	We arrange all your customs declarations: import, export and transit declarations (MRN documents) and PD and EDGB declarations. Transportation via Partner	1	**2**	4	**8**
Fiscal representation	2					
Organize outbound shipments	3	72h delivery in Europe full advantage of the favourable price agreements it has with parcel services like DPD, DHL and UPS.	1	**3**	4	**12**
Warehousing						
Receiving	3	x	1	**3**	2	**6**
Checking for damages/ quality	3	Checking goods	1	**3**	3	**9**
Registration of goods	3	entry	1	**3**	3	**9**
Storage	3	storage	1	**3**	3	**9**
Return goods	3	returns handling	1	**3**	3	**9**
Order processing						
Order entry/ fulfilment	3	x	1	**3**	2	**6**
Picking	3	order picking	1	**3**	3	**9**
Customized kitting	3	x	1	**3**	2	**6**
Packing	3	packing and repacking	1	**3**	3	**9**
Marking/ labelling	3	labelling and stickering	1	**3**	3	**9**
IT services						
IT systems	3	seamless EDI connection for data exchange Smart ICT	1	**3**	4	**12**
Tracking and tracing	3	available + other release-related activities	1	**3**	3	**9**
Value-added services						
Designing and recycling of packaging	1					
Billing (Payment control)	2					
Certification	2	AEO, ISO 9001:2008, TAPA	1	**2**	4	**8**
Other	2	Specialising in warehousing and Southern European transports	1	**2**	3	**6**
	50		**16**	**45**	**49**	**136**

D Outcome of the suitability analysis

Name	Available service variety	Quality of services	Weighted suitability score	Rank
	(C11)	(C12)	(C1)	
A6	49	149	0.0895	1
A1	50	147	0.0890	2
A3	49	140	0.0854	3
A7	49	139	0.0849	4
A5	49	139	0.0849	4
A10	45	141	0.0841	6
A9	46	140	0.0840	7
A4	49	136	0.0835	8
A2	49	133	0.0822	9
A12	45	136	0.0818	10
A8	49	130	0.0808	11
A11	40	115	0.0700	12

Figure 16: Service portfolio evaluation

Name	Distance Rotterdam - 3PL	Distance Schiphol - 3PL	Distance to closest highway junction	Distance to closest hub	Total Euclidean distance to customers	Weighted suitability score	Rank
	(C21)	(C22)	(C23)	(C24)	(C25)	(C2)	
A10	85,620	5,868	2,264	422	52,067,645	0.049	1
A2	101,070	14,237	1,682	8,880	52,110,906	0.055	2
A1	179,545	165,885	708	4,751	49,459,590	0.062	3
A7	175,849	162,189	1,589	1,055	49,519,441	0.063	4
A4	210,029	196,370	2,017	4,564	50,576,419	0.074	5
A8	65,360	99,773	281	41,268	52,711,539	0.074	6
A6	168,045	154,385	595	23,230	49,578,647	0.074	7
A11	140,962	54,130	148	42,738	51,391,533	0.079	8
A9	278,671	193,923	4,821	13,467	48,831,112	0.100	9
A3	78,451	112,864	4,034	57,185	53,517,900	0.106	10
A12	79,879	114,291	7,937	53,274	52,640,717	0.121	11
A5	169,885	133,320	11,149	54,307	48,914,496	0.145	12

Figure 17: Locations factors evaluation

	C1	C2’	Weighted suitability score	Rank
A1	0.089	0.085	0.0588	**1**
A10	0.084	0.086	0.0575	**2**
A6	0.089	0.084	0.0568	**3**
A7	0.085	0.085	0.0554	**4**
A2	0.082	0.086	0.0548	**5**
A4	0.084	0.084	0.0521	**6**
A8	0.081	0.084	0.0499	**7**
A9	0.084	0.082	0.0473	**8**
A3	0.085	0.081	0.0472	**9**
A12	0.082	0.080	0.0413	**10**
A11	0.070	0.084	0.0401	**11**
A5	0.085	0.078	0.0389	**12**

Figure 18: Final ranking

E Outcome of the sensitivity analysis

	Sensitivity analysis scenarios				
	0.9 / 0.1	0.85 / 0.15	**0.8 / 0.2**	0.25 / 0.75	0.7 / 0.3
A6	1	1	**1**	1	1
A1	2	2	**2**	2	2
A7	4	3	**3**	3	3
A3	3	4	**4**	5	5
A10	5	5	**5**	4	4
A4	8	8	**6**	6	6
A9	7	7	**7**	7	7
A5	6	6	**8**	9	9
A2	9	9	**9**	8	8
A8	11	11	**10**	10	10
A12	10	10	**11**	11	11
A11	12	12	**12**	12	12

Figure 19: Sensitivity analysis

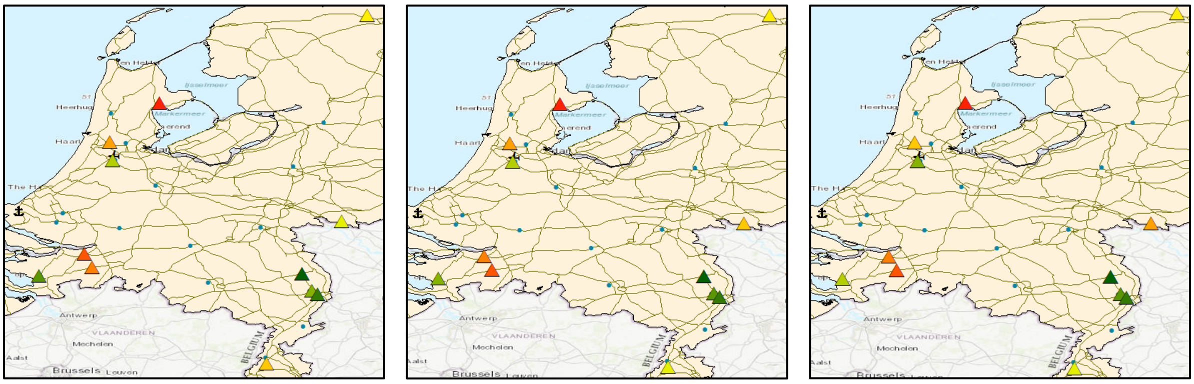

Figure 20: Sensitivity analysis (maps)