Exploring the transport efficiency for different types of logistics facilities

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by

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Preface

With the completion of this master's thesis, I am completing my journey of MSc Transport Infrastructure and Logistics. This thesis is a result of six months of hard work, and I am proud to share my work with everyone. The past six months have been informative, intensive, stressful, and gezellig, and I would like to thank each and everyone who was a part of this journey.

Firstly, I would like to thank my committee. Starting with Michiel de Bok, for supporting me during the period of defining my research goals, finding a company and also for allowing me to work with one of the most extensive truck diary database. I am grateful for his supervision and for keeping me heading for the end goal. I would also like to thank Ron van Duin for providing me with the necessary feedback, as well as Lori Tavasszy for his willingness to chair my thesis, sharing his knowledge and his critical feedback. My gratitude also goes to Raeed Ali Mohammed and Ali Nadi Najafabadi for answering all my questions regarding the truck diary database.

Secondly, I am grateful to Monique van den Berg for providing me with this opportunity to complete my graduation project at Rijkswaterstaat and for the active involvement in this research. I am glad I could contribute to the different goals of Rijkswaterstaat.

Finally, I would like to thank my family and friends for their constant love and support during this journey and for keeping me motivated during these difficult times. Especially my parents, who have always encouraged me to do what makes me happy. Because of them, I became the person I am today.

Dear readers, at this point, I will let my research unfold to you. Hopefully, you enjoy reading this report!

Ishani Bharadwaj
Delft, 14th December 2020

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List of Abbreviations

UC	Urban Centre
VKT	Vehicle Kilometre Travelled
SCM	Supply Chain Management
KPI	Key Performance Indicator
CBS	Centraal Bureau voor de Statistiek / Statistics Netherlands
RWS	Rijkswaterstaat
TMA	Tokyo Metropolitan Area
TT	Transshipment Terminal
APS	Advanced Supply Chain Planning System
SFC	specific fuel consumption
$hhkm^2$	Households per kilometre square
PCA	Principal Component Analysis
SBI	Standaard Bedrijfsindeling
HCA	Hierarchical Cluster Analysis
ABR	firm registration data
XML	Extensible Markup Language
NSTR	Goederenclassificatie
CV	Coefficient of Variation

Executive Summary

A new generation of logistics facilities has emerged due to the changing spatial pattern. The spatial reorganisation of logistics facilities is being observed across many countries. These logistics facilities are becoming an increasingly popular area of study not only for research but also for policy makers due to the concerns about the negative impacts caused by increased freight traffic. Hence, understanding the synergy between the spatial organisation of logistics facilities and freight transport activity is crucial. The current studies, however, focus primarily on the development of the location or freight activity. It is due to the absence of freight data, as it requires shipment data of different logistics facilities and their geographic characteristics.

As for 2030, the Netherlands aims to reduce greenhouse gas emissions by 49% compared to 1990 as per the Paris Agreement and the National Climate Act. About 21% of these emissions are due to freight road transport. However, the policy makers need to understand the road freight activities taking place before making any policies. It is foremost to understand which segments of freight road transportation have room for improvement. Understanding the current transport efficiency can help in determining the areas of improvement. Hence, this study captures the different logistics facilities in terms of spatial patterns in the Netherlands and also examines the transport efficiency to understands the freight activity for different spatial locations. Therefore, the main research question formulated for this research is:

What is the transport efficiency for the different types of logistics facilities in the Netherlands?

To answer the main research question several sub-questions need to be defined, and those are as follows:

- What are the different spatial and logistics characteristics that determine the logistics facility type?
- What are the different factors influencing transport efficiency?
- What are the indicators to assess transport efficiency?
- What are the different types of logistics facilities in the Netherlands?

An extensive literature study suggested that some of the components for differentiating the logistics facilities were the size of the facility, industry sector, construction year, land availability, water availability, population density (Households per kilometre square ($hhkm^2$)), distance to Transshipment Terminal (TT), Urban Centre (UC), ramps and ports. Subsequently, the literature suggested that the Supply Chain Management (SCM) factors distance of delivery, frequency, and weight were some of the factors influencing the transport efficiency. The literature also suggested that the SCM factors influence the different factors that would determine the logistics facility typology.

Multiple transport efficiency indicators were found, subsequently. But, the scope of the research was limited to the Centraal Bureau voor de Statistiek / Statistics Netherlands (CBS) truck diaries database. Therefore, the indicators used to understand the transport efficiency are the vehicle utilisation rate, kilometre per trip, number of trips, vehicle carrying capacity (payload), and empty kilometres. Based on the different indicators, a conceptual framework was formulated as shown in figure 1. The computation from the conceptual framework would result in the value of transport efficiency. The conceptual framework is an adapted version from Allen et al., (2012). The transport efficiency will be the ratio between road tonne-kilometre and total vehicle kilometre. This ratio will indicate three main indicators (vehicle carrying capacity, payload utilisation rate, and empty kilometres).

Cluster analysis differentiated the logistics facilities. Principal Component Analysis (PCA) was implemented to reduce the number of variables by grouping the significantly interrelated variables, followed by Hierarchical Cluster Analysis (HCA). The PCA resulted in reducing the variables into four key variables. Those are as follows:

- Geographical characteristics: Distance to ramps, land and water availability

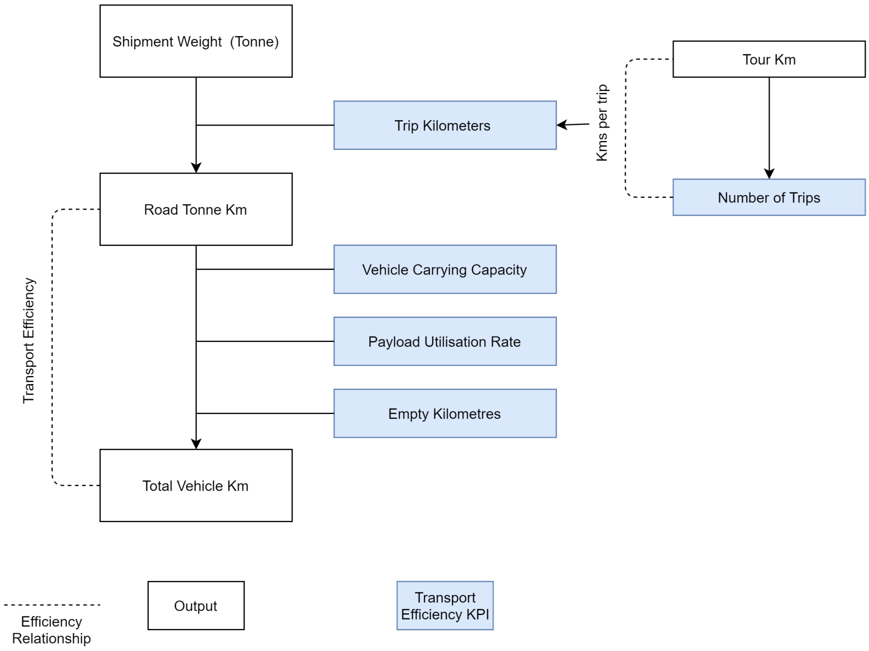

Figure 1: Conceptual Framework (Adapted from Allen et al., (2012))

- Intermediate hub availability: Distance to TT and ports
- Logistic sprawling characteristics: Construction year, distance to UC and $hhkm^2$.
- Industry characteristics: Industry sector and surface area of the logistics facility.

Finally, clustering the logistics facilities resulted in eight clusters for the Netherlands. These eight clusters found could be distinguished based on their size and the location of logistics facilities. Table 1 shows the different sizes and location of the logistics facilities.

Table 1: Naming of Logistics Facilities

Sizes of the Logistics Facilities	Locations of Logistics Facilities
Small Facilities (5,000 - 10,000 m^2)	Urban Centre
Medium Facilities (10,000 - 20,000 m^2)	Sub-Urban Areas
Large Facilities (20,000 - 30,000 m^2)	Peripheral Cities
XL Facilities (30,000 - 40,000 m^2)	Remote Locations
XXL Facilities (40,000 - 50,000 m^2)	
XXXL Facilities (50,000 - 60,000 m^2)	

The eight dominant categories of the facilities in the Netherlands found were:

- Cluster 1: Old Medium Facilities in Urban Centres
- Cluster 2: Medium Facilities in Urban Centres
- Cluster 3: Small Facilities in Sub-Urban Areas (constructed during compact city policy)
- Cluster 4: Small Facilities in Sub-Urban Area (constructed during compact urbanisation policy)
- Cluster 5: Large Facilities in Peripheral Cities
- Cluster 6: XXL Facilities in Peripheral Cities
- Cluster 7: Medium Facilities in Remote Location, away from hubs
- Cluster 8: Medium Facilities in Remote Location, close to hubs

Analysis of the transport efficiency was based on the conceptual framework. The table 2 shows the transport efficiency for the topology of the logistics facilities.

Table 2: Transport efficiency indicators for each cluster

Clusters	Avg. vehicle kms (A) (kms)	Avg. load handled by a facility (B) (tonnes)	Avg. empty kms (C) (kms)	Avg. payload of Truck (D) (tonnes)	Avg. number of Trips (E) (nos.)	Avg. load handled in a trip (F = B/E) (tonnes)	Avg. shipment distance in a trip (G = A/E) (kms)	Utilisation Rate (H = B/D*100)	Avg. road tonne km (I = F*G) (tonne-km)	Transport Efficiency (J= I/A)
1: Old Medium Facilities in UC	159	8	60	30	4	1.93	37.54	27%	72.38	0.46
2: Medium Facilities in UC	120	7	65	25	15	0.45	8.09	27%	3.66	0.03
3: Small Facilities in Sub-Urban Area (Compact city policy)	193	9	300	23	6	1.53	31.12	41%	47.47	0.25
4: Small Facilities in Sub-Urban Area (Compact urbanisation policy)	190	17	125	27	4	4.01	46.07	60%	184.78	0.97
5: Large Facilities in Peripheral cities	168	12	60	30	4	2.84	38.45	41%	109.24	0.65
6: XXL Facilities in Peripheral Cities	155	14	65	21	6	2.27	25.03	65%	56.76	0.37
7: Medium Facilities in Remote Locations, away from hubs	143	16	90	31	9	1.82	16.05	53%	29.28	0.20
8: Medium Facilities in Remote Locations, closer to hubs	143	16	100	30	3	4.74	41.26	54%	195.76	1.37

This study used extensive freight shipment data to investigate the freight activity of the different types of logistics facilities. The findings suggest that geographical and spatial characteristics influence freight activity. Regardless of the richness of the data, it also has limitations. The lack of vehicle routing data (trip information) would capture the efficiency of individual trips to different geographic locations. Despite these limitations, the analysis shed light on the relationship between the location of the logistics facilities and shipment patterns.

This research led to the following findings. Firstly, the analysis of distinguishing logistics facilities showed that categorising the facilities based on spatial and geographical locations could help in understanding the freight planning of the companies better. This study considered the distance to the Urban centre, Transshipment Terminal, Ports, Airports, Ramp (infrastructure), land availability, water availability, household per kilometre square, construction year, and surface area of the facility. Adding a few logistics characteristics such as market availability, the objective of the logistics facility, and position in the supply chain could improve the categorisation of the logistics facilities.

Secondly, the average load handled in the trips was lowest in urban centres, followed by sub-urban areas, peripheral cities, and highest in remote locations. The average shipment distance was seen as the lowest in the urban centre, followed by peripheral cities, remote locations, and then sub-urban locations. The average empty kilometre was also seen to have a similar variation as the average shipment distance. The comparison between the old and new logistics facilities in the urban, sub-urban areas, peripheral cities, and remote locations showed that the older facilities were more efficient.

Finally, the transport efficiency analysis, showed that the combination of the vehicle kilometres in a trip, load handled in a trip and empty kilometres is important. These factors influence transport efficiency. However, studying these different types of logistics facilities, led to an understanding that the comparison of transport efficiency is difficult. This is due to the significant difference in terms of their functionality, the kind of goods that need to be transported, and their position in the supply chain. However, a comparison of the facilities within the clusters can be done to understand their behaviour.

The freight transport factors are only a small part of the supply chain of a product. The complexity results in a potentially far greater set of factors that influence freight transport activity.

1 Introduction

This chapter presents the background, current situation, and research goal and will conclude with the outline of the report.

1.1. Background and Current Situation

Cities are the drivers for economic development and provide the infrastructure to support countless activities and services. The estimated population living in these cities would increase by 8.5 billion by 2030 (U.N., 2019). The increase in population puts additional stress on the demand for logistics activities. In 2015, the freight system moved about 56 tons of goods per person. Without regular freight delivery, basic human requirements would be in jeopardy (Department of Transportation and Bureau of Transportation, 2017). Efficient and reliable urban freight movement is vital for economic prosperity as well as the social welfare of any region.

Urban areas and freight movements have been explicitly linked together. Earlier, many urban areas were the centres of trade and commerce where goods were bought and sold to people. Multiple factors led to pushing the logistics activities and freight transportation away from the urban core. This movement of logistics facilities away from the Urban Centre (UC) (decentralisation) was termed as logistics sprawling by Dablanc (2009). The reason for the shifting of the location of these logistics facilities included an increase in land cost in UC, the need for better-quipped infrastructure, suitable modern storage, and processing operations. The expectation, however, was that the shifting of these logistics facilities would have negative consequences (Woudsma et al., 2016). These negative impacts include additional Vehicle Kilometre Travelled (VKT), and subsequent emissions and congestion, causing concern among city managers.

Freight related infrastructure in urban areas around the world has gone through a significant transformation. Over the last couple of decades, the evolution of global Supply Chain Management (SCM) practices and technological innovations in logistics led to the growth of the logistics industry. Governments often desire a flourishing warehousing and logistics industry for economic developments. The concern is, however, over the negative impacts caused by increasing freight traffic. Truck traffic, including carbon emissions, energy use, and congestion are some of the negative impacts associated with it. These are considered to be especially problematic when the development of logistics facilities occurs in an uncoordinated manner. Lack of logistics facility and shipping data has prevented researchers to study the issues concerning the logistics facilities. The need for analysing the impact of the logistics facilities using empirical data is recognised.

The new generation of logistics and distribution have emerged due to the changing spatial pattern of the logistics facilities (Higgins et al., 2012). Understanding the relationship between logistics-related activities, land use, and urban traffic are emerging issues. There has been little to no comparable research to understand the synergy between the spatial organisation and freight transport activity. The study of Allen et al. (2012) suggested that the logistics management of road freight transport operations was affected by the geographical location, in turn affecting the efficiency of road freight journey to, from, and within urban areas. The spatial distribution of the logistics facilities has been observed across many countries. The location of these logistics facilities is becoming an increasingly popular area of study not only for researchers but also for policy makers.

The research of Sakai et al. (2017) used the Tokyo Metropolitan Freight Survey (TMFS) from 2003 and 2013. The analysis showed higher inefficiencies in outward migrated logistics facilities. Study of Sakai et al. (2017) is the only study which shows there is a relation between spatial pattern and transportation behaviour. However, This study of freight transport and the geography of logistics facilities remains relatively under-researched. The existing studies, focus primarily on developments on the location or freight activity in the urban areas rather than the relationship between spatial structure and freight activity. It is due to the absence of freight data, as it requires shipment data of the different logistics facilities and their geographic characteristics.

The term logistics facilities have become the central element of the local, national, and international transportation systems. Nevertheless, there is a limited understanding of the various components of spatial patterns that affect logistics facilities. The actors in the logistics industry make decisions on different levels, operational, tactical, and strategic decisions. These are based on different Key Performance Indicator (KPI) to improve their efficiencies and effectiveness. Hence, understanding the different topologies of logistics facilities and their KPI for the transportation department of the SCM can help the transport planners to model the freight activities accurately.

1.2. Research Goal

The Netherlands aims to reduce greenhouse gas emissions by 49% by 2030 compared to 1990 as per the Paris Agreement and the National Climate Act. About 21% of these emissions are due to freight road transport. There are policies from 2025 to enforce zero-emissions zones in UC. While for other locations, similar regulations are equally important. However, the policy makers need to understand the freight activities taking place before making any policies. It is foremost to understand which segments of freight road transportation have room for improvement. Understanding the current transport efficiency can help in determining the areas of improvement.

The changes in the logistics industry in terms of location choice is vast. Various factors play an important role in understanding the types of logistics facilities. Thus this study tries to capture the different logistics facilities in terms of spatial patterns in the Netherlands. The location of these logistics facilities plays a crucial role in determining the performance of the supply chain. Understanding the different performance indicators for logistics facilities would beneficial for the policymakers. Hence, this research tries to understand different types of logistics facilities and their performances on different transport indicators.

1.3. Structure of the report

Figure 1.1 depicts the outline of the report. Chapter 2 discusses the research objective, question, and methodology. Chapter 3 reviews various literature related to logistics facilities and their location choices, as well as the factors influencing the efficiency of these facilities. It concludes with a conceptual framework of the transport efficiency indicators and the scope of the research. Chapter 4 explores the different aspects of logistics facilities and differentiates them. Chapter 5 takes the topology from chapter 4 and finds the transport efficiencies for each type of logistics facilities. Chapter 6 discusses the conclusions. Chapter 7 discusses the results and provides recommendations subsequently.

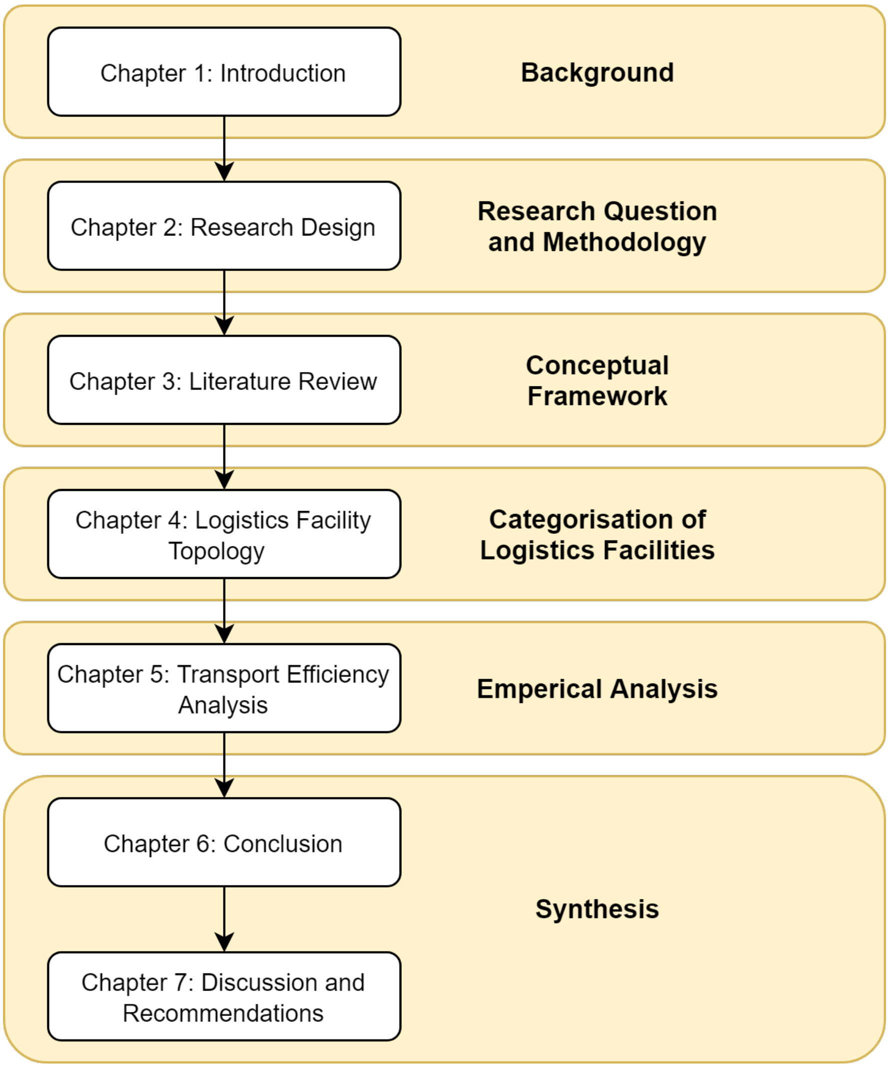

Figure 1.1: Report Outline

2

Research Design

This chapter provides the research objective, gap, research question, and scientific and societal relevance of the research undertaken. The chapter is concluded with the research methodology.

2.1. Research Objective

Mckinnon (2007) found a relation between the logistic facility location and the urban pattern. There were several factors that determine the location of logistics facilities. Supply chain, spatial patterns, worker availability, and logistics cost are some of these factors.

The lack of freight flow data makes it difficult to understand the effect of different logistics facilities. Ample qualitative studies have been done on different types of logistics (Yuan and Zhu, ; Giuliano et al., 2016). These studies suggested that the movement of freight is better in remote areas compared to the facilities in the urban centre. While there is an increase in carbon emissions as facilities move to remote areas.

This research would be a stepping stone to understand the different types of logistics facilities and their transport efficiency. Understanding this will help in understanding the logistic efficiency. Sakai et al., (2017) discussed that understanding the transportation indicators could be a starting point to understand the logistic efficiency. Understanding the transportation behaviour of different logistics facilities would help the government to make transportation green.

2.2. Research Gap

The logistics facilities have been classified based on surface area or by functionality. But, the logistics facilities have multiple characteristics that need to be studied together to understand the different types of logistics facilities. Recent studies showed that the newer logistics facilities are constructed away from the Urban Centre (UC). Gupta and Garima (2017) explained qualitatively that these logistics facilities have higher externalities.

The location of the logistics facilities have an impact on the transportation network, and the lack of data made it impossible to study these indicators empirically. An empirical study will help in getting insights into the classification of the logistics facilities and their transport performance. However, identifying the different indicators to understand the performance is the first step. Hence, this research looks into the different types of logistics facilities and the transport indicators. The study will combine large data sets on location patterns with shipment data.

2.3. Research Question

The main research question is formulated based on the research objective and gap discussed in section 2.1 & section 2.2. This section builds on developing the research question. The research objective stated the need to establish the different types of logistics facilities and to understand the different indicators of transport efficiency. Hence, it leads to the following research question:

Main Research Question:

What is the transport efficiency for the different types of logistics facilities in the Netherlands?

The main research question is divided into several sub-questions to answer it accurately. First, there is a need to understand what are the crucial factors segregating the logistics facilities from each other. This segregation is important due to the high variation among the logistics facilities. It will help in understanding the transport indicators of the different logistics facilities. A review of the related work and literature study can offer an overview of methods to adopt. Thus, the first research question formulated as:

Sub Question 1: What are the different spatial and logistics characteristics that determine the logistics facility type?

Next, the factors influencing transport efficiency are studied. Hence, the second research formulated as:

Sub Question 2: What are the different factors influencing transport efficiency?

The transport indicators are formulated based on the different factors influencing transport efficiency from sub-question 2. Subsequently, the logistics facilities are categorised. The next sub-questions formulated are:

Sub Question 3: What are the indicators to assess transport efficiency?

Sub Question 4: What are the different types of logistics facilities in the Netherlands?

Finally, the transport efficiency for the logistics facilities is studied.

2.4. Research Methodology

After identifying the sub-question, this section explains the steps. These relations would help in answering and understanding the main research question. Figure 2.1, shows the research methodology.

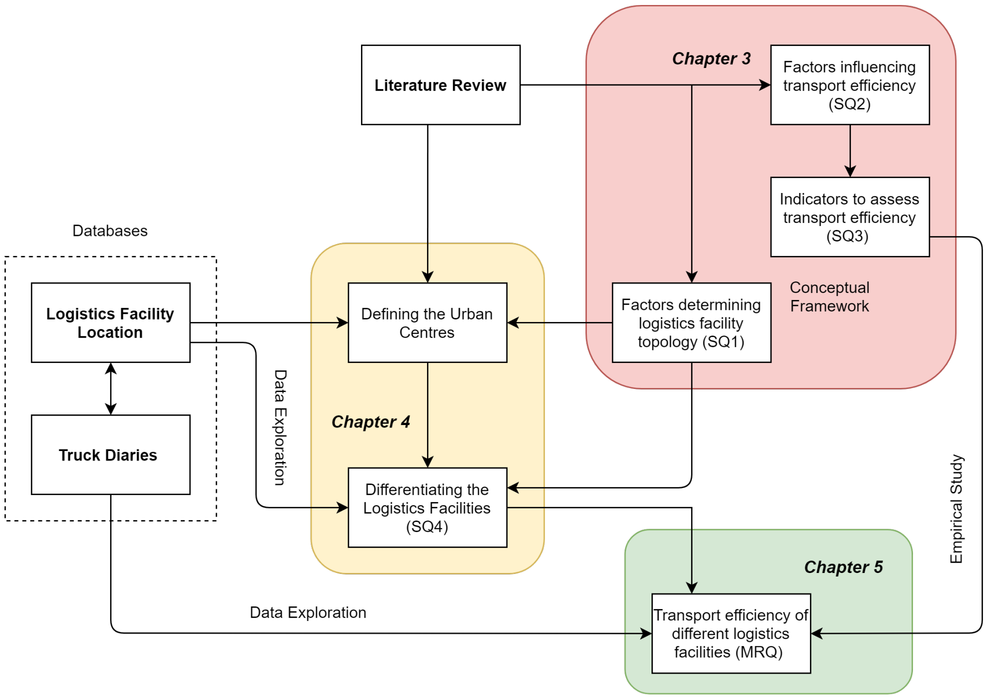

Figure 2.1: Research Methodology

The spatial and logistics characteristics that can determine the different topologies of logistics facilities are studied. The factors influencing transport efficiency are determined, and the formulation of the transport efficiency indicators subsequently. One of the components of spatial characteristics was the distance to UC. The UC are defined based on literature.

Based on the spatial and logistics characteristics as well as the logistics facility location database, the logistics facilities are differentiated. The transport efficiency of the different logistics facilities is calculated based on a conceptual model of transport efficiency and truck diary database.

2.5. Scientific and Societal Contribution

There are multiple qualitative studies of freight transport based on their distance to UC. The study of the transport characteristics of these logistics facilities based on their spatial and logistics factors are not present.

This study will aid in understanding the different types of logistics facilities and their transport performances. Most of the freight models consider that goods are transported from origin to destination without stops. The results of this study would also help in getting insights into the planning of freight transport over different logistics facilities. This study would also help the authorities to plan to tackle issues related to carbon emissions and congestion caused by trucks.

3

Literature Review

This chapter mainly focuses on literature related to logistics facilities, logistics sprawling, freight flow, logistics efficiency, and transport efficiency to provide a background for the research. Section 3.1 will help in understanding the structure of the different logistics facilities, looks into the reason behind the spatial shift, and reviews the ways of classification of the logistics facilities. Section 3.2 explores the changes in freight movement due to the new logistics facilities. Section 3.3 looks at the factors that influence the efficiency of a logistics facility and concludes with the indicators for transport efficiency. The literature review ends with a conclusion, which highlights the different indicators. Following, the scope of this research is defined. The chapter concludes with a formulation and discussion of the conceptual framework.

3.1. Logistics Facilities Location

The restructuring of the logistics facilities has resulted in a geographically fragmented supply chain, which implies geographically separated locations of suppliers, producers, distributors, and consumers (Rodrigue, 2008). The spatial reorganisation is an attribute of the economy of scales in goods production and distribution systems. Decreased freight transport costs due to transport technology advancement and transportation infrastructure improvements, has eased the spatial reorganisation process (Hall et al., 2006). These factors have facilitated the emergence of a logistics industry that emphasises reliability and high throughput of goods transportation (Hesse and Rodrigue, 2004). High throughput movement, rather than storage, has become the main goal of logistics, and demand for centralised good distribution system increased significantly (Cidell, 2011; Rodrigue, 2008). The decision of freight flow can be direct or a mutually dependent decision between various factors of SCM. Once the mode and the means are known, transport planners plan the route followed by intermediate points of (un)loading. There can be multiple origins per destination, multiple destinations per origin, or a combination. For each spatial structure, a distinct trip structure is planned. In freight flow, there is a complex tour, i.e. the empty trips created by the vehicles after delivery (Tavasszy and De Jong, 2013).

Logistics structure has various interrelations in production, supply, distribution, and transportation. When one of these is severely restricted, the negative externalities would increase significantly because some of the shipments become inefficient. It has been seen that the facilities are moving out of the urban centres causing a de-concentration of the logistics facilities/activities. This phenomenon was first explained by Dablanc, (2009) and is known as logistics sprawling.

The concept of sprawling has been seen in several metropolitan areas (Dablanc et al., 2014; Dablanc and Ross, 2012). Across many countries, urban sprawling and its impact and appropriate containment policy have become the most discussed issues in terms of urban planning. Many efforts were made to measure sprawl and test the relationship between sprawl and transportation. But, it is a combination of many variables such as population density, land use, degree of centrality, and street accessibility. (Ewing et al., 2003).

Dablanc and Rakotonarivo, (2010) studied the impacts of logistics sprawl on efficient movement of goods. This was done by studying the energy-efficient (carbon emissions) of each terminal. The research concluded that at least a total of 15,000 tonnes of excess carbon dioxide had been produced due when the logistics facilities move away from the cities. Woudsma et al., (2008) also tried to examine the relationship between urban structure development from the perspective of the logistics sector. The author found the pattern to be influenced by access to a location. Major highways and airports in the urban area are important for logistics land development. Woudsma et al., (2008) also found the local market condition as an important factor.

Researches have been done on the pattern of the movement of the logistics facilities and the factors of the movement. However, the relation between these factors and the movement has not been studied as it is difficult to quantify the degree of sprawling. Study-related to the movement of goods with different degrees of sprawling has not been carried out due to the insufficient data availability of freight flow in the country.

The logistics industry responded to high throughput pressure by an immediate expansion of freight capacity at freight hubs (e.g. hinterland of seaports or cargo service airports), but this approach soon reached the limit due to development density, land constraints, and arterial congestion (Hesse and Rodrigue, 2004). In search of alternative locations, increased distance from the urban core offered cheap land, larger parcels, access to congestion-free transportation infrastructure, and a supportive environment for logistics operations. Besides, global supply chains change the location calculus; access to major links in the national or international network that connect local and global became more important (Hesse, 2002).

This new location logic applies to major industry segments: warehousing, trucking, freight forwarding, and air cargo service providers (Hesse and Rodrigue, 2004). The result is logistics decentralisation and clustering of freight facilities in large metropolitan areas (Dablanc and Ross, 2012).

Decision-makers decide the location of the logistics facilities simultaneously with the distribution structure. It is done to make a profit as well as have good customer service. The location of a logistic facility depends on multiple elements such as total logistics cost, which includes inventory cost and delivery cost. The logistics facilities can be used as a de-consolidation, storage, or/and transshipment location. These logistics facilities are generally the centre point of the SCM. The main purpose of these inventories is to keep the logistic cost low by bundling inventories, transport flows, and to maintain high service levels with proximity to markets. If an intermediate inventory is required or worthwhile depends on many factors, including the physical characteristics of goods that determine the logistics cost structure and the service requirements. They affect the spatial pattern of trade, i.e. new origin and destination are created (Tavasszy and De Jong, 2013).

3.1.1. Spatial Characteristics to distinguish logistics facilities

Wagner, (2010) explained that the location of the logistics facility depends on factors such as centrality with the service areas, location of other facilities, or transfer depot, land availability, land price, access to infrastructure, and traffic volumes with the region. Logistics facilities affect the global economy, social geography of suburban areas as well as landscape (Cidell, 2011). More important it influences both private and public stakeholders. The location of logistics facilities impacts the truck traffic pattern and the well-being of individuals. For instance, logistics activities tend to create issues such as noise, air quality, safety, and congestion (Dablanc et al., 2014; Lindsey et al., 2014).

de Carvalho et al., (2019) found access to retail and facilities, population density, geographical area and the distance to the urban centre are very important while studying logistics sprawling. Woudsma et al., (2008) also found access to retail being the major spatial characteristics that influence urban structure developments. Most of the researchers found the following spatial characteristics which can help in understanding the location choice of the logistics facilities (Wiśnicki and Kujawski, 2019; Xydianou, 2019):

- Distance to the Urban Centre (UC)
- Population density of the area
- Transshipment Terminal (TT) availability
- Distance to Infrastructure (Ramps)

3.1.2. Logistics Characteristics to distinguish logistics facilities

McKinnon, (2009) differentiated the logistics facilities based on the categories and objectives of the facility. Some research works have attempted to introduce a difference between the logistics sector (Hesse and Rodrigue, 2004). Heitz et al., (2019) tried to distinguish based on the services the logistics facilities provide. While Wiegmans et al., 1999 classified the terminals based on sizes.

3.1.3. Other Characteristics to distinguish logistics facilities

The facilities could also be distinguished by location: service terminal, distribution centers, and inland port (Raimbault et al., 2012). Higgins et al., (2012) tried to categorise the logistics facilities based on hierarchy: satellite terminal, distribution centre, and gateway terminal. Another way to distinguish the facilities is based on their location in the supply chain or the firm's network of interaction (Cui and Hertz, 2011).

3.2. Freight Movements

The relation between the shipment pattern, location, and characteristics of facilities must be considered when analysing the effect of spatial distribution. Giuliano et al., (2016) recognised a relationship between shipment patterns, location, and characteristics of facilities. This would help in understanding the effect of the spatial distribution of distribution facilities on Vehicle Kilometre Travelled (VKT). He found that if all the logistics activities were locally oriented there would be more vehicle movements. But, if logistics activities were decentralised, there was no proof that it would result in high vehicle movements.

Aljohani and Thompson, (2016) studied logistics sprawling and found a hike in freight flows, due to increased frequency and low-weight deliveries. Sakai et al., (2017) study suggested that even though the average distance travelled had increased, the delivery efficiency would increase. The study also suggested that the distance of the facility from the urban centre and logistics facilities have an impact on efficiency. The congestion effects, vehicle routing, and vehicle types were not taken into consideration for the study. This research was one of a kind, due to the extensive data collected in Tokyo Metropolitan Area (TMA). The efficiency was calculated based on load and distance travelled, but there are many other factors which was not considered while taken the efficiency into account.

3.3. Logistics Efficiency

Köksal and Aksu, (2007) points out that the efficiency of the service sector has a significant issue in global trade. Logistics is considered to have a significant impact on a manufacturing organization's performance. Logistics influences the manufacturer's ability to satisfy customers and overall performance (Tracey, 1998). The SCM practices and logistics capabilities lead to an improvement in SCM strategies, which can result in an overall improvement in a firm's performance (Sezhiyan et al., 2011). Most of the supply chain planning is done on the Advanced Supply Chain Planning System (APS) module (figure 3.1).

Fawcett and Fawcett, (1995) stated that delivery speed, quality service, flexibility, cost, and innovation are essential to achieve optimal operational performance. Iyer et al., (2004) tried to empirically investigate the relationship between the supply chain, environmental uncertainty, organisational structure, and delivery performance. It demonstrated that e-commerce tries to enhance delivery performance as it mainly contributes to the firm's performance. The other dimensions which contributed to overall firm competitiveness are higher in-stock rates, lower lead time, and improved flexibility. The delivery performance was measured by the delivery lead times and on-time delivery to customers.

The logistics performance is a combination of logistics effectiveness and logistics efficiency. Efficiency refers to the ability to provide the desired product/service mix at a level of cost that is acceptable to the customers, Simply, efficiency means how well the resources are utilised (Fugate and Mentzer, 2010). The logistics efficiency of the logistics network was investigated for 25 cities by Jiang, (2010). The input characteristics were the level of economic development, the accessibility of transport. The output was the freight transport performance measured in tonne-kilometre on the different elements of the transport network.

The material flow in the supply chain is impossible without transport involvement. However, the efficiency of the supply chain based on transport efficiency indicators is not appropriate (Kush et al., 2018). It is important to understand all the elements of the supply chain and organise them in such a way that it gives maximum synergetic effects. Researchers have been studying the elements of efficiency increase in supply chain functioning. However, the changes in the performance include parameters of the transportation pro-

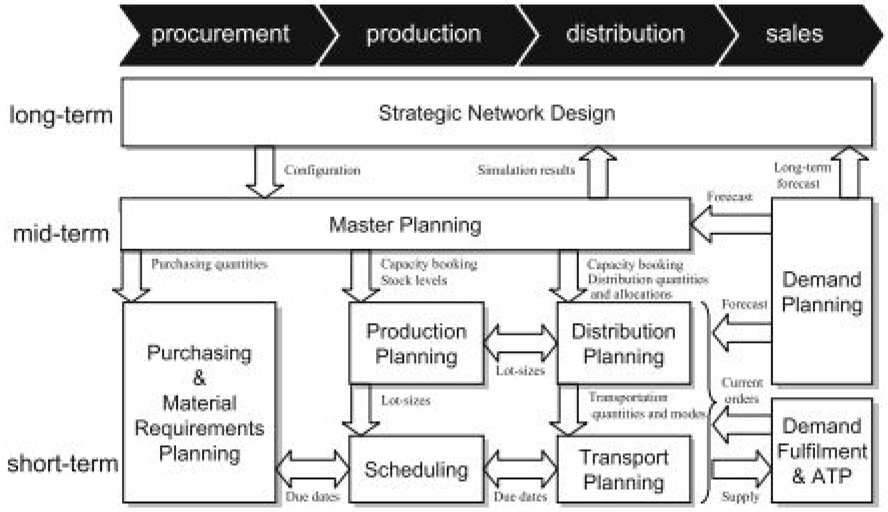

Figure 3.1: APS Module (Stadtler et al., 2015)

cess, which has not been fully discovered (Kush et al., 2018; Tracey, 2004).

3.3.1. Factors of transportation influencing supply chain

A study was done by Prasad and Sounderpandian, (2003) showed the different characteristics of transportation that influence the supply chain and their planning. The transportation cost, accessibility, shipping patterns, warehouse locations, routing constraints, the ratio of infra to inter-company traffic, carrier qualifications, inter-modal systems, and services of third party freight forwards are some of the transportation characteristics that influence the supply chain. The figure 3.2 below highlights these factors.

3.3.2. Indicator for Transport Efficiency

The efficiency of transportation can be determined by the effectiveness of the flow movement system integrally. In current market conditions, the issue of transport efficiency is of crucial importance. This is due to the changing economic situation in the countries, increasing competition among the retail network participants, and constantly changing demand for material flow. In this regard, the issues of transport operation improvement, costs reduction and reliability ensuring are quite relevant (Kush et al., 2018).

Costs such as vehicle cost, mileage of the vehicle, cost of the driver, insurance, payload of the truck, and cost per ton are the important factors to investigate. The transportation costs typically comprise 6–8% of the company's costs. In most cases, transportation costs can be reduced by 10–15% (Ivanov et al., 2019).

The rated load capacity of the vehicle and the specific fuel consumption (SFC) are some of the variable costs. While salary, depreciation deduction, insurance, utility charge, and other costs are the fixed cost of transport services. The fixed cost also depends on the number of vehicles, their type, and carrying capacity. Kush et al., (2018) found that the logistical system participants such as the transport and warehouse interact through the parameter called transport load.

The economy of scale is desired by most of the companies which can be done by consolidation, postponement, and transshipment. The size of the shipment oscillates due to the external impacts and customer demand. Either the vehicles travel in Full truckload (FTL) or Less-than-truckload (LTL) (Stadtler et al., 2015). Transport planning affects inventory planning. The production rate, demand rate, maximum load per shipment, transport lead timed, cycle time, shipment quantity, inventory holding cost, and the cost of the shipment of quantity are the various variables that help in the planning (Stadtler et al., 2015).

Ivanov et al., (2019) and Kush et al., (2018) found a load on the vehicle, utilisation of the vehicle, distance travelled by the vehicle, trip duration, and empty kilometres as useful indicators to understand the trip efficiency. Some of the other indicators can be seen in table 3.1.

	Procurement	Processing	Distribution
Markets			
Customers and governments			X
Rate of change toward a market economy			X
Relative size of the market			X
Price, market share and competition for the product			X
Level of customer service			X
Order size			X
Product life cycle			X
Degree of product adaptation to local needs			X
Transportation			
Transportation cost	X		X
Accessibility	X		X
Shipping patterns	X		X
Warehouse location			X
Routing constraints	X		X
Ratio of intra to inter company traffic	X		X
Carrier qualifications	X		X
Intermodal systems	X		X
Services of third party freight forwarders	X		X
Technology			
Machines and equipment	X	X	X
Work methods	X	X	X
Flow of ideas, drawings and technical reports	X	X	X
Intellectual property rights	X	X	
Network learning	X	X	X
Financial			
Economies of scale and scope	X	X	X
Cost of capital and land		X	X
Transfer pricing	X	X	X
Organizational behavior and HRM			
Level and type of education			
Documentation methodology			
Workforce teams			
Number of labor grades			
Number of staff positions			
Career paths			

Figure 3.2: Factors of transportation influencing supply chain (Prasad and Sounderpandian, 2003)

Table 3.1: Transport Efficiency Indicators

Indicators	References
1. Kilometres per day	Krauth et al., (2005)
2. Kilometres per trip	Krauth et al., (2005)
3. Planned vs Actual distance travelled	Robinson, (n.d.)
4. Number of trips	Robinson, (n.d.)
5. Number of trucks in use	Krauth et al., (2005)
6. Vehicle Utilisation	Krauth et al., (2005)
7. Average fuel consumption	Krauth et al., (2005)
8. Level of CO_2 emission	Krauth et al., (2005)
9. Carrier Performance	Smokers et al., (2019)
10. Network Performance	Smokers et al., (2019)

3.4. Overview of the Indicators

This section compiles and gives an overview of the different indicators found in the literature. Table 3.2, shows the spatial and logistics characteristics based on which the facilities that can be distinguished and the indicators to understand transport efficiency.

Table 3.2: Overview of the different indicators

Indicators to differentiate Logistics Facilities	**Indicators to assess Transport Efficiency**
Distance to Urban Centre (UC)	Kilometres per day
Distance to Transshipment Terminals	Kilometres per trip
Distance to Ports	Planned vs actual distance travelled
Distance to Airports	Vehicle carrying capacity
Population Density (Households per kilometre square ($hhkm^2$))	Number of trips
Land Availability	Number of trucks in use
Access to Infrastructure	Vehicle Utilisation Rate
Size of the Logistics Facility	Average fuel consumption
Objective of the Logistics Facility	Level of CO_2 emission
Land Price	Carrier Performance
Proximity to markets	Network performance
Sector of the Logistics Facility	Empty Kilometres
Construction Year of the Logistics Facility	Trip Duration

3.5. Research Scope

The research is based on the shipment data collected by Centraal Bureau voor de Statistiek / Statistics Netherlands (CBS) in 2015 and the logistics facility database[1] by Rijkswaterstaat (RWS). The data includes information about the shipments. The departure and arrival location of the shipments were known, as well as the vehicle which carried the shipment. Based on that information Mohammed et al., (2020), made an algorithm which constructed the tours of these vehicles. Keeping the data and the literature review as the basis, the indicators for the research were defined. figure 3.3 shows the scope of this research. It also shows the selected indicators in boxes and the relation between the different indicators.

The literature review showed that the spatial factors that influence the location choice of logistics facilities are land availability, centrality to service locations, access to infrastructure, the population density of the area, distance to ports and TT and proximity to markets.

On the other hand, the literature suggests the companies try to minimise their total logistics cost by the economy of scale. The total logistics cost is a combination of inventory cost and delivery cost. A comprehensive look into the costs suggested that distance, frequency, and weight of the deliveries including the vehicle costs influence the delivery cost. While the inventory planning, production rate, demand, and size of the facility influence the inventory cost. It was also seen that location choice indicators influence these variables.

The factors distance, frequency, and weight of the delivery were used to find some of the important transport efficiency indicators. Length of the trips, vehicle kilometre per tour, number of trips, vehicle utilisation rate (Loading factor), empty kilometres, planned versus actual distance travelled, number of trucks in use, average fuel consumption, and network performance and some of the indicators which influence transport efficiency.

The location choice indicators in the red box influence the factors of delivery cost and will be used for the analysis. The proximity to the markets was left out of the study due to a lack of data on the exact markets and the number of markets in the Netherlands. While the indicators in the green box influence the inventory cost. Land price and objective of the logistics facilities were left out. Since the land price is highly dynamic it is difficult to study and due to insufficient information, the objective of the logistics facility was not studied.

The Transport efficiency indicators in the blue box are the selected and are the ones that will be studied, as only information on those indicators can be calculated. For this research, the other variables are out of scope.

3.6. Conceptual Model

An analytical model to calculate transport efficiency was created by Mckinnon, (2007), later adapted by Allen et al., (2012) (figure 3.4) to calculate the efficiency of the on-road vehicles. The ratio of tonne-kilometres to

[1] In this study the distribution centres are termed as logistics facilities.

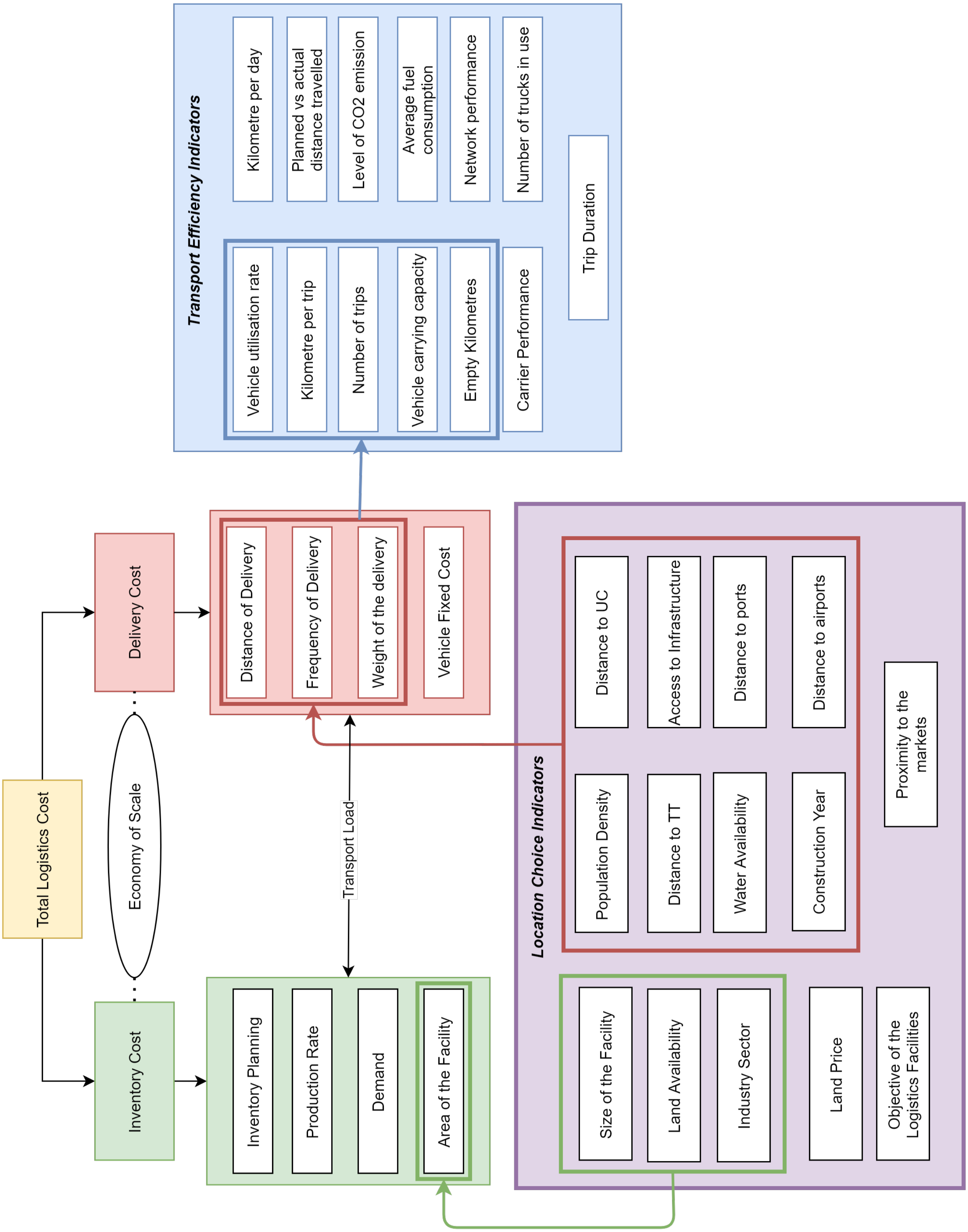

Figure 3.3: Research Scope

vehicle kilometres performed by vehicle reflects the road freight transport efficiency with higher numbers indicating more efficient operations. The ratio reflects the average vehicle carrying capacity, loading factor on loaded journeys, and the extent of empty running by vehicle. An adaptation of this framework would be used for this research (figure 3.5).

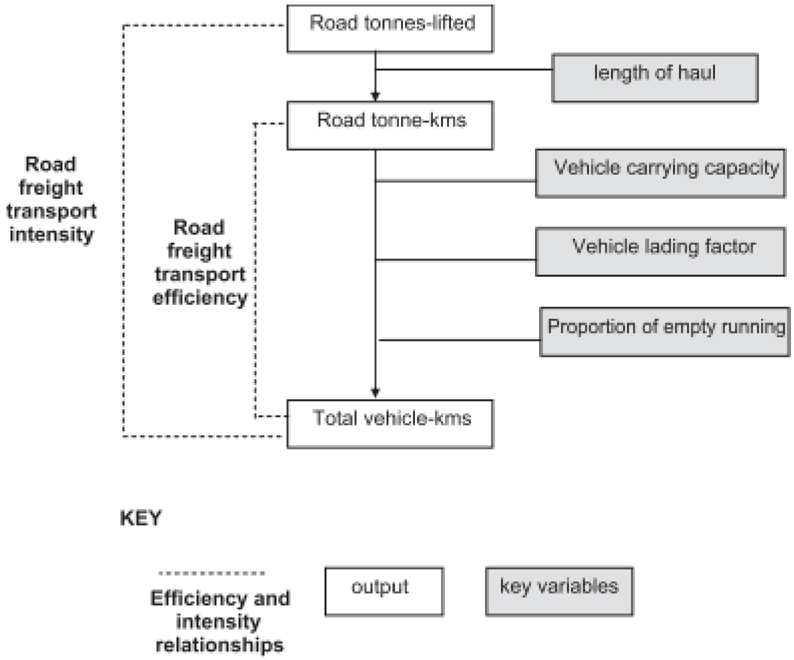

Figure 3.4: Model to calculate road freight transport efficiency (Allen et al., 2012)

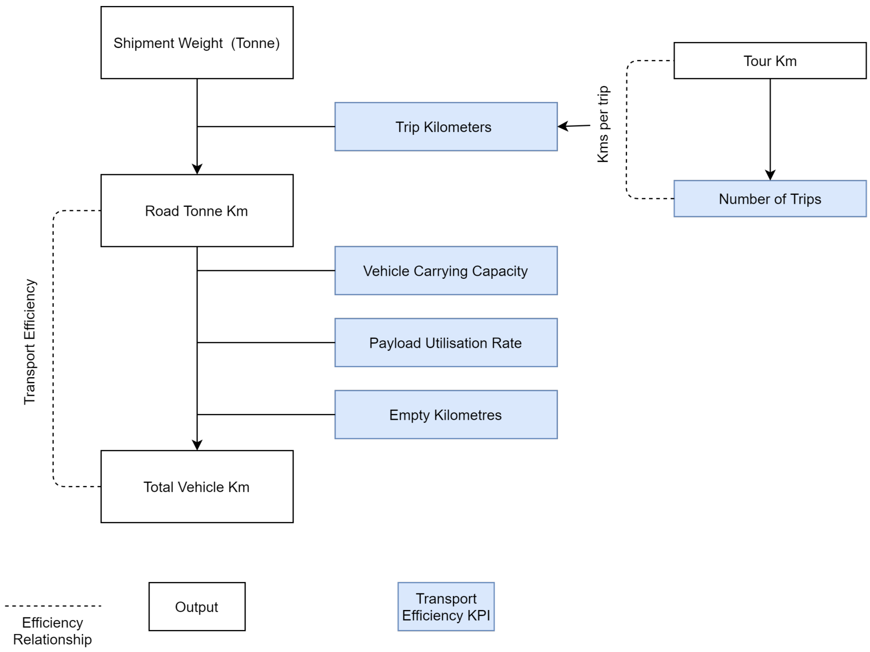

Figure 3.5: Conceptual Framework

The conceptual framework presented in figure 3.5 explains the relation between the different aspects of the study. The conceptual framework was constructed based on the literature study done in the above sections.

The framework uses the shipment weight and trip kilometres to find the road tonne-km of a trip. The road tonne-km divided by the total vehicle kilometres gives the transport efficiency. This gives an indication of the vehicle carrying capacity, payload utilisation rate, and empty kilometres. If a leg in the tour carries travels with no shipment/load, then the transport efficiency of that leg would be 0. This can also be seen in the different indicators. There will a high empty kilometre and no payload utilisation rate.

If the shipment weight is equal to the vehicle carrying capacity (i.e., the highest shipment load that can be carried in the vehicle) and that the tour only has one journey. Then, the transport efficiency would be equal to the shipment weight. This is the highest value of transport efficiency that can be reached. There would be no empty kilometres and a high payload utilisation rate. The value of the transport efficiency is a relative number. These values can be compared against each other, but a number 1 doesn't mean the transport efficiency of 100%.

The above-explained method is to be followed for each leg of the trip. Since. from the database we don't have each trip legs, an average trip distance will be calculated. This will be done by, calculating the minimum number of trips in a tour possible. The total tour length is divided by the number of trips subsequently. This assumption makes the calculation of transport efficiency a little different than calculating for each leg.

The minimum number of trips in a tour is calculated by summing the departure location of the vehicle with the arrival location of the vehicle and the total unique locations the vehicle visits subtracted by 1 (figure 3.6)

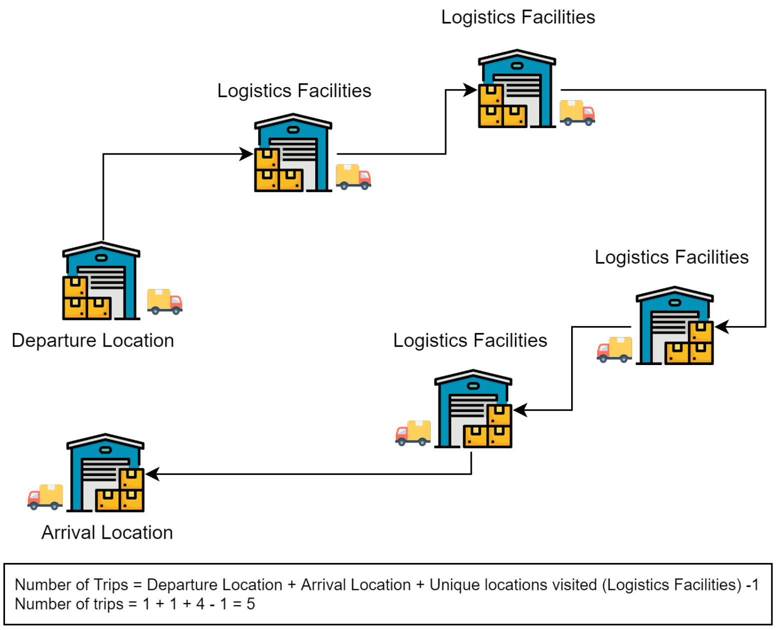

Figure 3.6: Number of trips calculation

The other transport efficiency indicators were not added to the conceptual framework, due to the no data availability. The network and carrier performance can also help in getting insights into the transport emissions. Network performance is the ratio of the total greenhouse gas emissions to the total weight of goods shipped. While the carrier performance is the ratio of the total greenhouse gas emissions to the weight of goods per trip.

4

Logistics Facility Topology

This chapter introduces the different databases used in this research. The introduction of the database helps in aligning with the literature review. Based on the exploratory study further progress will be made in the research. Following, the logistics facilities will be classified based on the different spatial and logistics indicators.

4.1. Study Area

The population of the Netherlands exceed 17 million (Centraal Bureau voor de Statistiek, 2019) and is continuously increasing (figure 4.1). The Netherlands has a total land area of 41,545 km^2 and a population density of $521/km^2$ making it the second most populated member of the European Union (Waar staat je provincie, 2020). Most of this population living in urban areas. Consequently, the Netherlands is highly urbanised. Resulting in an increase in freight movement with the urban areas.

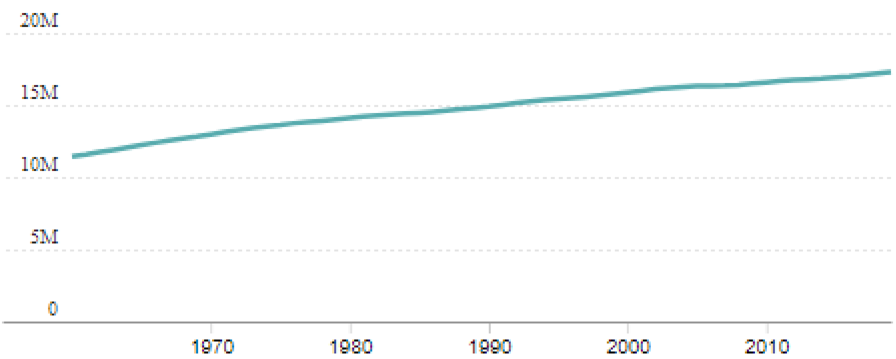

Figure 4.1: Population of the Netherlands (Data Commons, 2019)

The Netherlands location also acts as a hub for freight distribution in Europe. As a result, it is the location choice for logistics facilities by most of the companies in Europe (Government of the Netherlands, n.d.). Venlo and Rotterdam are considered the most desirable logistics location in Europe (PROLOGIS, 2013). Figure 4.2 shows the location of Venlo and Rotterdam. Each company uses the distribution centres for multiple purposes. The vast varieties of the logistics facilities make it important to differentiate them, for a better understanding and the impact on transport infrastructure. In the next sections, the introduction to the different locations of the logistics facilities in the Netherlands and the truck tour databases will be introduced and explored.

Figure 4.2: Location of Venlo and Rotterdam

4.2. Logistics Facility Database

On average there are more than 1,000 logistics facilities in each country (United Kindgom Warehouse Association, n.d.). To understand the logistics facility location and its impacts Rijkswaterstaat compiled the information of all the logistics facilities in the Netherlands. The compilation of this database was done in 2015, hence the logistics facilities built after has not been taken into consideration. The logistics facility database includes 1681 logistics facilities which include the construction year, industry sector (Standaard Bedrijfsindeling (SBI)), surface area, and 6 digit postcode. The frequency of different SBI codes was calculated at three-digit accuracy and can be seen in figure 4.3. Most of the logistics facilities belonged to wholesale food, beverages and tobacco, consumer goods, machine and equipment, other specialised wholesaler, and freight transport by road. The logistics facilities in the database only include facilities with a surface area of more than 5,000 metres square. But there are more facilities with smaller size. The percentage share for the logistics facilities in different provinces was calculated and was seen that Gelderland, North Brabant, North Holland and South Holland combined have 61% of logistics facilities. Table 4.1 shows the percentage share of logistics facilities for each province. The construction year ranges from 1835 to 2016. Approximately half of the logistics facilities were made from 1995 as seen in table 4.3. 24 logistics facilities were constructed before 1935 and it has been constantly increasing. 24 logistics facilities were constructed before 1935 and it has been constantly increasing.

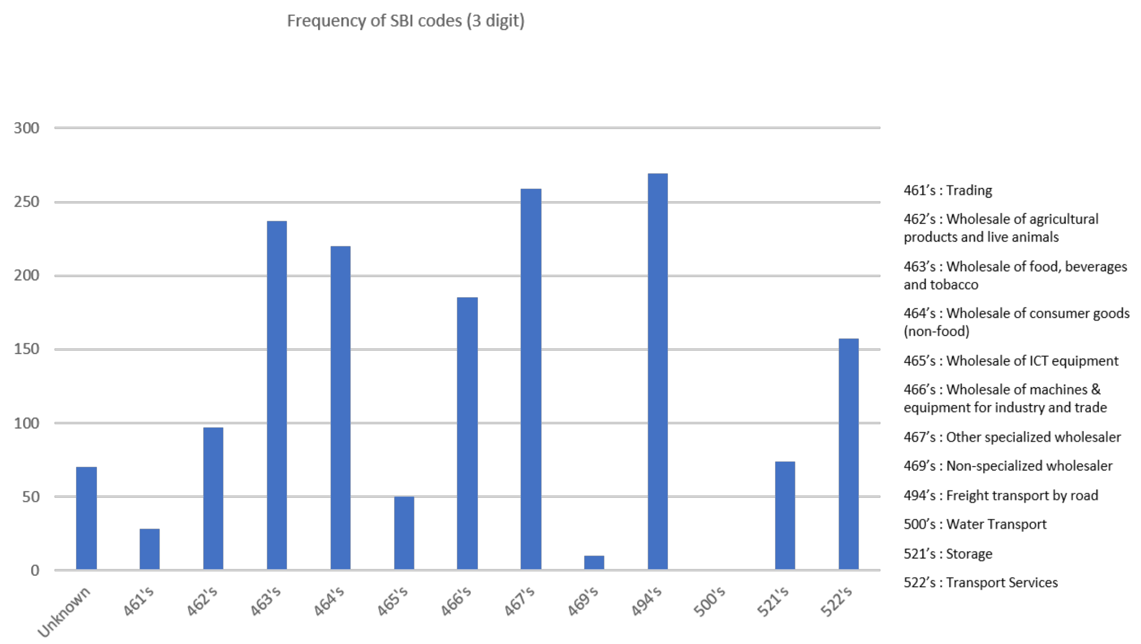

Figure 4.3: Frequency of different Industry Sector

Table 4.1: Percentage share of logistics facilities in each provinces

Provinces	Percentage share of Logistics Facilities
Unknown	4%
Friesland	2%
Groningen	1%
Drenthe	1%
Overijssel	6%
Gelderland	12%
Flevoland	4%
North Holland	12%
South Holland	18%
Utrecht	6%
Zeeland	1%
North Brabant	23%
Limburg	8%

It was seen that most of the logistics facilities were locates in the North Brabant, North-Holland, South Holland and Gelderland region. The table 4.2 shows the average surface area is $14,314.20m^2$ and the average construction year as 1990. But, there is a high standard deviation due to different types of industry sectors. Hence, there is a need to take spatial and logistics features into consideration, to distinguish the facilities as

Table 4.2: Averages and standard deviations for surface area and construction year

	Surface Area(m^2)	**Construction Year**
Average	14,314	1990
Standard Deviation	15,552	18

discussed in section 3.5. The spatial features such as distance to UC, distance to port, ramps (infrastructure) & TT, land, water availability and $hhkm^2$ will also be taken into consideration. The SBI code will be used as a logistics feature to distinguish the logistics facilities.

4.3. Spatial characteristics

The database for the spatial characteristics of the Netherlands was received from Rijkswaterstaat. It contains the network, population density of every region, land, and water availability.

The Netherlands being a polycentric country it is important to determine the UC. The Urban Centre (UC) was defined based on the household density of 2015 for the different neighbourhoods. The most used definition of urban centres is municipalities with more than 2,500 households per kilometre square. Dubie et al.(2018), Strale(2019), and Xydianou(2019) used similar methodologies.

The Netherlands' urban area was divided into 5 different regions based on the population density. The areas with the highest population densities are considered as urban centres. The scale is as follows:

1. More or equal to 2,500 households per kilometre square
2. 1,500 – 2,500 households per kilometre square
3. 1,000 – 1,500 households per kilometre square
4. 500 – 1,000 households per kilometre square
5. Less than 500 households per square kilometre square

The households in each neighborhood for 2015 with the land area were used to differentiate the urban centre. table **??** shows the share of each region and figure 4.4 shows the different regions in the Netherlands. A detailed description of the number of facilities in different zones with their average distance to the urban centre can be found in Appendix A.

captionPercentage share of different level of urbanisation

Urbanisation Level	**Percentage share**
Urban Centre (≥ 2,500 hh/km2)	23%
Sub-Urban Area (1,500-2,500 hh/km2)	5%
Peripheral Cities (1,000 - 1,5000 hh/km2)	6%
Rural Areas (500 -1,000 hh/km2)	13%
Remote Location (< 500 hh/km2)	53%

The average distance of facilities to the urban centre for each of the periods is shown in table 4.3. The change in the average distance to UC from period 1 (before 1935) to 2 (1935 - 1976) was seen to be 24%, for the time period 2 (1935 - 1976) to 3 (1976-1995) was 5.88%, for time period 3 (1976 - 1995) to 4 (1995 - 2005), 6.73%, and for the final period was seen as 10.29%. It is seen that the highest shift can be seen in 1935, but that period cannot be considered significant due to the low number of observations. Therefore, 2005 has seen the major shift of the logistics facilities to the outskirts.

4.4. Classification of Logistics Facilities

To quantify and describe the different types of logistics facilities present in the Netherlands, a statistical analysis was done on SPSS based on the different spatial and logistical indicators discussed in 3.1. This helps us to understand the different types of facilities and how their efficiencies look like. The methodologies mentioned

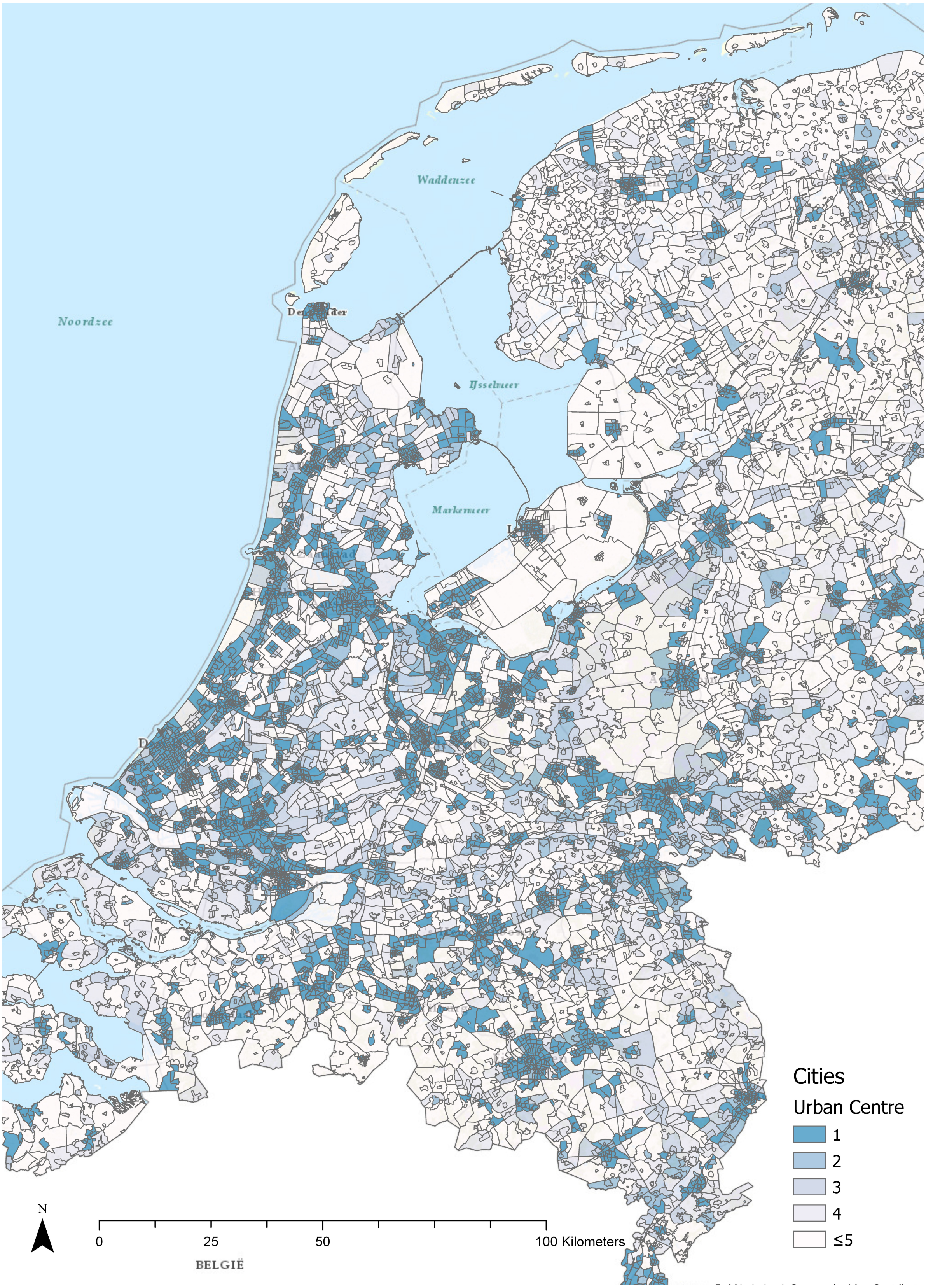

Figure 4.4: Urbanisation level in the Netherlands

Table 4.3: Average distance to UC for different time periods

Time Period	Number of Logistics Facilities	Average Distance to UC (kms)	Percentage shift
Before 1935	24	2.03	
1935-1976	284	1.87	24%
1976-1995	530	1.85	5.88%
1995-2005	510	1.95	6.73%
2005-2016	333	2.16	10.29%

below were performed iteratively to reach the optimal results from a statistical and theoretical perspective. Spatial analysis of the location of the logistics facilities was done, and no significant correlations between the facilities were found (Appendix B). Hence, clustering analysis is crucial to distinguish the facilities.

4.4.1. Principal Component Analysis (PCA)

Statistical analysis was performed on SPSS, to quantify and describe the topology of the logistics facilities. An implementation of the PCA relies on the fact that the variables have a considerable variance and are significantly interrelated.

Heitz et al., (2018) and Strale, (2019) implemented PCA, due to a high number of observations. For the same reason, PCA will be performed. PCA is a statistical method that dimensionally reduces the initial database by identifying principal components uncorrelated to each other (Jaadi, 2019).

Following PCA, the implementation of cluster analysis is done. It is a classification technique before which outliers should be removed (Liu et al., 2018). Liu et al., (2018) considered this a pre-processing step of clustering analysis. The outliers are removed as it results in the overestimation of extracted components, hence reducing the reliability of the cluster analysis. Each of the components explains partially the variance in the database. The information must be evenly distributed.

The PCA included the factors discussed in section 3.5. Kaiser Meyer Olkin measure of sampling adequacy was 0.6 (> 0.5) making the analysis useful. Four components were found in our case, the first component explains 16.2% of the variation, while component 2 shows 16.2%, 2&3 explains 12.6% and 11.6% of the variation. As a result, the ten variables were dimensionally reduced to four components, which can be seen in table 4.4. The table shows the correlation of each variable with the component. The principal components were entitled as follows:

1. **Geographical Characteristics:** The variables integrated into this principal component are distance to ramps(infrastructure), land, and water availability. These variables are positively correlated with the component. It can be seen that the land and water availability have a high effect on the component compared to the distance to ramp (table 4.4).
2. **Intermediate Hub availability:** This includes the distance to TT and ports. The correlation of both the variables is very high for the principal component 2.
3. **Logistics Sprawling characteristics:** The variables integrated are construction year, distance to the urban centre, and household per kilometre square. These variables are positively correlated with the component.
4. **Industry characteristics:** The variables integrated are includes SBI (industry sector) and the surface area. Both the variables have a correlation of 0.75 and 0.82 respectively.

4.4.2. Hierarchical Cluster Analysis (HCA)

Succeeding PCA is the clustering analysis, it deals with the grouping of logistics facilities based on the components extracted from PCA. HCA provides a realised cluster, the objective is to segregate the facilities homogeneously internally and with each other simultaneously. Researches have seen that there is a relation between the logistics facilities' location and urban structure. Chhetri et al., (2014); Cidell, (2010) & Rodrigue, (2020). saw that there is a preference in specific locations.

Variables	Components			
	1	2	3	4
Construction Year			0.77	
Industry Sector				0.75
Distance to Urban Centre			0.75	
Distance to Transshipment Terminal		0.93		
Distance to Ramp	0.44			
Land Availability	0.86			
Water Availability	0.86			
Distance to Port		0.94		
Surface Area				0.82
Household per kilometre square			0.74	

Table 4.4: Principal Component Analysis

The components extracted from PCA were used as the foundation for the clustering of the locations. HCA ward's method was used as it divides the logistics facility location into eight different clusters, that were statistically significant level of 95% (p-value = 0.00).

A study conducted by Xydianou, (2019) used four principal components to create five different logistics clusters. The components were also related to population density and geography, similar to this research. The facility characteristics (storage, distribution, etc.) were excluded from that study. The averages of the different components of each cluster can be seen in figure 4.5.

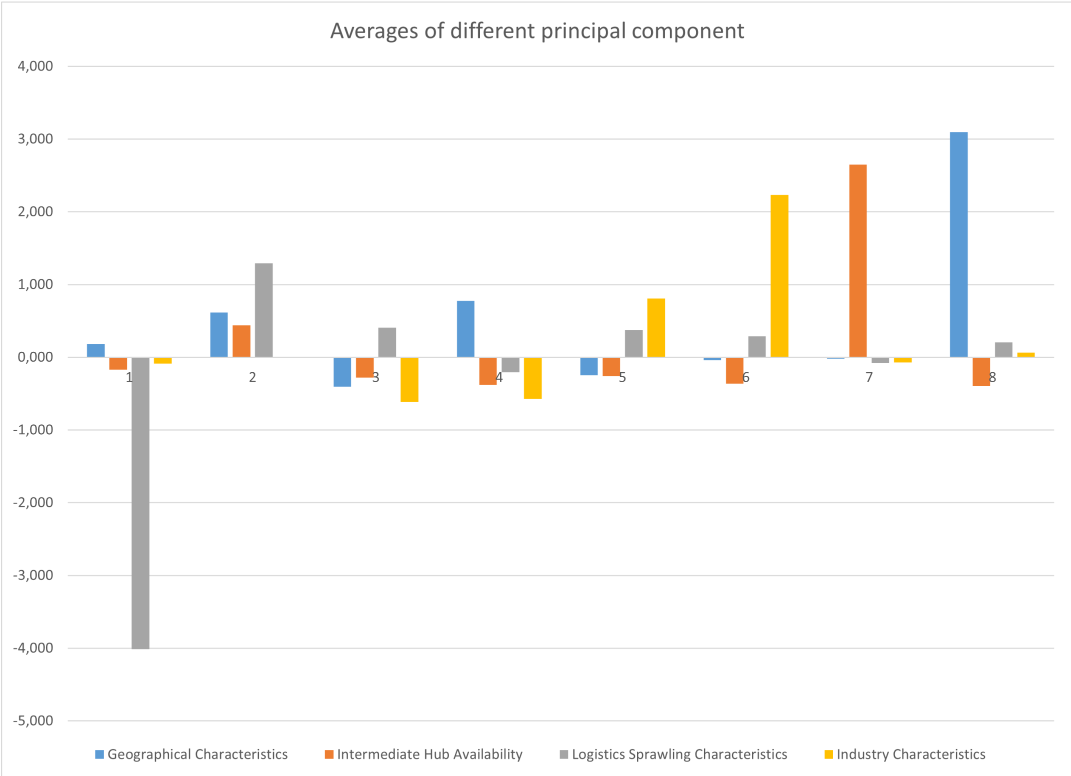

Figure 4.5: Averages of the principal component for different clusters

The different clusters that were found from the analysis are presented below and can be seen in figure 4.6. The sizes of the cluster related to the different sizes of the facilities while the red facilities are in UC and green in remote locations. Details of each cluster can be seen in table 4.5. The values in the table are based on the averages over all the logistics facilities in the cluster. Table 4.6 shows the different types of sectors in each cluster.

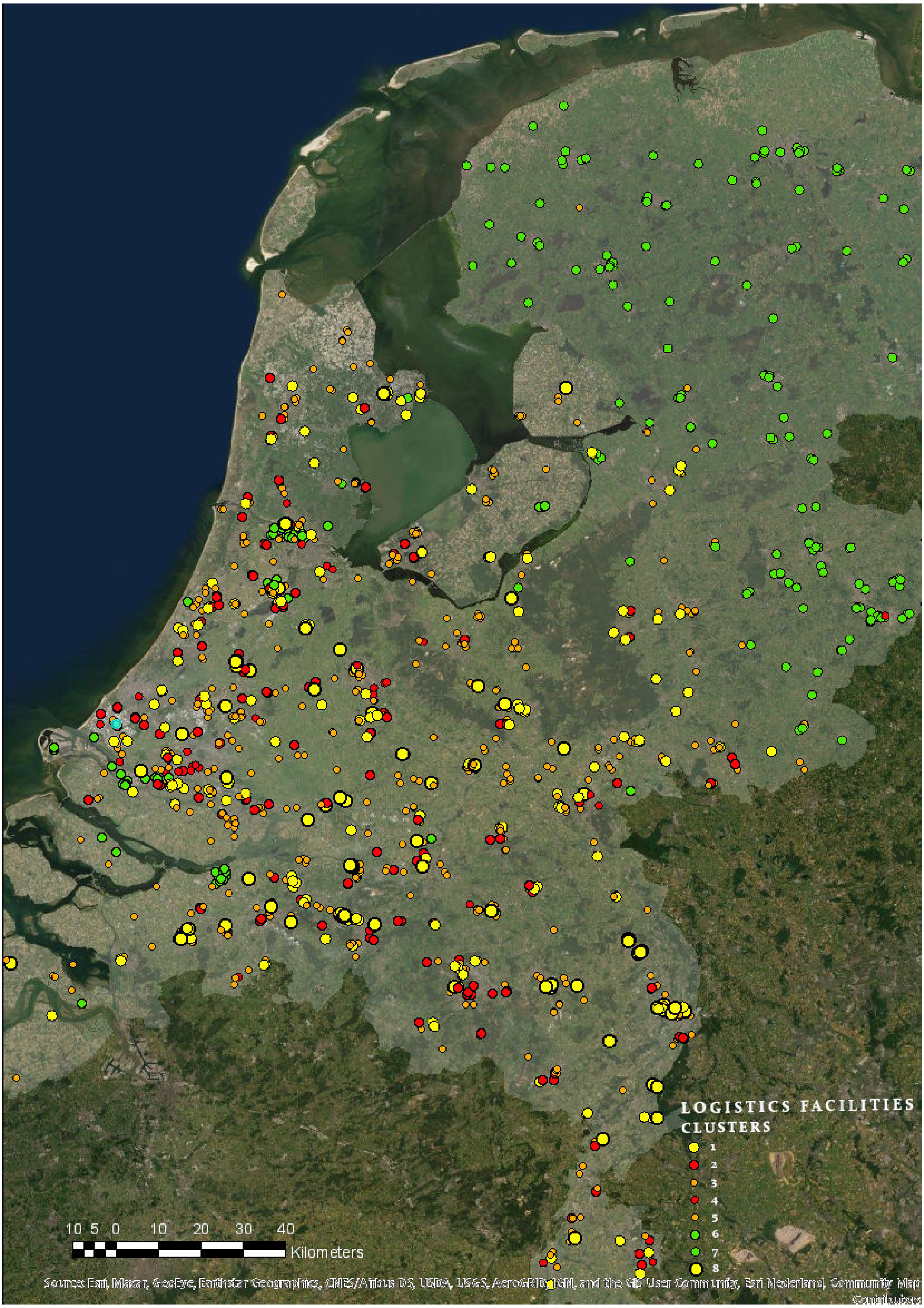

Figure 4.6: Visualising the spatial location of different clusters

Table 4.5: Averages of each variable for different clusters

Cluster	Frequency	Surface Area	Year of construction	Distance to UC (kms)	Distance to TT (kms)	Distance to Ramp (kms)	HHKm2	Land availability	Water availability	Distance to port (kms)
1	38	11026	1950	0.46	463	0.29	19957	124	38	25590
2	163	12947	1980	0.78	455	0.25	13676	144	5	24570
3	622	8529	1990	1.67	463	0.29	1242	237	8	33092
4	188	9460	1985	1.70	456	0.47	2824	711	52	31066
5	283	20335	1995	1.64	458	0.40	726	271	14	31738
6	123	41979	1995	1.76	442	0.49	918	347	20	29891
7	176	11474	1990	2.13	568	0.34	2184	381	17	116115
8	79	12086	1995	2.66	461	0.69	556	2179	454	11331

Table 4.6: Cross-table of industry sector and clusters

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	Cluster 7	Cluster 8
Unknwown	3%	5%	2%	2%	10%	7%	4%	0%
Trading (461's)	11%	1%	2%	4%	2%	0%	1%	0%
Agricultural products and live animals (462's)	5%	7%	7%	7%	7%	2%	5%	1%
Food, beverages and tobacco (463's)	21%	18%	15%	19%	14%	2%	14%	8%
Consumer goods (non-food) (464's)	21%	10%	18%	14%	10%	1%	11%	6%
ICT equipment (465's)	8%	2%	5%	1%	2%	0%	2%	3%
Machines & equipment for industry and trade (466's)	11%	11%	16%	17%	1%	1%	14%	4%
Other specialised wholesaler (467's)	5%	17%	19%	22%	4%	1%	24%	20%
Non-specialised wholesaler (469's)	0%	1%	0%	1%	1%	0%	1%	1%
Freight transport by road (494's)	13%	18%	15%	12%	23%	14%	17%	18%
Water Transport (500's)	0%	0%	0%	0%	0%	0%	0%	1%
Storage (521's)	0%	4%	0%	1%	6%	31%	3%	4%
Transport Services (522's)	3%	6%	0%	0%	20%	42%	6%	34%

The naming of each cluster was based on the size of the logistics facility and the location. Buck Consultants Internationals, (2020) looked into the XXL logistics facilities and also identified facilities with surface area more than 40,000 m^2 as XXL size. Hence, the naming of the facility based on sizes are as follows:

- Facilities with surface area 5,000 - 10,000 are considered as small logistics facilities.
- Facilities with surface area 10,000 - 20,000 are considered as medium logistics facilities.
- Facilities with surface area 20,000 - 30,000 are considered as large logistics facilities.
- Facilities with surface area 30,000 - 40,000 are considered as XL logistics facilities.
- Facilities with surface area 40,000 - 50,000 are considered as XXL logistics facilities.
- Facilities with a surface area of more than 50,000 are considered as XXXL logistics facilities.

The name of the locations found was segregated into urban centres, sub-urban areas, peripheral cities, and remote locations. The urban centres are areas, which are highly dense and the distance to UC is less than 1 km. Sub-urban areas are the areas just outside the UC. These areas are a little less populated compared to the urban centres and are at a distance of 1 to 2 kms to the UC. The extended cities are similar to sub-urban areas with a lesser population density. Remote locations are 2 kms away from the UC. Figure 4.7, shows the different locations.

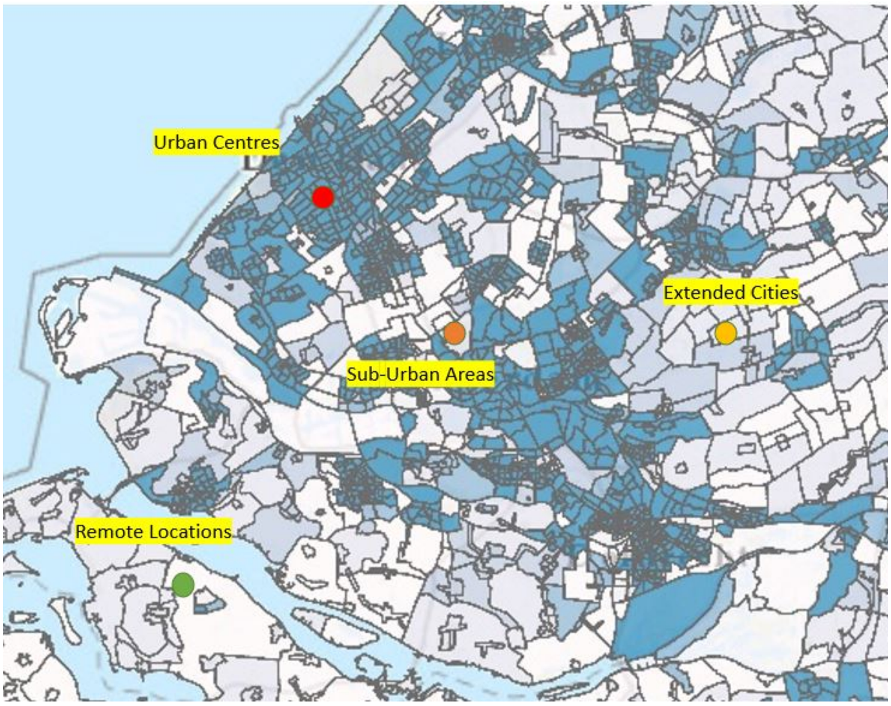

Figure 4.7: Example of Urban Centre, Sub-Urban Areas, Extended Cities & Remote Locations

Cluster 1: Old Medium Facilities in Urban Centre

These are medium-sized facilities (11,000 m^2). These types of facilities are seen as the oldest. Hence, these are located in the densely populated region (1,900 $hhkm^2$). There are only 38 logistics facilities in this category. There is a low land availability of facilities in this cluster due to the location (UC). The logistics facilities in this group mainly belong to the wholesale food and consumer goods (table 4.6). Figure 4.8 shows the averages of this type of logistics facilities to the average of the whole database.

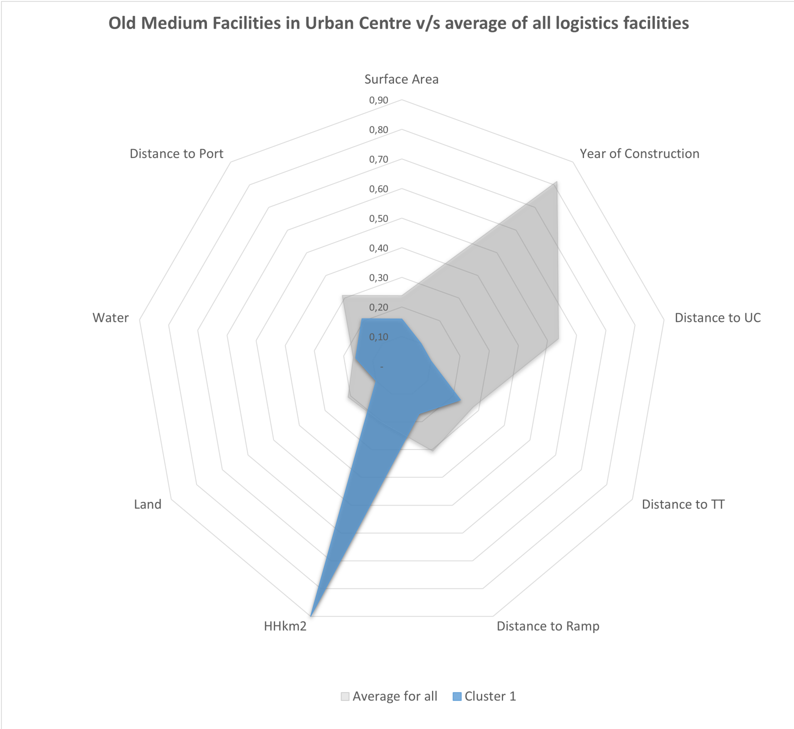

Figure 4.8: Comparing facilities in cluster 1 to the average of all the facilities

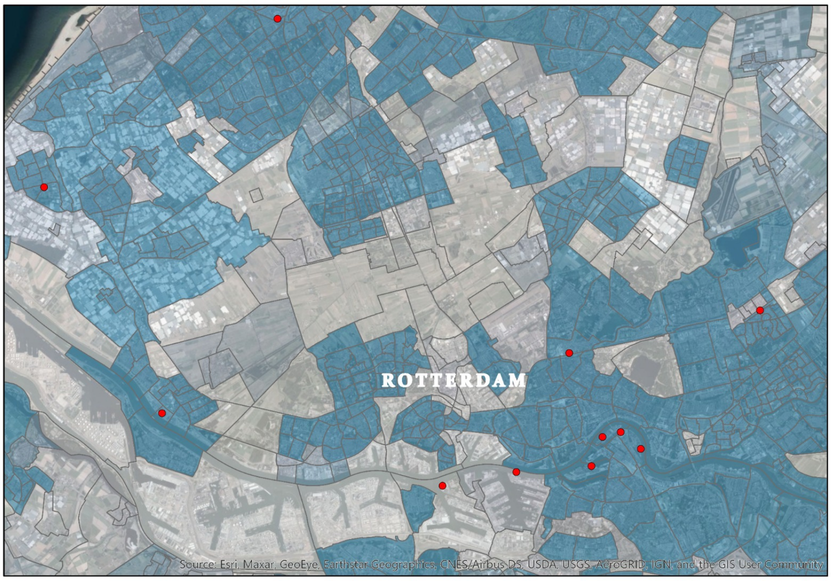

Figure 4.9: Location of logistics facilities in cluster 1

These facilities could be used for the last mile delivery to the customer. Figure 4.9 displays that these facilities are located in the central region of the urban area. This can also be seen in figure 4.8. It is logical to say that as they have been present for a long time and the supply chain grew around these facilities. Though some of them are already located close to the port of Rotterdam, there is a likelihood that these facilities can be used for both international as well as last-mile deliveries. These facilities were built between 1830-1950.

Cluster 2: Medium Facilities in Urban Centre

These logistics facilities have an average surface area of 13,000 m^2 with the construction year of 1986. They are newer compared to the other medium facilities in the urban centre (cluster 1), as these logistics facilities are built after them. The distance to the urban centre is 0.8 km with a household density of 13,500. These facilities are located at a distance of 454km, 0.25 km, 24.5km to TT, ramp, and ports. They mainly include the wholesale sector. Figure 4.10 shows the averages of this type of logistics facilities with an average of the whole database.

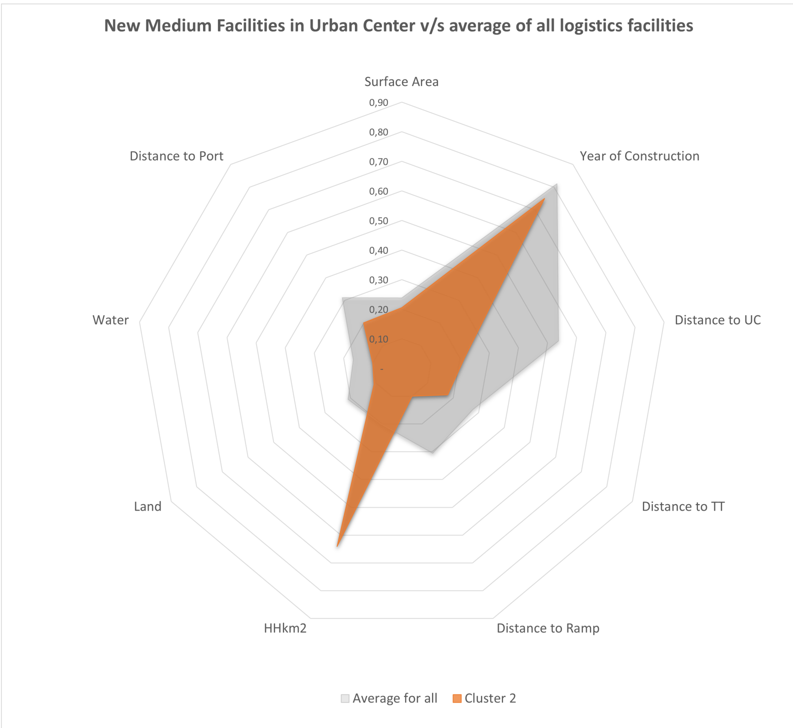

Figure 4.10: Comparing facilities in cluster 2 to the average of all the facilities

These logistics facilities can also belong to the last mile of the supply chain. The logistics facilities in figure 4.11 appears to be located just on the edge of the urban areas. It can be due to a lack of land availability and companies trying to reach the centre as much as possible. It can be validated by figure 4.10 as the land availability is very less and the distance to the UC is lesser than the average of all the facilities.

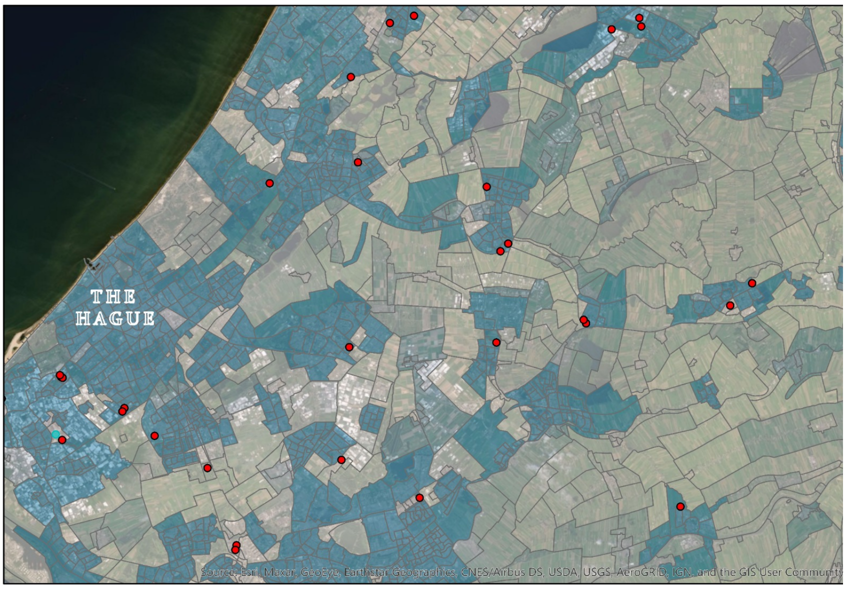

Figure 4.11: Location of logistics facilities in cluster 2

Cluster 3: Small Facilities in Sub-Urban Areas (constructed during compact city policy)

These logistics facilities belong to facilities with a small area and with the average construction year as 1992. These logistics facilities were built around the time when the Dutch national authorities pursued the policy of compact city (VINEX) (Geurs et al., 2003). This policy focused on (re)development towards location within existing urban areas. The facilities in this group are located in the sub-urban region (1,200 $hhkm^2$). These are at a distance of 1.7 km, 463 km, 0.3 km and 33 km to UC, TT, ramp and ports respectively. They mainly belong to wholesale non-food, machines, and other specialised wholesalers.

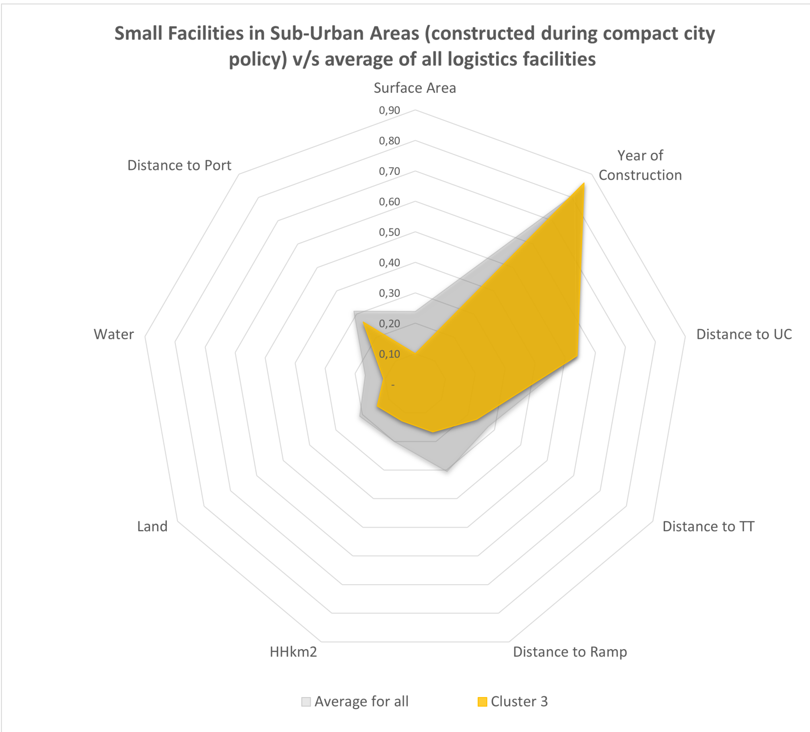

Figure 4.12: Comparing facilities in cluster 3 to the average of all the facilities

Figure 4.12 shows the averages of this type of logistics facilities with an average of the whole database. It could be seen that these facilities behave very similar to the average of all the facilities. The facilities in this cluster might deliver products to multiple shops. These could be a small distribution centre for a region delivering food and consumer items. From figure 4.13 it is also seen that these facilities are located at small clusters far from each other. It is interesting to note that these facilities have less $hhkm^2$ and more land availability than the previous cluster, yet its surface is very low.

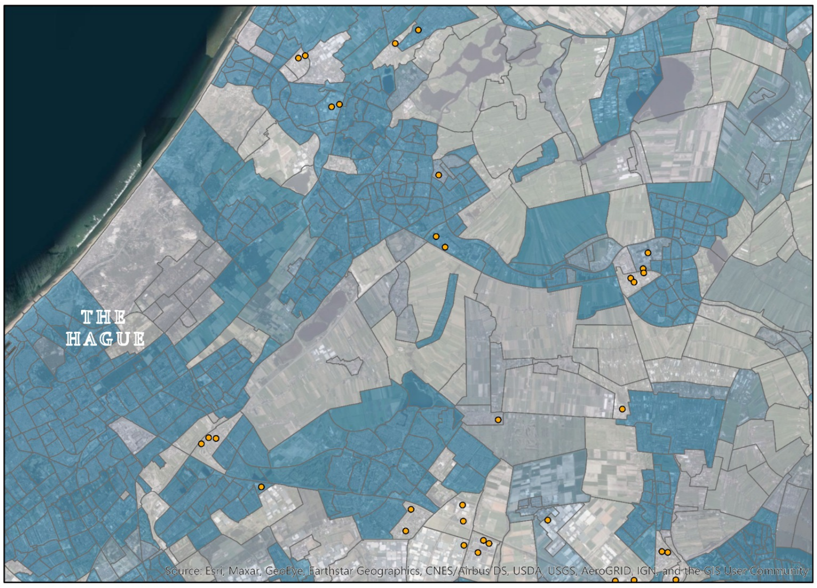

Figure 4.13: Location of logistics facilities in cluster 3

Cluster 4: Small Facilities in Sub-Urban Areas (constructed during compact urbanisation policy)

This group of logistics facilities belongs to small facilities with an average construction year of 1984. These were constructed during the time when the Dutch national authorities pursued the policy of compact urbanisation (Geurs et al., 2003). The compact urbanisation policy was meant to accommodate new urban growth outside existing urban areas in a number of designated overspill centres. The facilities in this category are located in sub-urban areas (2,000 $hhkm^2$). These are at a distance of 1.7 km, 455 km, 0.5 km and 31 km to UC, TT, ramp and ports respectively. They mainly belong to wholesale non-food, machines, and other specialised wholesalers. Figure 4.14 shows the averages of this type of logistics facilities with an average of the whole database.

Similar to cluster 3, these facilities also have a low surface area compared to land availability. Figure 4.15 suggests that these facilities could be used for distribution to the larger shops. It can be seen that these facilities are located in a region surrounded by urban areas for easy access.

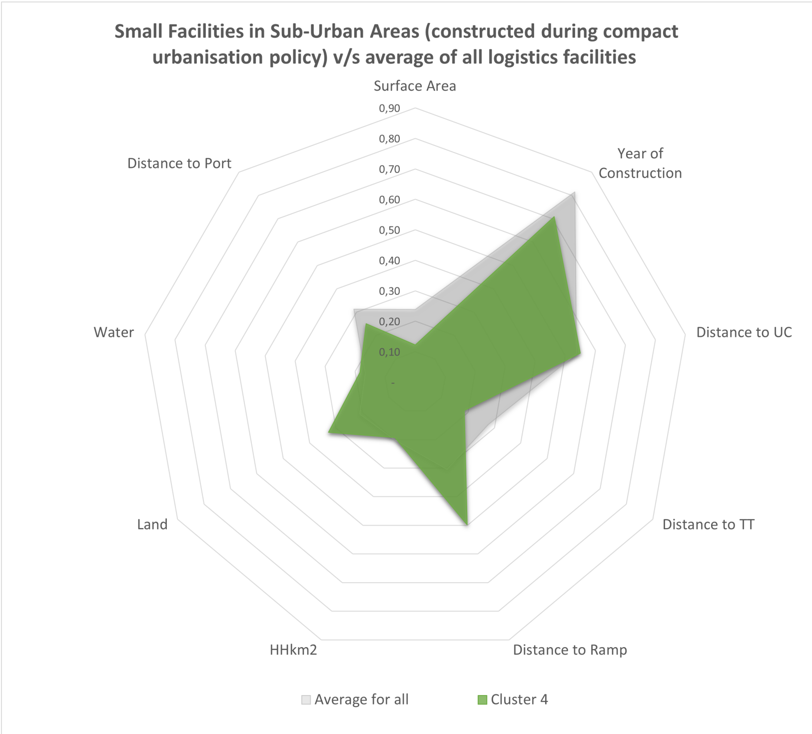

Figure 4.14: Comparing facilities in cluster 4 to the average of all the facilities

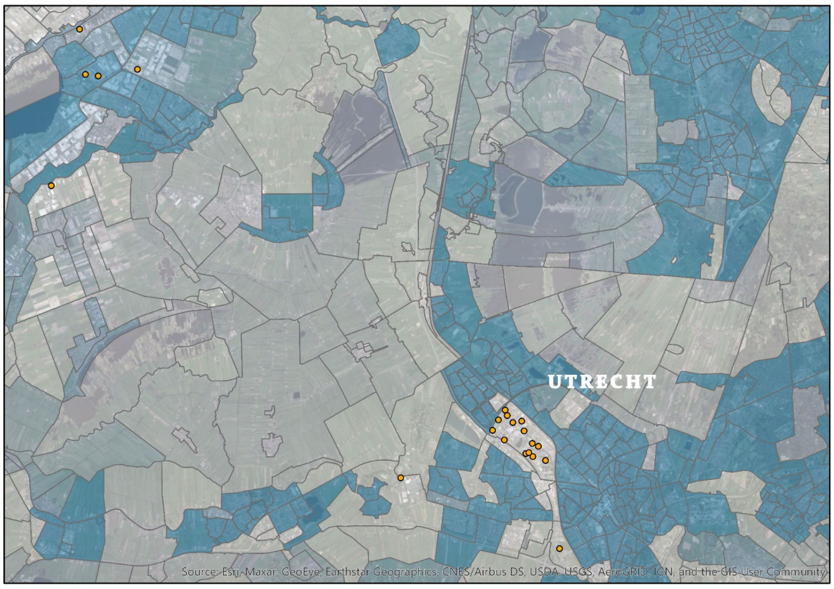

Figure 4.15: Location of logistics facilities in cluster 4

Cluster 5: Large facilities in Extended Cities

These are the large logistics facilities with a surface area of 20,500 m^2. The growth of these facilities was seen in 1995. These types of facilities are mostly seen in the extended cities with a distance to UC of 1.6 km. Extended cities have an average distance to the urban centre, transshipment terminal, ramp, and ports. These logistics facilities mainly comprise transport services, wholesale products (agriculture, food, and non-food), and unknown category. Figure 4.16 shows the averages of this type of logistics facilities with an average of the whole database.

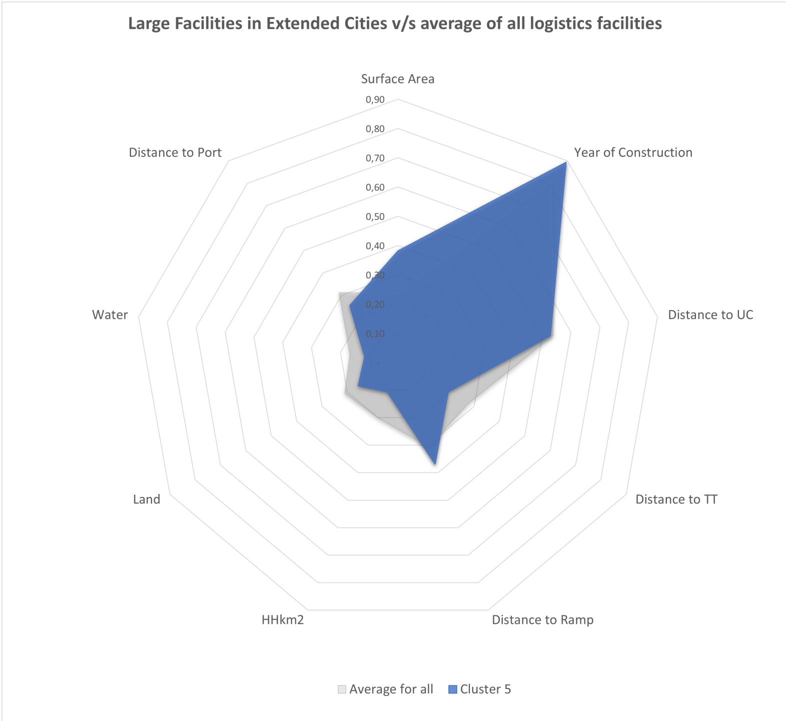

Figure 4.16: Comparing facilities in cluster 5 to the average of all the facilities

In this cluster, it can be seen that the construction year in this type of facility is higher than the overall average. Figure 4.17 shows the facilities in cluster 5 around the Rotterdam region. It could be said that these facilities are warehouses for storage and distribution. Since these are located around the port regions and of a large size and away from the UC. The distance to the ramp of these facilities can be seen more than the average, it is mainly because the on/off ramps are located closer to the urban areas. Hence, these facilities have to make a bigger trip to reach the ramps.

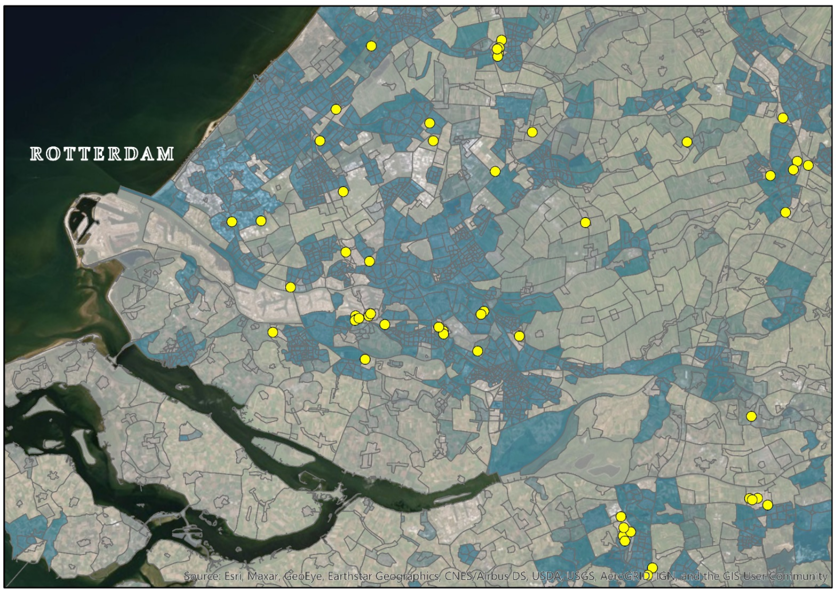

Figure 4.17: Location of logistics facilities in cluster 5

Cluster 6: XXL facilities in Extended Cities

These are the XXL facilities with a surface area of 42,000 m^2. It can be seen that the average year of construction is 1995. The most noticeable feature of this cluster is that the distance to UC, transshipment terminal, Ramp, and port is at an average. But, mainly locates in a sparsely populated region. This cluster mainly comprises transportation and storage facilities. Figure 4.18 shows the averages of this type of logistics facilities with an average of the whole database.

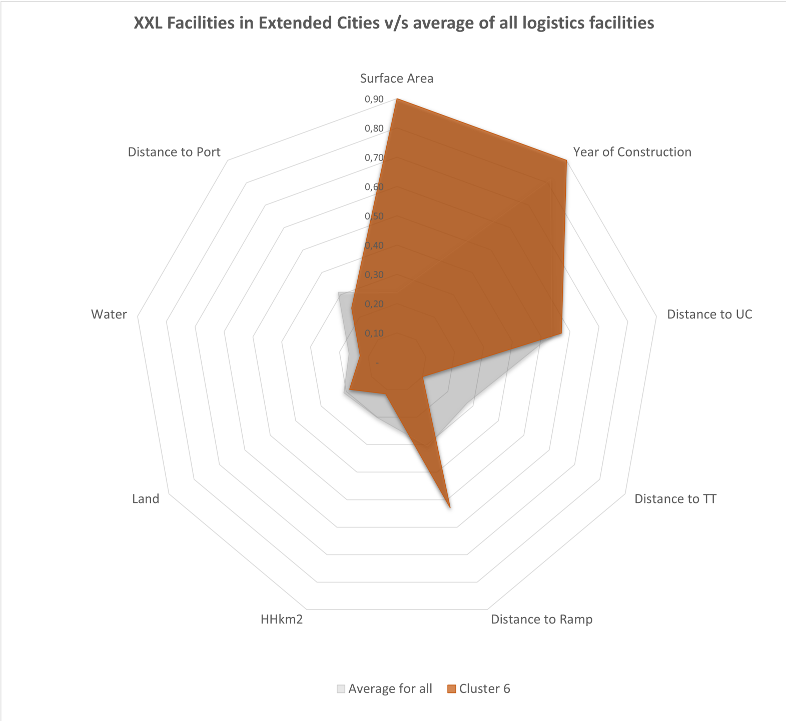

Figure 4.18: Comparing facilities in cluster 6 to the average of all the facilities

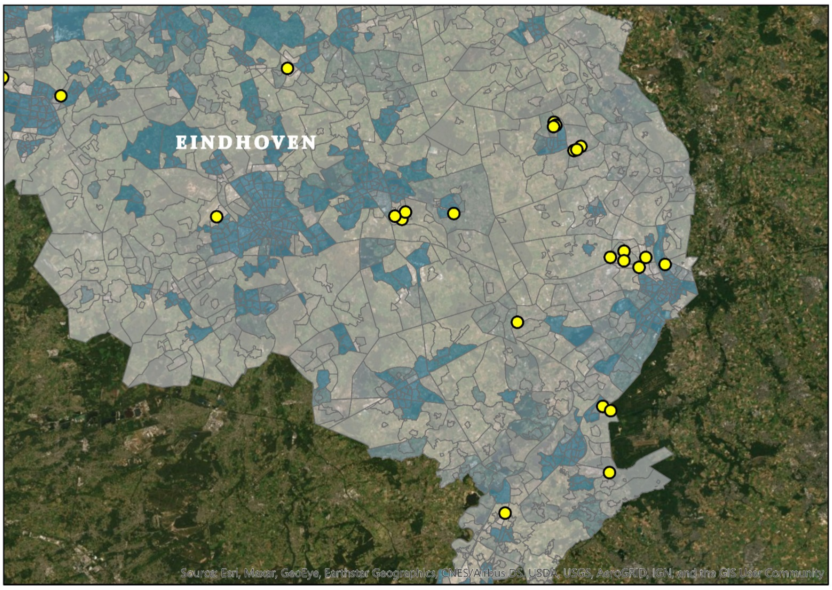

Figure 4.19: Location of logistics facilities in cluster 6

These facilities are big distribution centres used for delivering to multiple locations. There are about 125 of these types of logistics facilities sparsely located all over the Netherlands. The sizes and the location of these facilities are very suitable for international trade and distribution.

Cluster 7: Medium Facilities in Remote Locations, away from hubs

These medium-sized facilities with a surface area of 11,500 m^2. These are constructed around 1987. The facilities are 2 km from the urban centres and 0.4 km to ramps. They are farthest from the transshipment terminals (567 km) and ports (116 km). But, they are located in a dense household region (2,200 $hhkm^2$). This type of logistics facility is a mix of the different industrial sectors such as food and beverages, consumer goods, equipment for industry, other specialised wholesaler, and freight transport by road. Figure 4.20 shows the averages of this type of logistics facilities with an average of the whole database.

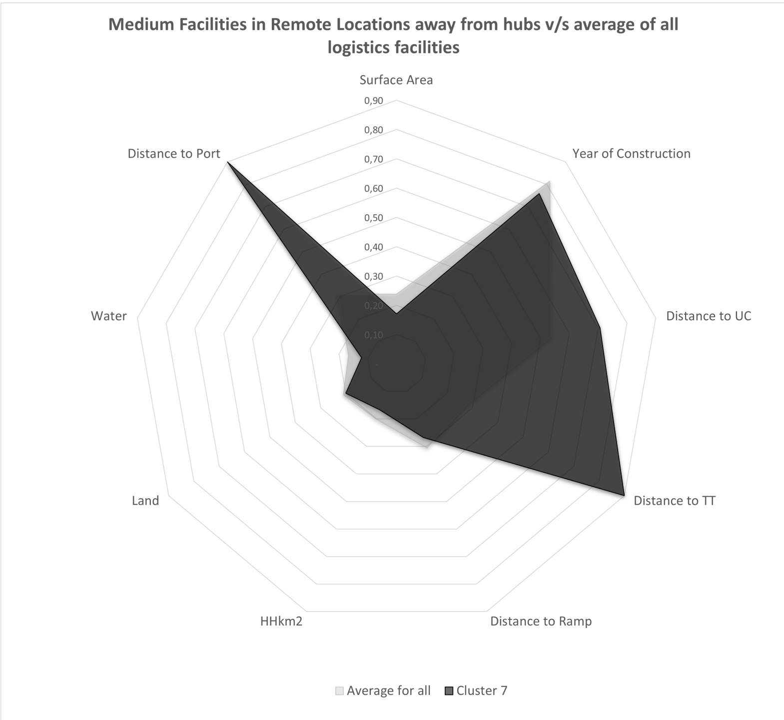

Figure 4.20: Comparing facilities in cluster 7 to the average of all the facilities

While studying the topologies it was seen that the facilities in the northern part of the Netherlands were clustered together. This was due to low TT availability and no port availability. The population density is also very low for this area of the Netherlands. Hence, it is difficult to predict the nature of such a topology.

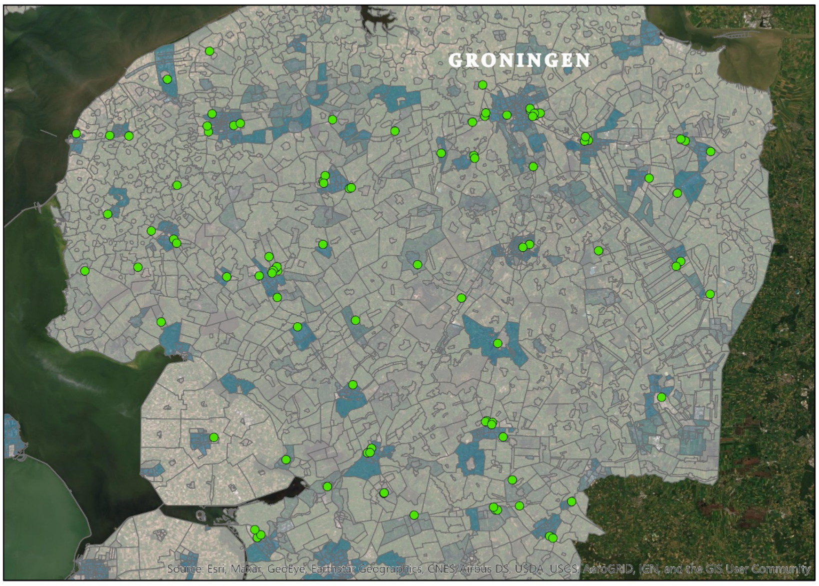

Figure 4.21: Location of logistics facilities in cluster 7

Cluster 8: Medium Facilities in Remote Location, closer to hubs

These medium-sized logistics facilities (12,000 m^2) were constructed around 1994. They are located away from the urban centre (2.7 km) compared to other logistics facilities. They have a household density of 550. But there is a high availability of land (2178 km sq.) and water (453 km sq.) also, these facilities are closer to the ports (11 km approximately). These logistics facilities belong to the other specialised wholesaler and freight transport services sector.

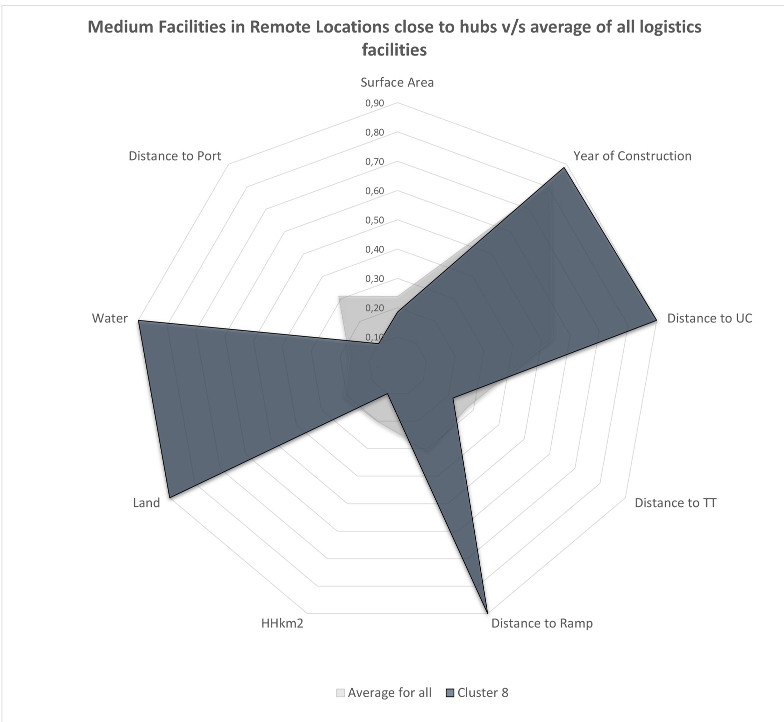

Figure 4.22: Comparing facilities in cluster 8 to the average of all the facilities

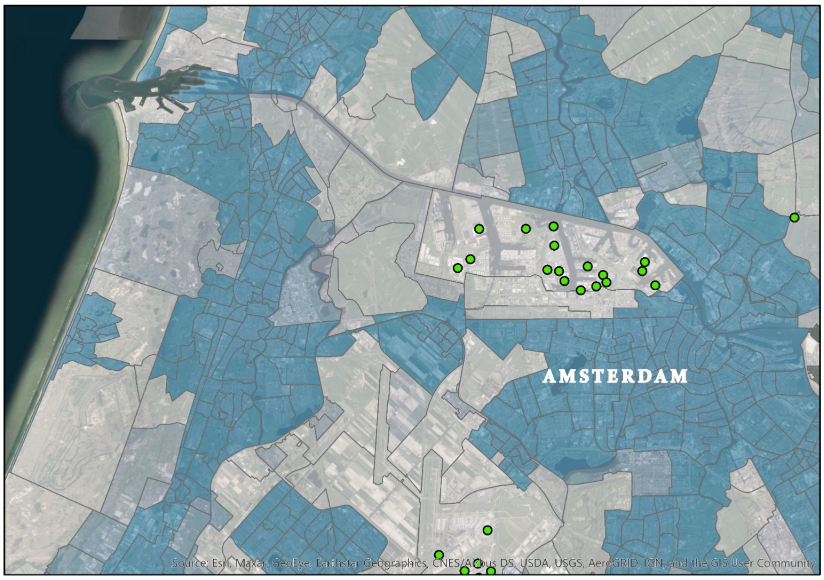

Figure 4.23: Location of logistics facilities in cluster 8

Figure 4.22 shows the averages of this type of logistics facilities with an average of the whole database. It can be seen very clearly that these facilities are newer, located in a region with a lot of water and land availability. These facilities could be primarily used for international trade through the port region.

4.4.3. Comparing the Topology

Reviewing these logistics facilities, it is noticed that some of the clusters have some major similarities and some are significantly different than the other. Clusters 2 (Medium facilities in Urban Centre) and cluster 1 (Old Medium facilities in Urban Centre), like their name, suggest they are similar clusters. The main difference is due to the construction year. Cluster 2 is newer compared to the facilities in cluster 1 and located in a lesser populated area. The facilities in cluster 2 are a little further from the urban centre compared to facilities in cluster 1. It could be said that the urban centres are old and due to less space availability, the newer ones can not be located in the real urban centre. But it appears that the companies select a space that is as close as possible. This can however mean that the transport to cluster 2 should be organised differently than to cluster 1, while they have the same purpose.

Furthermore, Cluster 8 and 7 also have similar features, medium facilities located in remote locations. The main difference is that the facilities in cluster 8 are located in the port region, where the transshipment terminal and international hubs are nearby, while the other (Cluster 7) is the farthest for those mainly in Groningen. This could suggest that the ones close to the port areas are used for international shipping while the other ones can are used for consolidation and distribution purposes.

After studying the different clusters, we can say that cluster 5 (Large Facilities in the Extended Cities) and cluster 6 (XXL Facilities in Extended Cities) are the newest facilities and away from the UC. Cluster 3 (small facilities in Sub-Urban Area) and cluster 4 (small facilities in Sub-Urban Area) have similar features, only the facilities in cluster 4 are located art a highly populated region compared to the newer ones.

To conclude, this analysis showed that the medium-sized facilities are the most common size of the facility and have the most variation. The logistics facilities have similar features but the main difference is the construction year, which was seen that the newer facilities are located in the less densely populates area compared to the old facilities. Finally, the newest facility with the largest size was expected to be located in remote regions, but those facilities were mainly around the peripheral regions of the city.

4.4.4. Hypothesis for the transport efficiency indicators for each cluster

The characteristics of the logistics facilities give us an idea about the transport of the attribute. Based on that these characteristics of the facilities, this section makes a hypothesis on the transport efficiency indicators.

- **Cluster 1 (Old Medium Facilities in Urban Centres):** These facilities would be mainly focused on delivering to consumers in urban centres as they are wholesale purchasers. The trips of these facilities would have high efficiency due to the low length of the journey, and a few empty running.
- **Cluster 2 (Medium Facilities in Urban Centres):** Medium facilities in the urban centre will have complex trips, mainly small vehicle loads with multiple trips. Making it less efficient in terms of truck operation.
- **Cluster 3 (Small Facilities in Sub-Urban Areas: constructed during compact city policy):** Small facilities would have high operational efficiency. Simultaneously, these facilities would act as an intermediate location, it would have empty trips on both sides, making high empty kms.
- **Cluster 4 (Small Facilities in Sub-Urban Areas: constructed during compact urbanisation policy):** These facilities would be efficient as the number of customers for these companies would be less, causing fewer trips and low journey length but will have some empty trips.
- **Cluster 5 (Large Facilities in Peripheral Cities):** Large facilities will be using heavy vehicles with less number of truck and stop. It would result in high transport efficiency and high empty vehicle kilometres.
- **Cluster 6 (XXL Facilities in Peripheral Cities):** These facilities are located in close proximity to transshipment terminals and ports but not the farthest to the urban centres. They may be mainly used for distribution and collection from the UC and the trips would high utilisation rate.
- **Cluster 7 (Medium Facilities in Remote Locations, away from hubs):** These facilities can be mainly used for consolidation and distribution as they are away from the urban centres, transshipment terminals, port but have good proximity to infrastructure. Hence, the trips from these facilities would be highly efficient but could be that the inbound trips would be less efficient.
- **Cluster 8 (Medium Facilities in Remote Locations, close to hubs):** These facilities are mainly located in the port region, causing big inbound and outbound trips. These trips would be highly efficient due to the high utilisation of the vehicle. As ports distribute and collect on a higher scale.

5

Transport Efficiency Analysis

To make an empirical study of the transport from the logistics facilities we use the truck diary database. This chapter discusses the truck diary database and exploratory study of the database. Thereafter the transport efficiency indicators will be evaluated and this chapter will conclude with testing the hypothesis for each cluster discussed in section 5.6.

5.1. Truck Diaries Database

The database used to study the indicators transport efficiency is a fusion between the transport shipment data by Centraal Bureau voor de Statistiek / Statistics Netherlands (CBS) and firm registration data (ABR), logistics facility and TT database by Rijkswaterstaat discussed in section 4.2.

The data collected by CBS were from dispatchers through automated truck surveys. The survey was compulsory for transport companies, allowing huge data. CBS used the Extensible Markup Language (XML) interface to extract information from the companies. 2.65 million shipment data for 2015 were found. The data is rich in information as it provides the geographic location of truck loading and unloading activities in detail [1]. About half of the records are registered with a 6-digit postal code, while the other with a 4-digit postal code. The weight and type of commodity shipped and the vehicle used was recorded. But there is a lack of sender and receiver information (Mohammed et al.), 2020.

The ABR database in the Netherlands contains all the registered companies. It provides SBI, and postal code (6-digit). This database was used to identify producers and consumers and differentiate the economic sectors.

The data primarily includes multiple shipments with each shipment having a unique shipment ID. For the shipments, the loading and unloading locations are known. It also includes the tour in which the shipment is picked up. Each tour has a unique tour ID and the starting and the ending point of the tour is known. The type of the vehicle, km travelled by the vehicle, and the payload of the vehicle is also known (More details on the type of data can be found in Append D, figure D.1).

5.1.1. Truck touring information

The truck touring is when the vehicle leaves a depot and reaches a loading and unloading location and returns back to a depot. In a tour, the vehicle can make multiple trips in a different order depending upon the needs of the company and regulations. Figure 5.1 illustrates a simple example, touring can in reality be very complex.

An exploration of the data showed that the percentage of trucks starting in the Netherlands is 85.35% while the rest of the 14.65% is from France, Belgium, Germany, and Austria (outside NL). The table 5.1 shows the percentage share of the tours and shipments leaving and entering the Netherlands.

[1] Due to privacy reasons, only higher-level results are presented. But, for the analysis, the detailed information of the tour was used.

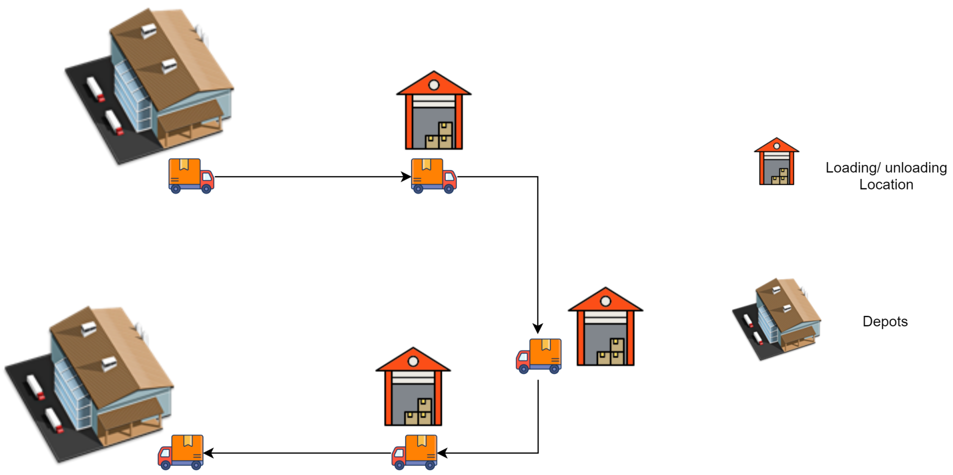

Figure 5.1: Touring of a vehicle

Table 5.1: Share of tours and shipments

Tours	
Share within NL	79.62%
Share outside NL	6.61%
Share originating in NL and ending outside	8.07%
Share originating outside and ending in NL	5.96%
Shipments	
Share within NL	72.81%
Share outside NL	5.36%
Share originating in NL and ending outside	5.14%
Share originating outside and ending in NL	16.69%

The table 5.2 shows the percentage of the starting points of the truck tour for different logistics facilities. Among the known facilities, about 37% and 24% of the tours start from new small facilities in sub-urban areas and medium facilities in a remote location away from terminals respectively. The different types of goods transported (NSTR) over these shipments were agriculture (0), other feed (1), solid minerals (2), petroleum (3), oars and metals (4), iron and steel (5), raw minerals (6), chemicals (8), and vehicle and machines (including general cargo) (9)

Table 5.2: Share of starting location of the tours

Type of Facility	Starting Location Share
Cluster 1: Old Medium Facilities in Urban Centre	0%
Cluster 2: Medium Facilities in Urban Centre	9%
Cluster 3: Small Facilities in Sub-Urban Area	37%
Cluster 4: Small Facilities in Sub-Urban Area	2%
Cluster 5: Large Facilities in Extended Cities	15%
Cluster 6: XXL Facilities in Extended Cities	12%
Cluster 7: Medium Facilities in Remote Location away from hubs	24%
Cluster 8: Medium Facilities in Remote Location closer to hubs	1%

5.1.2. Transport Characteristics for each logistics facility type

The database of the truck tours showed that the logistics facilities in the Netherlands mainly carry agriculture products, live animals, food products, animal feed, chemical products, vehicles, and machines. Most of the products use cluster 7 (medium facilities in remote locations away from hubs) and cluster 3 (small facilities in the sub-urban region) as a depot. While Iron, steel, and non-ferrous metals use medium facilities in urban centre and Crude minerals and products, construction materials large facilities in extended cities. The share of the NSTR in different logistics facilities can be seen in the table 5.3. The sectors Solid mineral fuels, petroleum products, ores, and metal waste, and iron and steel, have little to no transportation between these facilities. The old medium facilities inUC (Cluster 1), transports agricultural products, and live animals while the medium facility in UC (Cluster 2). transports Vehicles, machines, and other goods. Cluster 3 and 4 (Small facilities in sub-urban areas) transport a mix of agricultural products, chemical products, and vehicles. The facilities in the peripheral cities (Cluster 5 and 6) travels with vehicles, machines, and other cargo and chemical products. The XXL facilities (Cluster 6) also transport agricultural products. The medium facilities in remote locations, away from intermediate hubs also transports agricultural products and vehicles, machines, and general cargo. Although, the medium facilities in remote locations close to intermediate terminals transport crude minerals, construction materials, chemical products and vehicles, machinery, and general cargo.

Table 5.3: Percentage share of NSTR in each cluster

NSTR	Agricultural product and live animals	Other food products and animal feed	Solid mineral fuels	Petroleum oils and petroleum products	Ores, metal waste roasted iron molars	Iron, steel and non-ferrous metals	Crude minerals; construction materials	Chemical products	Vehicles, machines and other goods (general cargo)
Cluster 1	63%	5%	0%	0%	0%	0%	0%	10%	21%
Cluster 2	4%	6%	0%	0%	0%	0%	0%	6%	82%
Cluster 3	28%	10%	0%	0%	0%	0%	1%	37%	23%
Cluster 4	32%	13%	0%	0%	0%	0%	4%	25%	26%
Cluster 5	0%	13%	0%	0%	0%	1%	9%	33%	45%
Cluster 6	29%	15%	0%	0%	0%	0%	2%	21%	34%
Cluster 7	39%	15%	0%	0%	0%	0%	1%	17%	27%
Cluster 8	11%	8%	0%	0%	0%	0%	23%	32%	26%

The share of starting and ending location of the tour can be seen in table 5.4. More than 70% of the tours from each cluster end in its own cluster apart from cluster 4 (small facilities in sub-urban areas) and cluster 8 (medium facilities in remote locations close to intermediate hubs). Both of these clusters end 50% of their tour in cluster 3 (small facilities in sub-urban areas). Another key point that could be seen was that no facilities end their trip in the old medium in UC (Cluster 1) and medium facilities in remote locations, close to intermediate hubs (Cluster 7). Only medium facilities in remote facilities close to intermediate hubs (Cluster 8) have a wide variety of ending locations.

Table 5.4: Cross-table for departure and arrival clusters

Arrival	**Cluster 1**	**Cluster 2**	**Cluster 3**	**Cluster 4**	**Cluster 5**	**Cluster 6**	**Cluster 7**	**Cluster 8**
Departure								
Cluster 1	70%	1%	14%	1%	1%	4%	8%	0%
Cluster 2	0%	82%	7%	0%	10%	0%	1%	0%
Cluster 3	0%	1%	91%	2%	4%	1%	0%	0%
Cluster 4	0%	6%	53%	18%	15%	5%	1%	1%
Cluster 5	0%	3%	14%	1%	72%	7%	2%	0%
Cluster 6	0%	0%	5%	0%	4%	88%	2%	0%
Cluster 7	0%	0%	1%	0%	1%	1%	97%	0%
Cluster 8	0%	6%	50%	9%	7%	7%	1%	20%

The central tendency of each cluster was measured for the two main factors (load and vehicle kilometre) influencing transport efficiency. Cluster 3 (new small facilities in sub-urban areas) and cluster 5 (old small facilities in sub-urban areas) travel the highest distance but with load compared to the other facilities (table 5.5). These facilities mainly serve cluster 3 (table 5.4). Since the facilities in this cluster are away from the urban centres but relatively close to the population, it could be making multiple stops causing the increased vehicle km. While the facilities in cluster 1 (large facilities in peripheral cities) and 8 (XXL facilities in peripheral cities) are large facilities located in the periphery of the cities, having a low average distance but a high average weight. Since, they mainly serve facilities with similar, hence making a high vehicle km.

Table 5.5: Average distance and shipment weight for different logistics facilities

Cluster	Average distance (km)	Average weight of the shipment (tonne)
1	69	3.0
2	74	0.4
3	363	0.8
4	276	1.4
5	49	3.3
6	61	2.1
7	172	1.1
8	122	9.5

5.2. Transport Efficiency Indicators

Multiple indicators were found from the literature (section 3.4). There are multiple indicators, but due to the scope of this research only the discussed indicators in section 3.3 will be studied. Below the different indicators are explained and the method to evaluate them.

Performance Indicators

- **Vehicle km in a tour (Unit: km)** (A): This is a distance performance indicator. It is an important indicator for the logistics provider to keep track of the total vehicle kilometres. Knowing this indicator helps in minimising the distance travelled. Measuring This gives an insight into the effectiveness of the operations. For each tour, the total vehicle kilometres travelled by truck was collected by CBS.
- **Load handled by a facility (Unit: Tonnes)** (B): This is a fleet usage performance indicator. Keeping track of the loading, the loading capacity can be calculated. The load handled while transporting shows the effectiveness of the logistics service provider. To calculate the total weight loaded in a truck by the DC, the shipment ID was used. The weight of the shipments was summed together for the same logistics facility on a tour.
- **Empty km (Unit: km)** (C): This is also a fleet usage performance indicator. It shows the logistics provider the length of the empty running the vehicle has had in a tour. When the shipment weight or the weight of the truck travelling was specified empty or zero in the database (CBS). Those journey lengths were used to calculate the empty km.
- **Payload of the truck (Unit: Tonnes)** (D): This is also a fleet usage performance indicator. It will help in understanding the utilisation rate of the vehicle. This was already cited by CBS while collecting the data.
- **Number of trips (Unit: Nos.)** (E): This is a delivery performance indicator. Using the total number of trips can help in understanding the effectiveness of logistics service providers. These numbers help them to spot the inefficient routing. The total number of trips were calculated based on summing the departure point, arrival point, unique postcodes for loading and unloading in a tour subtracted by 1. This is the minimum number of trips that were taken place in a tour. There could be more trips as well since in some cases the total weight exceeds the average payload of the truck. Hence, the vehicle would have made more trips to stay within the regulations.

$$\textit{Number of trips} = \textit{Departure Location} + \textit{Arrival Location} + \textit{Unique logistics facilities visited - 1} \quad (5.1)$$

$$\textit{Unique logistics facilities visited} = \textit{shipment pick-up locations} + \textit{shipment drop-off locations} \quad (5.2)$$

- **Load handled in a trip (Unit: Tonnes)** (F): This is the initial part to study the transport efficiency (figure 5.2). It is the total weight that is carried by a facility divided by the total number of trips.

$$loadhandledtrip = \frac{loadhandledbyafacility}{Numberoftrips} \quad (5.3)$$

- **Shipment distance in a trip (Unit: km)** (G): It is a key variable which will help in understanding the road tonne per km. It is the total vehicle kilometre travelled by truck in a tour divided by the total number of trips in a tour.

$$Shipmentdistancetrip = \frac{vehiclekmsinatour}{Numberoftrips} \tag{5.4}$$

- **Utilisation Rate** (H): This is a fleet usage performance indicator. This number gives insights into correctly allocating the vehicles to routes. The utilisation rate was calculated by dividing the load handled by a facility by the payload of the truck.

$$UtilisationRate = \frac{loadhandledbyafacility}{payloadofthetruck} \times 100 \tag{5.5}$$

- **Road tonne per km (Unit: Tonne-km)** (I): This is the output which will be finally used in understanding the transport efficiency. This unit of measurement indicates the overall level of freight transport activity as it takes into account both the number of goods transported and the distance transported. Road tonne-km is calculated by multiplying the average shipment distance by the load that has been carried in that distance.

$$Roadtonnekm = loadhandledinatrip \times shipmentdistanceinatrip \tag{5.6}$$

- **Transport efficiency (Unit: Tonne)** (J): This reflects the efficiency of the vehicle operation. This ratio reflects the utilisation rate, empty kilometres, payload of the truck. The transport efficiency is calculated by dividing the road tonne-km by the total tour length.

$$TransportEfficiency = \frac{Roadtonnekm}{Averagevehiclekmsinatour} \tag{5.7}$$

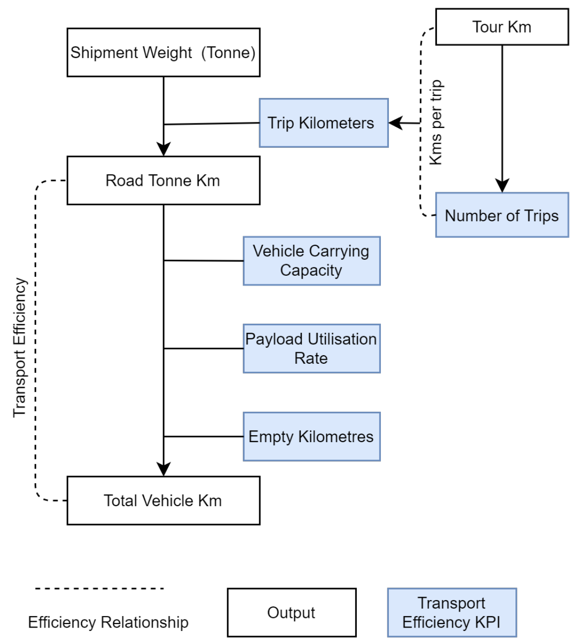

Figure 5.2: Conceptual Framework

5.3. Transport Efficiency Indicator Evaluation

The indicators discussed in section 5.2 are calculated for each of the clusters. Table 5.6 shows the averages of each cluster with respect to each cluster. The following subsections discuss each KPI's for the different logistics facilities in detail.

Table 5.6: Transport Efficiency Indicators for each cluster

Clusters	Avg. vehicle kms (A) (kms)	Avg. load handled by a facility (B) (tonnes)	Avg. empty kms (C) (kms)	Avg. payload of Truck (D) (tonnes)	Avg. number of Trips (E) (nos.)	Avg. load handled in a trip (F = B/E) (tonnes)	Avg. shipment distance in a trip (G = A/E) (kms)	Utilisation Rate (H = B/D*100)	Avg. road tonne km (I = F*G) (tonne-km)	Transport Efficiency (J = I/A)
1: Old Medium Facilities in UC	159	8	60	30	4	1.93	37.54	27%	72.38	0.46
2: Medium Facilities in UC	120	7	65	25	15	0.45	8.09	27%	3.66	0.03
3: Small Facilities in Sub-Urban Area during compact city policy	193	9	300	23	6	1.53	31.12	41%	47.47	0.25
4: Small Facilities in Sub-Urban Area during compact urbanisation policy	190	17	125	27	4	4.01	46.07	60%	184.78	0.97
5: Large Facilities in Peripheral Cities	168	12	60	30	4	2.84	38.45	41%	109.24	0.65
6: XXL Facilities in Peripheral Cities	155	14	65	21	6	2.27	25.03	65%	56.76	0.37
7: Medium Facilities in Remote Locations, away from hubs	143	16	90	31	9	1.82	16.05	53%	29.28	0.20
8: Medium Facilities in Remote Locations, closer to hubs	143	16	100	30	3	4.74	41.26	54%	195.76	1.37

5.3.1. Cluster 1: Old Medium Facilities in Urban Centre

These facilities are the oldest in the topology. There are only 38 facilities in this cluster. They have a size of 11,025 m^2. They are located in densely populated regions, with low land availability. Most of the tours end up in the same cluster or unknown regions (figure 5.4), and mainly carrying agricultural products (figure 5.3). These facilities have a very low load handling (8 tonnes) but travelling for above-average vehicle km (159 km).

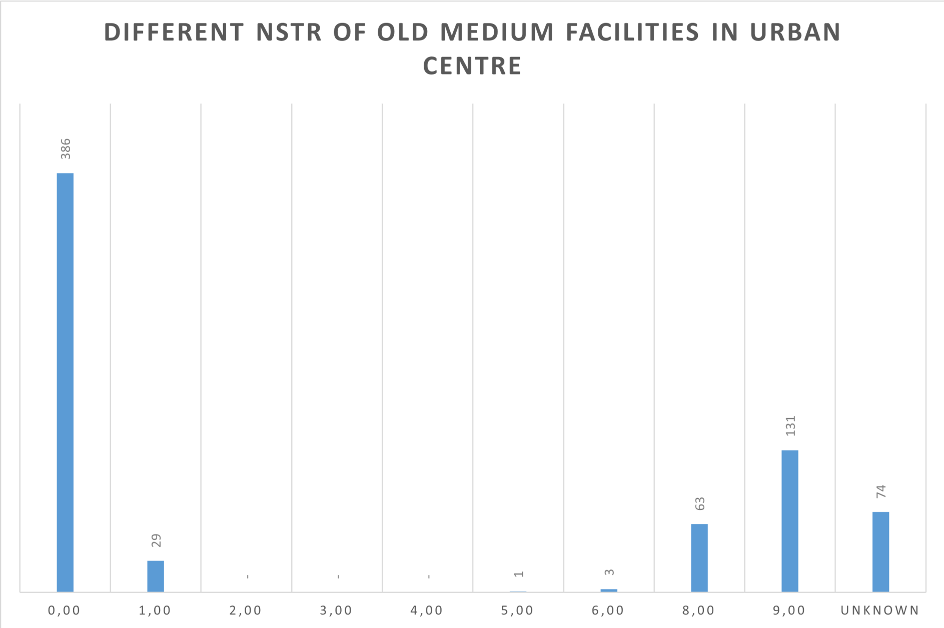

Figure 5.3: NSTR Composition for Cluster 1

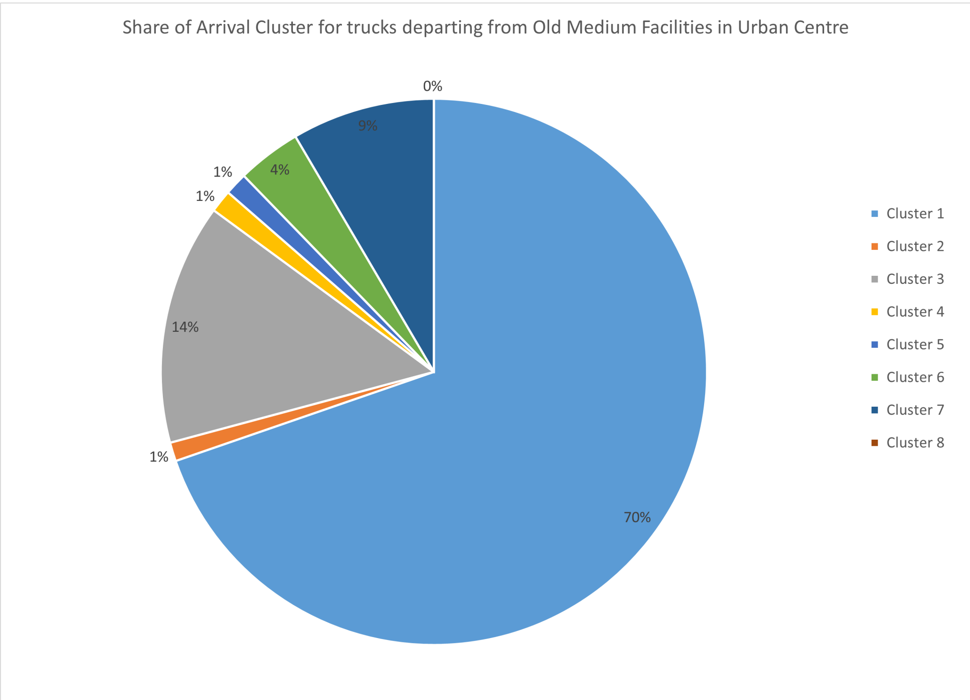

Figure 5.4: Arrival Cluster composition for Cluster 1

These trips are mainly long trips (38 km) and low weight (2 tonnes). Compared to the other medium facilities in the UC, they have better transport efficiency (high tonne-km). While similar utilisation rate. These facilities also have one of the highest payloads of the vehicle (30 tonnes). Figure 5.5, shows that these facilities perform well in empty kms and the number of trips, while poorly in utilisation rate and the average load handled.

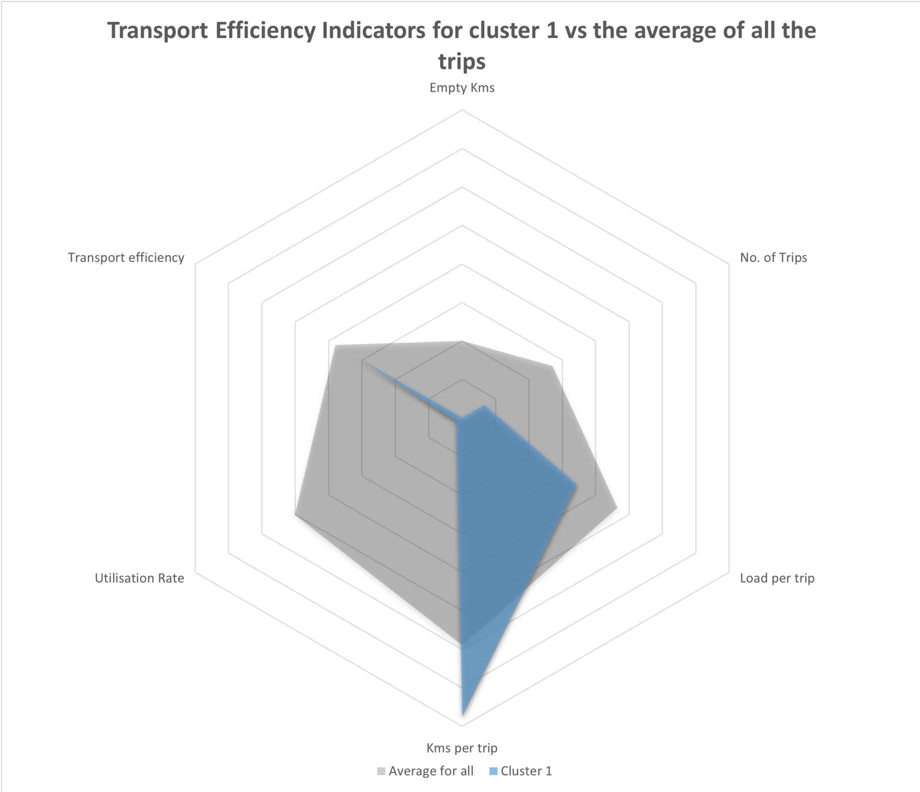

Figure 5.5: Transport Efficiency Indicators for Cluster 1

The hypothesis stated for old medium facilities in urban centres (Section 4.4.4) was that these facilities would have a high transport efficiency. These will also have low length trips and low empty running. This hypothesis was rejected since the trip length was high due to the low number of trips. It was expected that there will be multiple trips in a tour leading to low trip length. These facilities also have low transport efficiency. But, these logistics facilities have low empty km as expected, due to the location (spatial characteristics).

5.3.2. Cluster 2: Medium Facilities in Urban Centre

The new medium facilities have a surface area of 13,000 m^2. These facilities are newer compared to the other medium facilities in the Netherlands. The tours starting for these locations have a low load handled by the facility (7 tonnes) even with a medium facility size. They also have a vehicle with a payload of 25 tonnes (table 5.6). Figure 5.6 shows that the vehicle carries majorly vehicles and machines (including general cargo). The vehicles leaving these facilities primarily ends in a similar type of facility (figure 5.7).

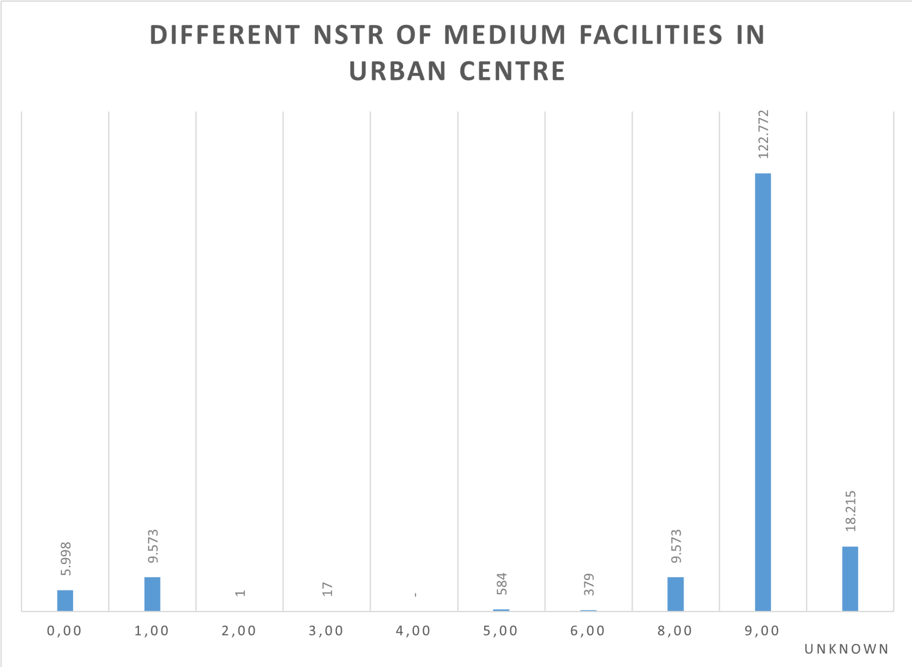

Figure 5.6: NSTR Composition for Cluster 2

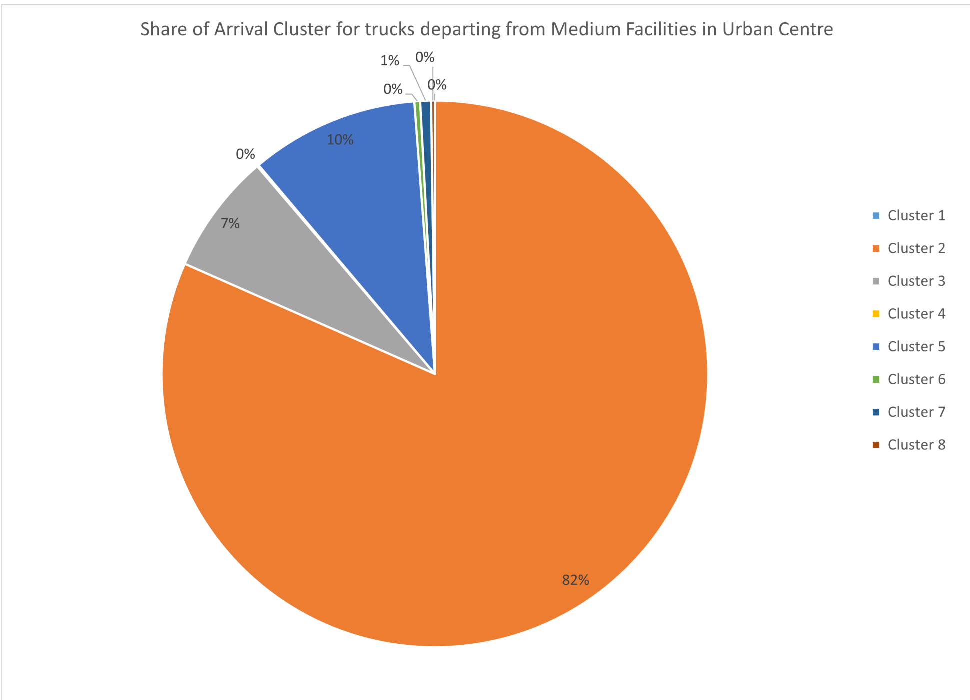

Figure 5.7: Arrival Cluster composition for Cluster 2

Logistics facilities in these clusters make on an average 65 empty kms. They handled 0.45 tonnes for a distance of 8.09 kms. These facilities make the maximum number of trips (15). The utilisation rate is the lowest 27%. This is because some of the logistics facilities in this cluster distribute flowers, leading to low weight transport. The transport efficiency is also the lowest (0.03), due to the load handled by the vehicle. Allen et al., (2012) also found that the journeys between UC are less efficient (tuck operational efficiency) than the others. Figure 5.8 suggests this type of logistics facility performs the worst in all aspect except the empty km. Making this facility less efficient.

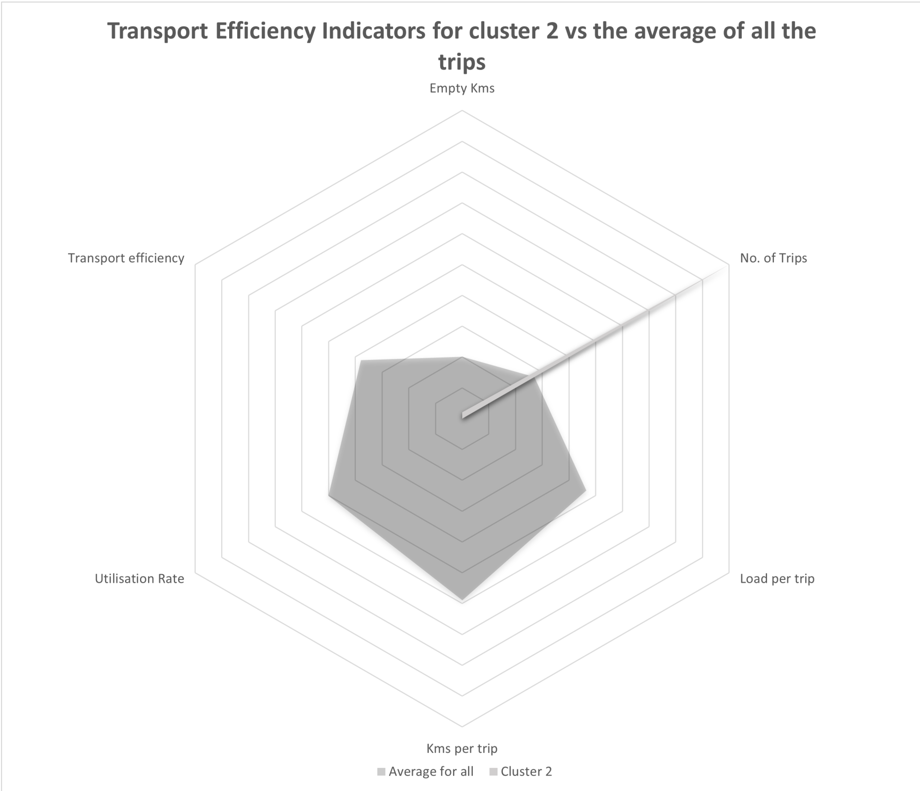

Figure 5.8: Transport Efficiency Indicators for Cluster 2

The hypothesis for medium facilities in urban centres stated in section 4.4.4 is that they would perform multiple trips with low vehicle load and low transport efficiency. This hypothesis is accepted as these facilities mimic the assumed transport behaviour. Being in the urban centre, it makes multiple trips with low transport load travelling for short distances.

5.3.3. Cluster 3: Small Facilities in Sub-Urban Areas

These are the smallest facility in the topology located in the sub-urban areas. These have a population density of 1,200 $hhkm^2$. The tours starting from this location have an average load handling of 300 tonnes. The vehicles leaving this facility have a low average payload of 23 tonnes. But, they have a high empty kilometre. These facilities carrying goods similar to the logistics facilities in cluster 5 (figure 5.9). About 63% of the tours starting from this location ends in facilities in cluster 3 (figure 5.10).

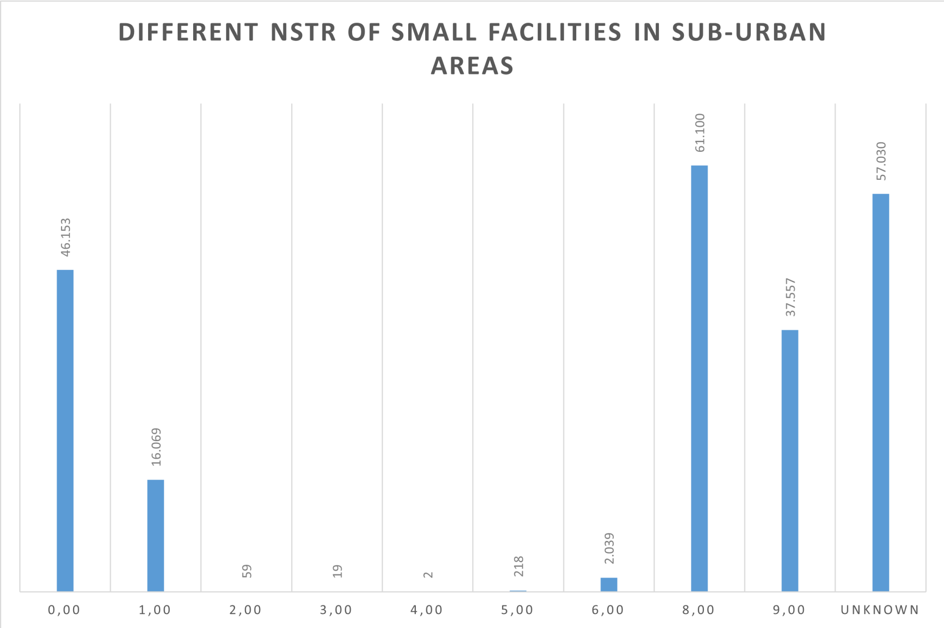

Figure 5.9: NSTR Composition for Cluster 3

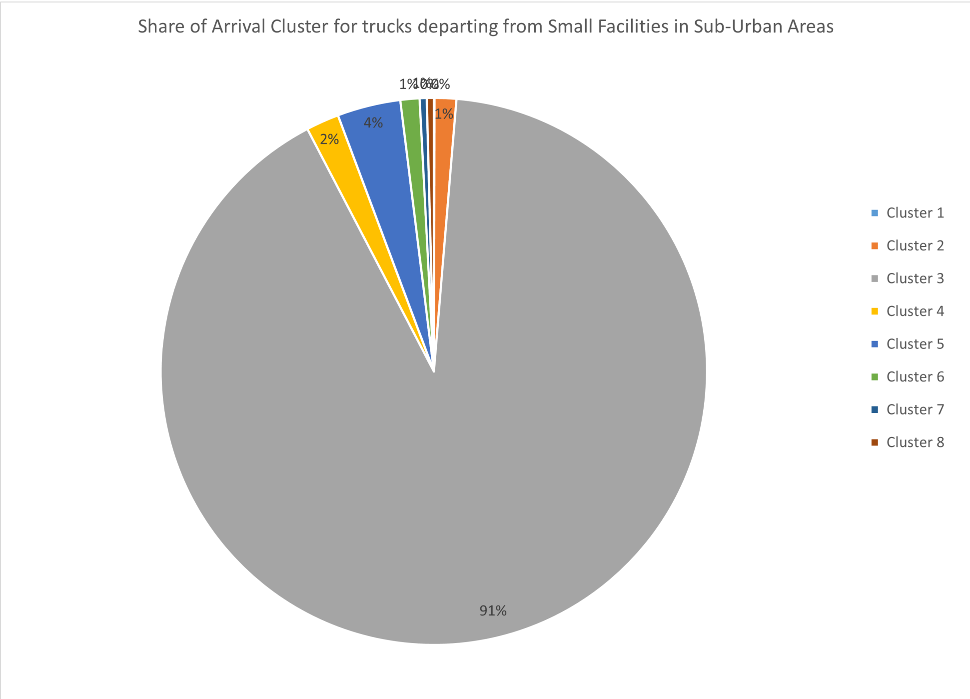

Figure 5.10: Arrival Cluster composition for Cluster 3

These facilities in this cluster are scattered all over North Holland, South Holland, and the North Brabant region. Even with such a small size, these facilities make handle tours with a load more than the medium facilities. They carry an average load of 1.53 tonnes for or a long distance (31 km) (table 5.1.2). These facilities have the highest vehicle kms (193 kms) and make 6 trips in a tour. Due to the similar types of goods being transported as cluster 5, it has a similar utilisation rate (41%). Due to the shorter trips compared to cluster 5, this facility has a lower truck operational efficiency. Figure 5.11 shows, that these facilities perform below average in many aspects.

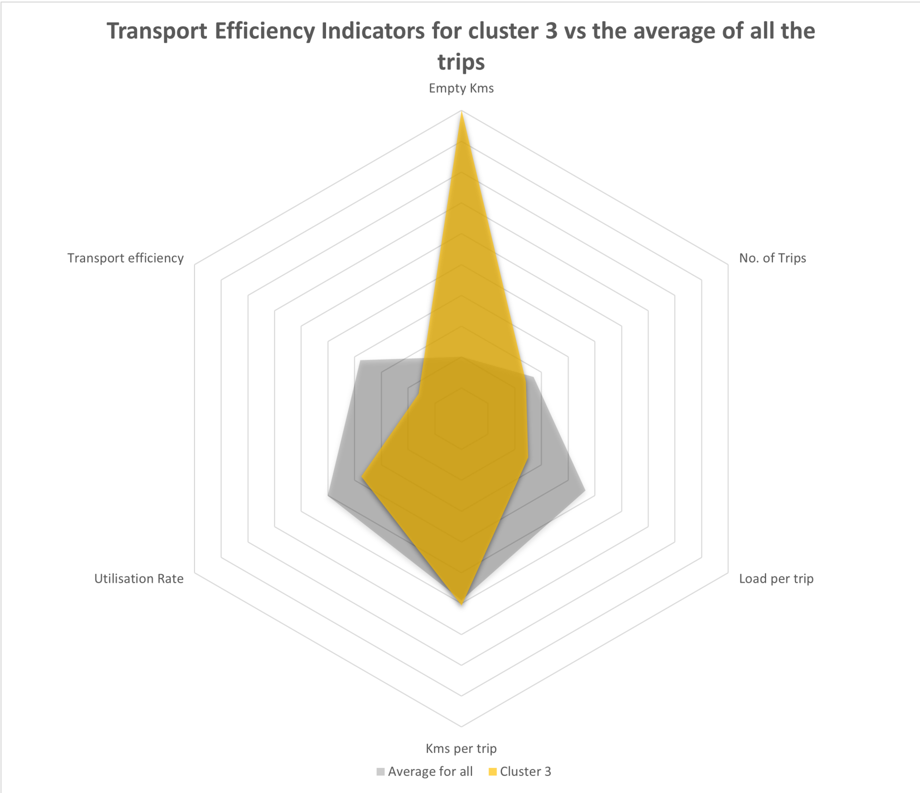

Figure 5.11: Transport Efficiency Indicators for Cluster 3

The hypothesis small facilities in sub-urban areas were constructed during the compact cities stated: these facilities would have a high transport efficiency, but also will have high empty trips. The first part of the hypothesis is rejected while the second is accepted. These facilities perform poorly in most of the indicators and also has a very high empty trip. The low transport efficiency is due to the low payload utilisation and the high empty km. Since these facilities are could be in the centre of the supply chain, supplying to upstream and downstream.

5.3.4. Cluster 4: Small Facilities in Sub- Urban Areas

Logistics Facilities in this segment were constructed during the compact urbanisation. These are located in a populated region with high land availability. The facilities in this cluster, transport multiple types of goods (figure 5.12). The tours starting from this facility type majorly ends in facilities in cluster 3 (Facilities in the Sub Urban Areas) (figure 5.13). These facilities also carry a low load (81 tonnes) compared to the others for 190 kms.

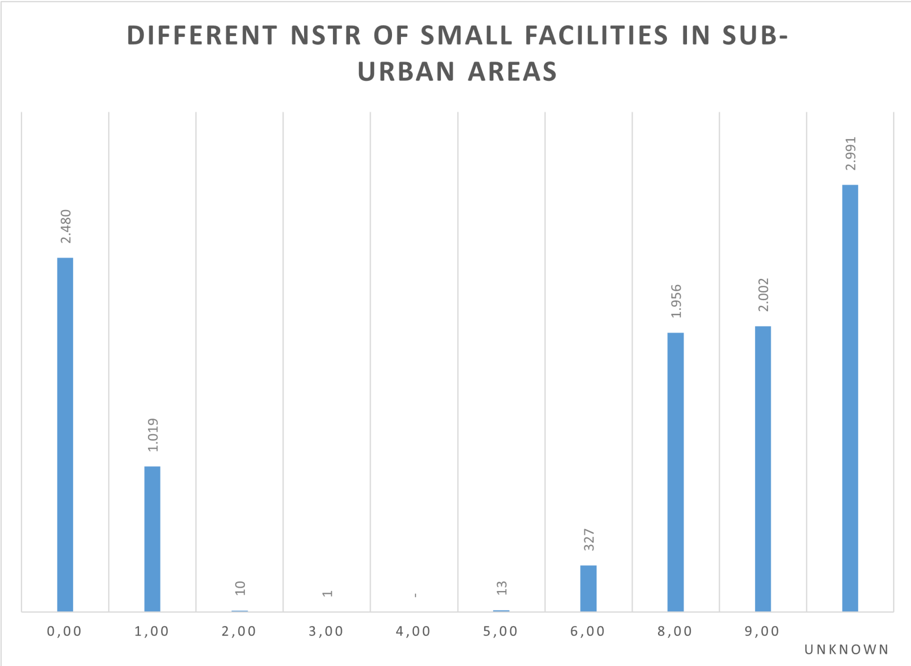

Figure 5.12: NSTR Composition for Cluster 4

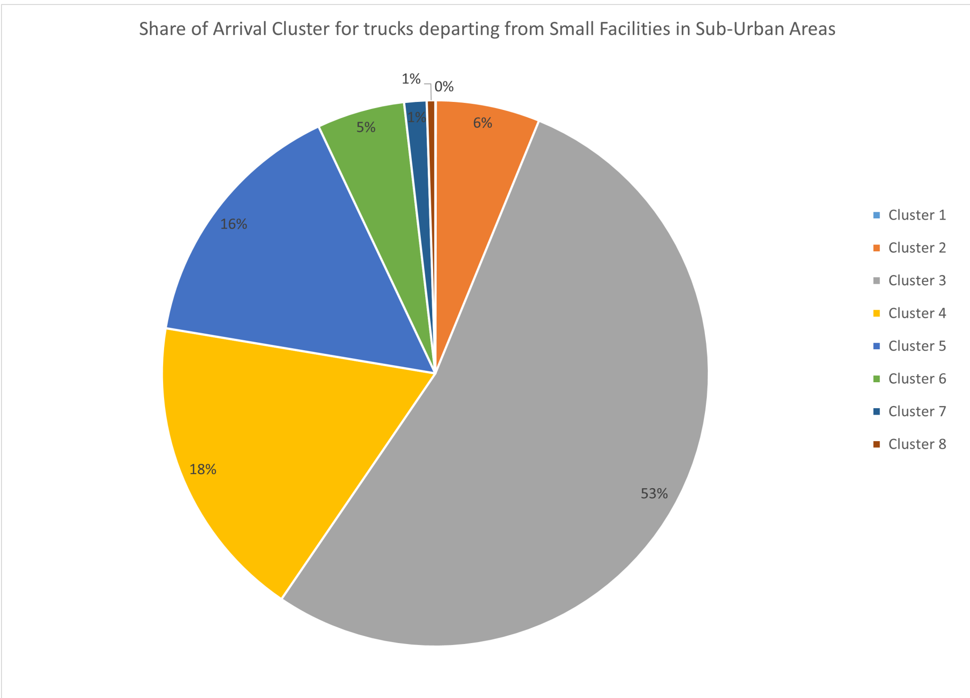

Figure 5.13: Arrival Cluster composition for Cluster 4

These facilities have the second-highest empty kilometres (125 kms) and these facilities make only 4 trips in a tour. They travel with an average load of 4 tonnes in a trip for an average distance of 46 km (table 5.1.2). The utilisation rate of these facilities is very high (60%) and with good transport efficiency (0.97). Figure 5.14 shows that these facilities perform on an average better than other facilities.

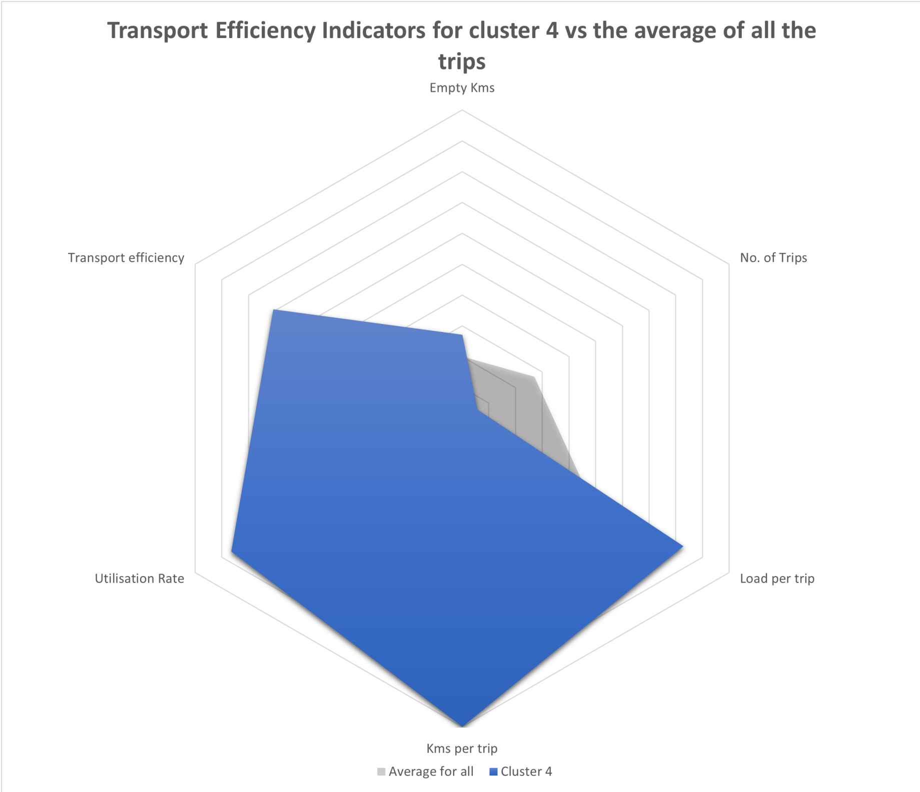

Figure 5.14: Transport Efficiency Indicators for Cluster 4

The hypothesis stated that these facilities would have fewer trips, low journey length, and some empty trips aggregating to high transport efficiency. The hypothesis on low journey length is rejected while the others are accepted. These facilities have high transport efficiency as well as the utilisation rate. But, they have a high trip length. The load carried by the vehicle for long distances results in high transport efficiency.

5.3.5. Cluster 5: Large Facilities in Peripheral Cities

These facilities are the newer facilities constructed around 1995 and have a surface area of more than 20,000 m^2. Table 5.6, shows that the tours starting from these locations have a load of 12 tonnes. The payload of trucks in these facilities is also as high as 30 tonnes. Figure 5.15, shows that most of the goods that are transported are 0 (agriculture), 8 (chemicals), and 9 (vehicles and machines). These shipments mainly travel to unknown clusters and cluster 1 (figure 5.16).

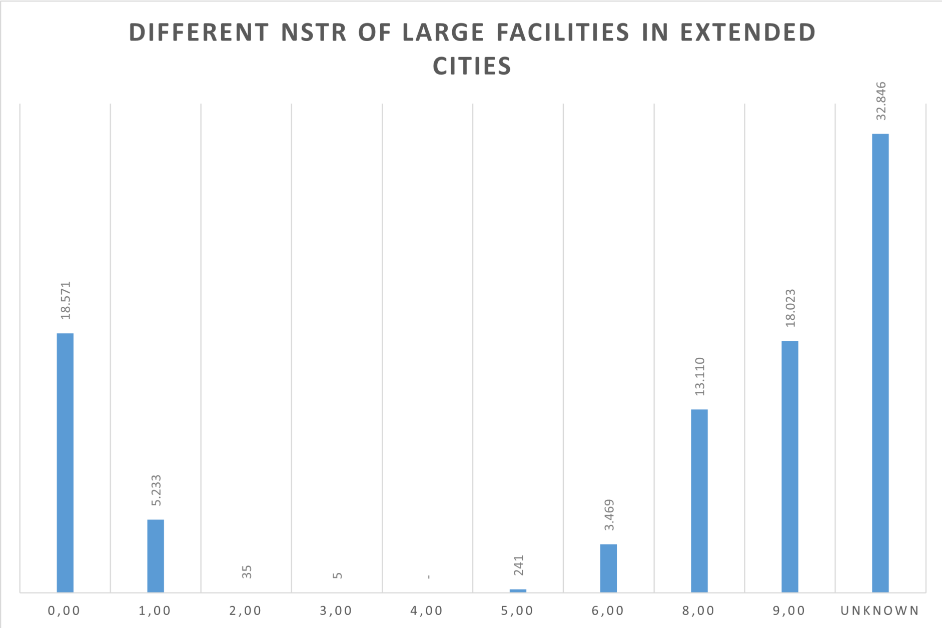

Figure 5.15: NSTR Composition for Cluster 5

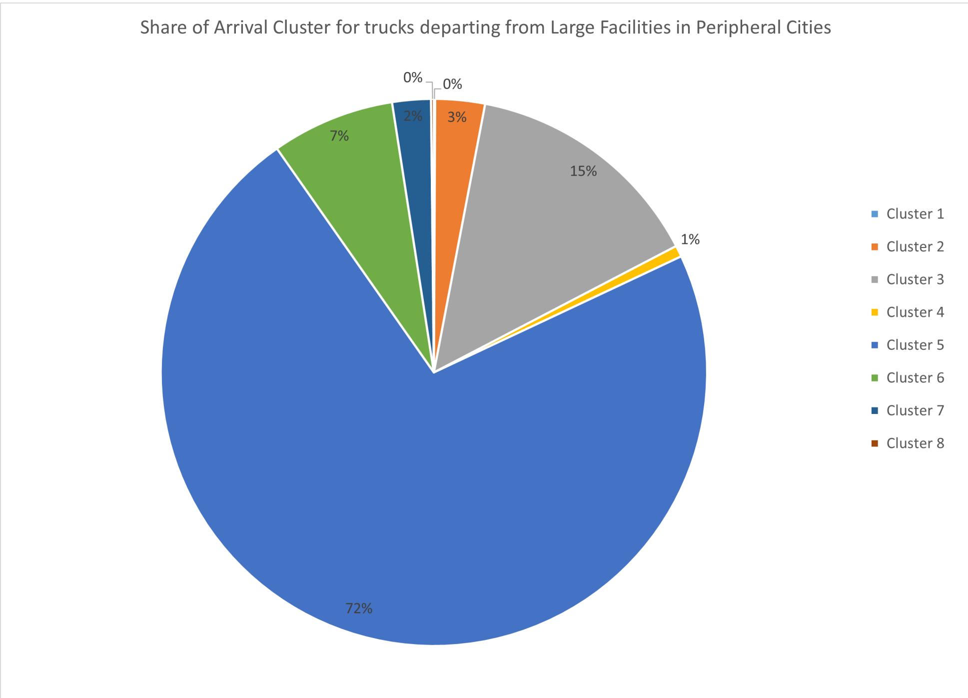

Figure 5.16: Arrival Cluster composition for Cluster 5

Logistics facilities in this cluster make the least empty vehicle kms. On average they handle 2.84 tonnes of load on a trip for a distance of 38 kms. They make about 168 vehicle kms. Due to the heavyweight of the vehicle and machines compared to other products, the utilisation rate is 41%. But based on the total distance it travels it has a transport efficiency of 0.65. The figure 5.17 shows that this type of facility performs better in all aspects compared to the average of all the other facilities.

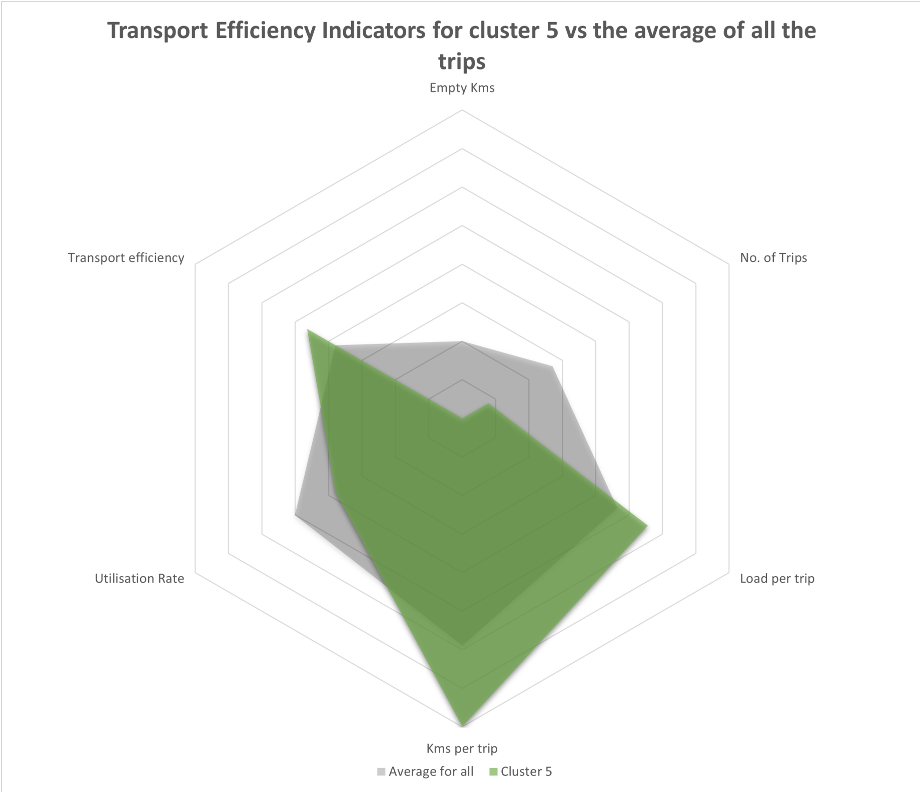

Figure 5.17: Transport Efficiency Indicators for Cluster 5

The hypothesis for large facilities in peripheral cities stated was that they would perform with high transport efficiency indicators and poorly in empty kms. The first regarding the high transport efficiency is accepted as most of the indicators are above average. The second part of the hypothesis is rejected as this type of facility doesn't make a lot of empty km. The high payload of the vehicle allows carrying a higher load and the low empty km combined together results in high transport efficiency.

5.3.6. Cluster 6: XXL Facilities in Peripheral Cities

These facilities are the biggest sized category of the facilities and the newest. They are located in a sparsely populated region. This category of facility carries similar types of goods compared to the large facilities in peripheral cities (Cluster 5) and mainly arriving in the similar facilities as itself (figure 5.19).

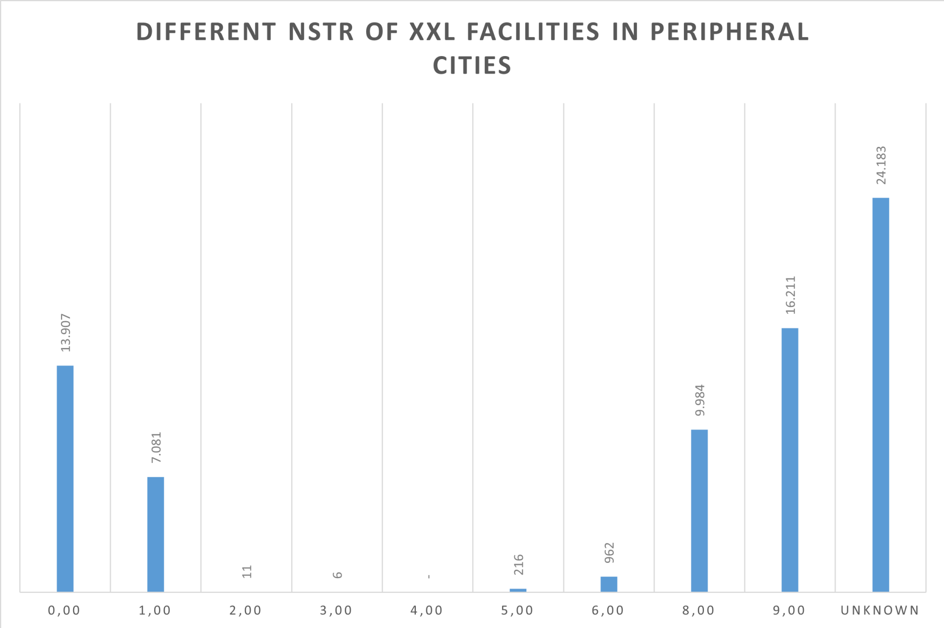

Figure 5.18: NSTR Composition for Cluster 6

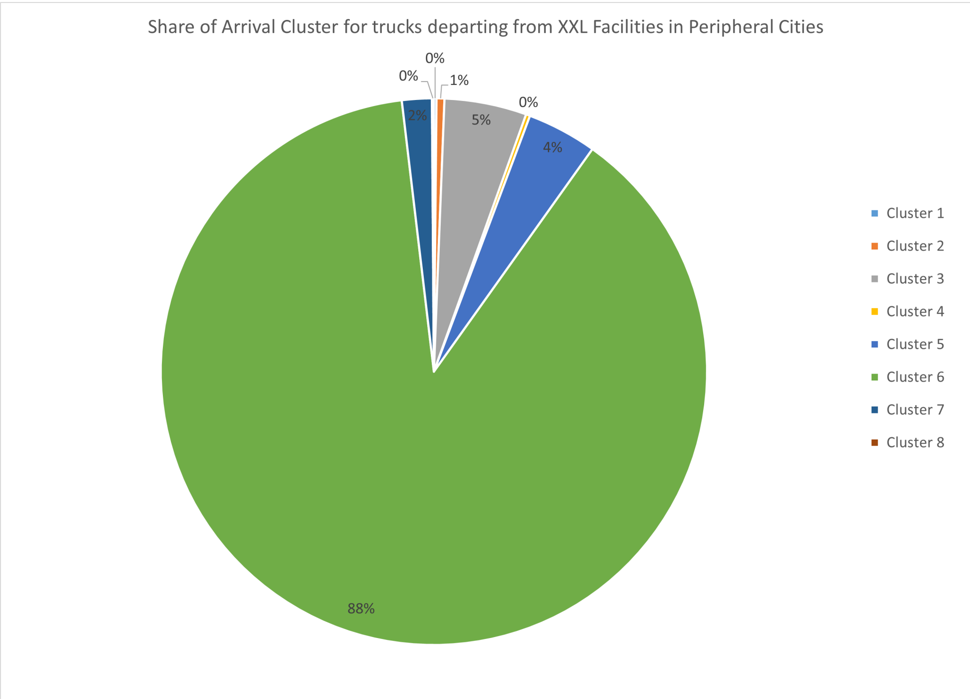

Figure 5.19: Arrival Cluster composition for Cluster 6

These facilities are scattered all over the Netherlands. Facilities perform similar to the small facilities in the sub-urban areas. Even with the biggest size of the logistics facilities, these have the lowest payload of the vehicle, making the transport efficiency of these logistics facilities low. They have a low empty kms (65 kms) and make 6 trips in a tour. Even though the transport efficiency is low (0.37), these facilities have a good utilisation rate of the truck (65%). Facilities in this cluster include big companies. Figure 5.20 depicts that this cluster performs well in utilisation rate and empty kms but not the others.

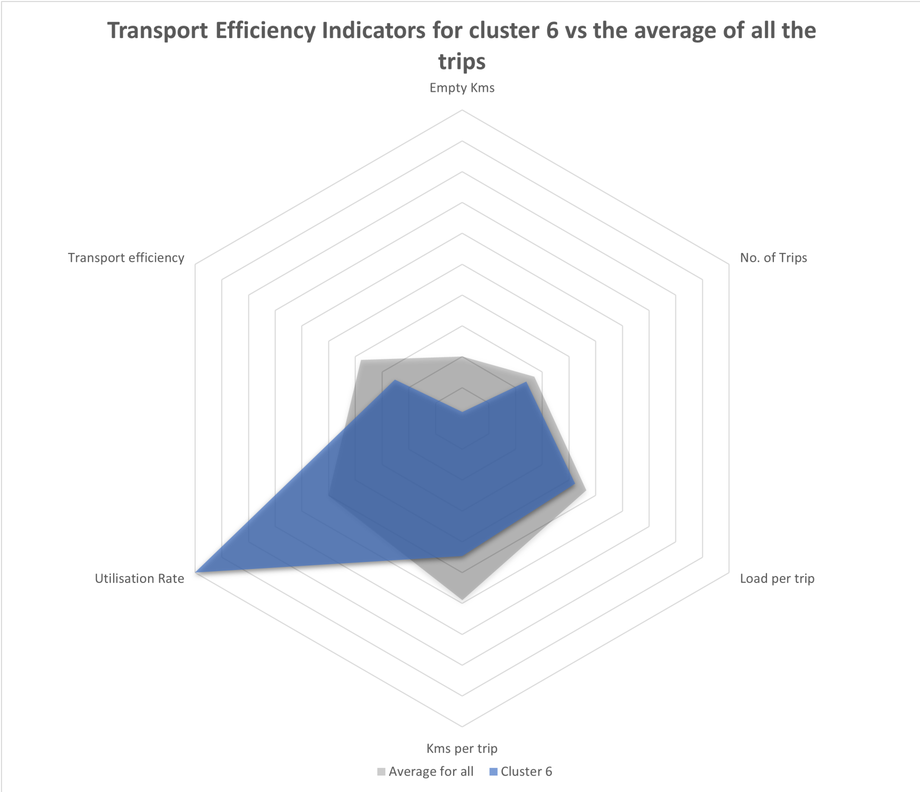

Figure 5.20: Transport Efficiency Indicators for Cluster 6

The hypothesis stated for XXL facilities in peripheral cities was that they would have a high utilisation rate and good transport efficiency. The hypothesis for the utilisation rate is accepted as they have a very high utilisation rate. The performance of transport efficiency was lower than expected due to the low road tonne-km due to the lower vehicle carrying capacity.

5.3.7. Cluster 7: Medium Facilities in Remote Locations, away from hubs

These facilities are of a similar size as cluster 8, with a similar spatial structure. The main difference is that cluster 7 is the furthest away from the transshipment terminals and ports. These facilities transport agriculture, and vehicle, and machines (other trade) (figure 5.21). The tour ends within the same clusters (figure 5.22). Facilities in this cluster transport a high load (16 tonnes) for a small vehicle kms (143 km).

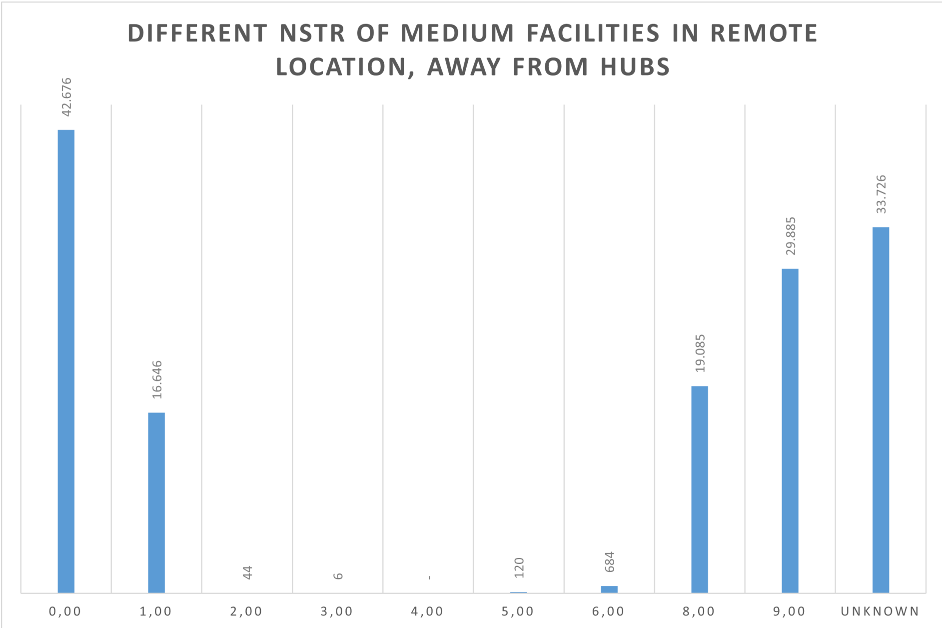

Figure 5.21: NSTR Composition for Cluster 7

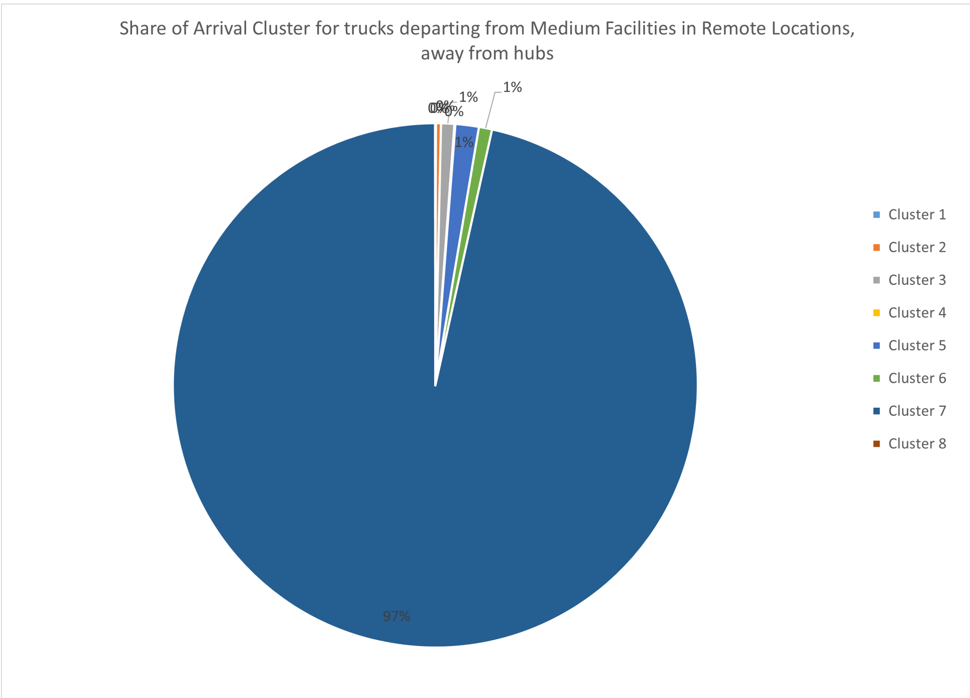

Figure 5.22: Arrival Cluster composition for Cluster 7

This cluster of facilities belongs to the northern part of the Netherlands. These facilities have trips with low load (1.82 tonnes) and making smaller trips (16 kms). They also have at least 9 trips on a tour. The trucks in this cluster have a very low truck operation efficiency (0.2) but have the same utilisation rate as the other medium facilities in remote locations (53%). These facilities have a lower transport efficiency, one of the reasons for this could be that the facilities in cluster 8 travel internationally (to an unknown location) making a big tour. While these facilities deliver locally, hence having a transport efficiency. Figure 5.23, shows the performance of these facilities compared to the average. The already stated facility performs well on utilisation rate and empty kms but poorly on the other.

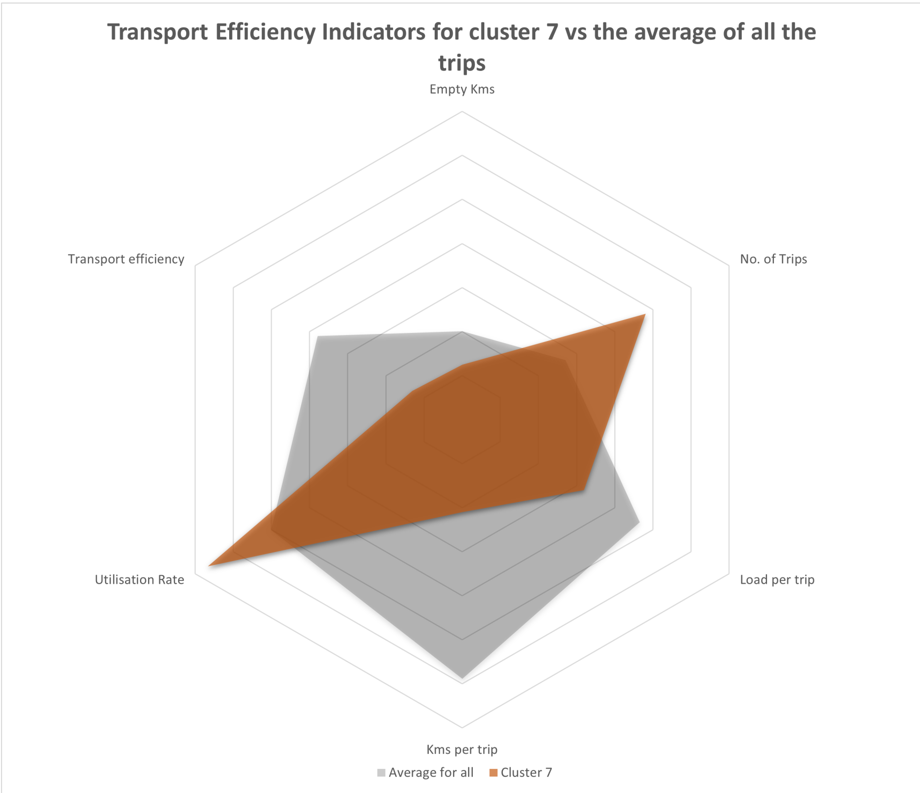

Figure 5.23: Transport Efficiency Indicators for Cluster 7

The hypothesis for Medium facilities in remote locations, away from hubs was that they would be high transport efficiency, but some trips (inbound) being less efficient than the others. The hypothesis for this facility is rejected. These facilities have very low transport efficiency but a high utilisation rate. This is a result of the low load handled in a trip.

5.3.8. Cluster 8: Medium Facilities in Remote Locations, closer to hubs

These facilities are in close proximity to the transshipment terminals and ports. These facilities have a mix of goods and most of the goods transported through this facility are unknown (due to containerisation) and arriving at multiple locations (figure 5.24 & figure 5.25). Facilities in this cluster carrying an average load of 16 tonnes in a tour for an average vehicle km of 143 kms. Facilities in this cluster make the least number of trips (3).

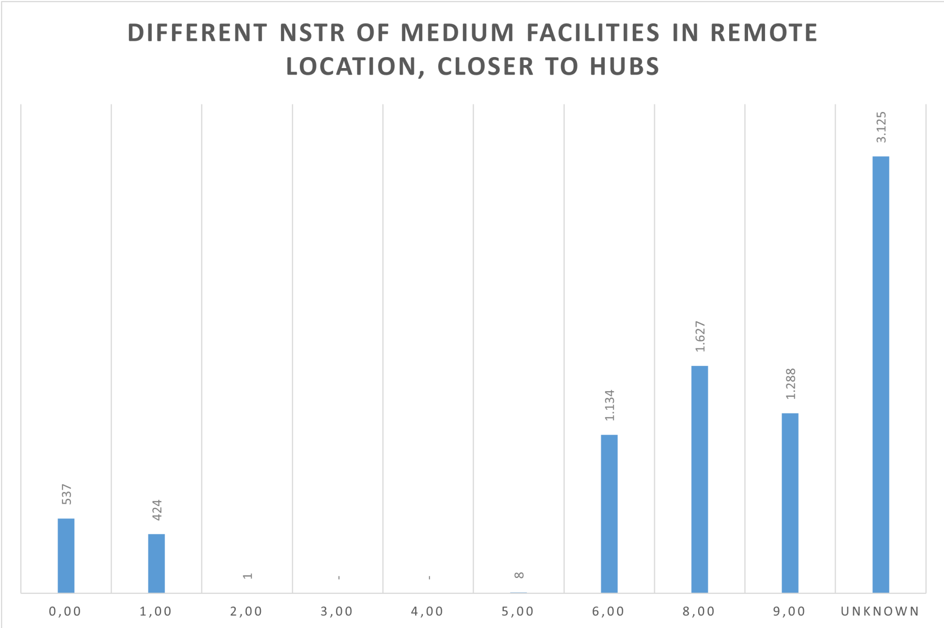

Figure 5.24: NSTR Composition for Cluster 8

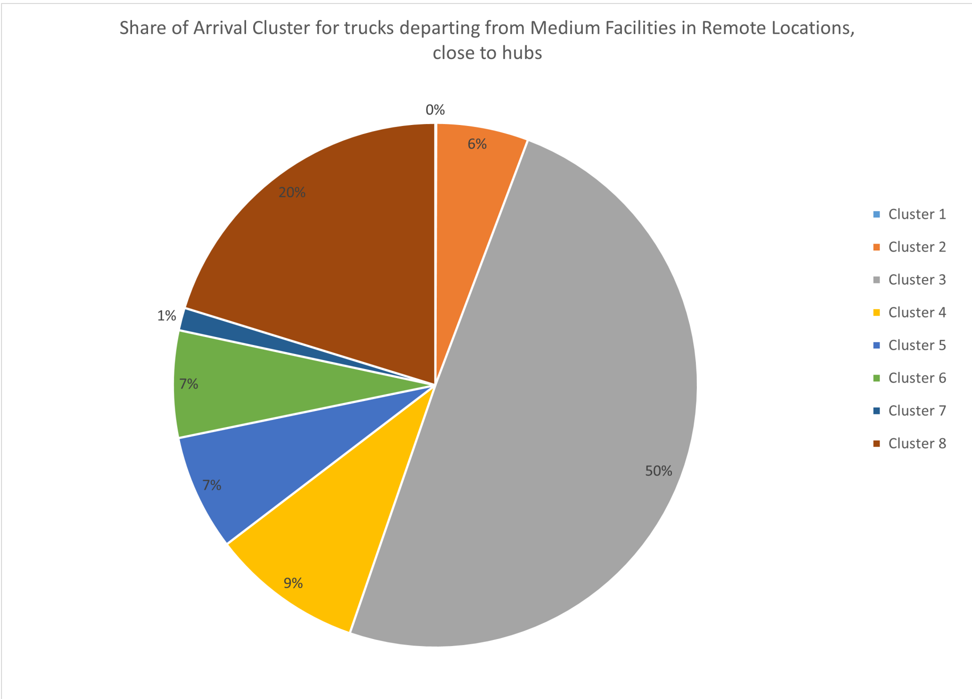

Figure 5.25: Arrival Cluster composition for Cluster 8

Facilities in this cluster are concentrated around the Amsterdam and Rotterdam regions. These logistics facilities have the highest transport efficiency (1.37). Having a medium-size, these facilities make heavyweight (4 tonnes) trips for a long distance (41.26 km). These facilities have an avg of 100 km of empty running. The utilisation rate of the vehicle is 54%, which can be considered high compared to the other facilities. Figure 5.26 shows that this facility performs better than the average of all the facilities.

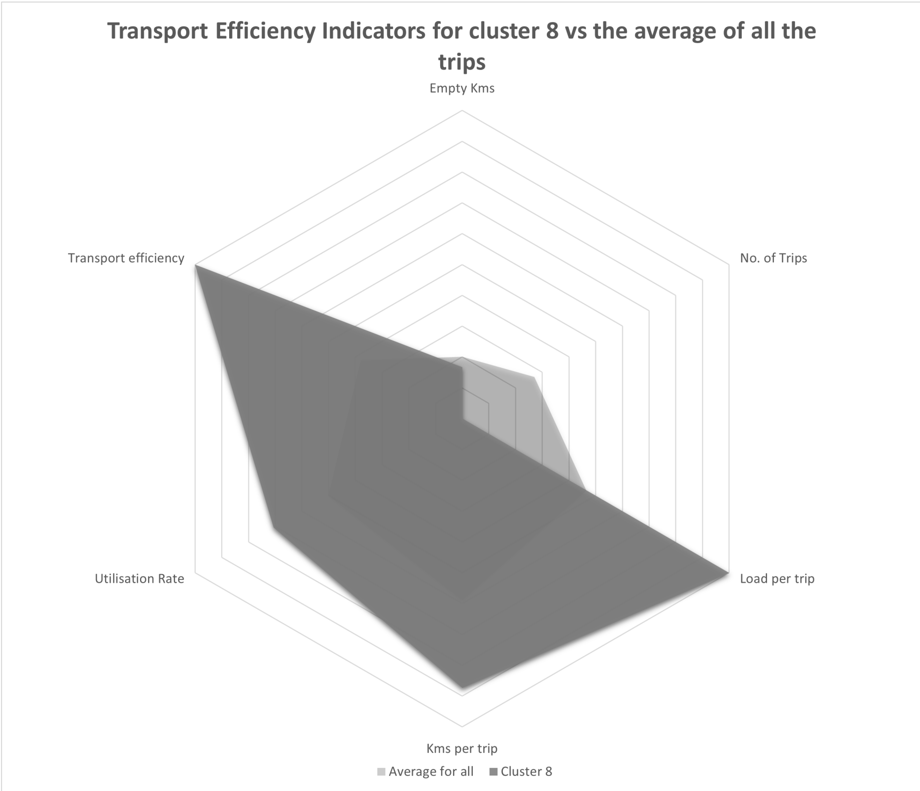

Figure 5.26: Transport Efficiency Indicators for Cluster 8

The hypothesis stated for medium facilities in remote locations, close to hubs was that these facilities would have a highly efficient with a high utilisation rate of the vehicle. The hypothesis of this facility type is accepted, they have a very high truck operational efficiency and utilisation of the vehicle. Being in the port regions makes it easier for these facilities to consolidate making the transport efficiency the highest.

5.4. Comparing different Transport Efficiency Indicators

This section examines the different indicators of transport efficiency. It should be noted that all the variables to understand transport efficiency for the logistics facilities can be found in table 5.6.

Vehicle kilometres

The table5.6 shows the vehicle kilometres for different types of logistics facilities in 2015. The data showed that the medium facility in urban centres and medium facilities in remote locations which are both close and away from hubs generate the least vehicle kilometres. It is likely due to direct shipments from the remote locations to the destination and last-mile delivery in urban centres. Meanwhile, small facilities in sub-urban areas (constructed during compact city and compact urbanisation policy) generated more vehicle kilometres than others. The reason could be due to being in the middle of the supply chain, it facilitates the upstream and downstream supply chain.

The freight journey of the filled vehicle kilometres is average from large and XXL facilities peripheral cities and also for old medium facilities in UC. It could likely be because these facilities have specific tasks to perform.

Load handled by logistics facilities

The relationship between the load handled by a facility was seen to have a proportional relationship to the distance from UC. The facilities located in the UC carry lower loads compared to the facilities in the remote location. This is due to the area these facilities serve. The pick up/delivery points for remote location is higher compared to the urban centre. However, one of the facilities performed differently. The small facilities in the sub-urban areas (constructed during compact urbanisation) were found to have a high load handling. One such reason found was that these facilities carry a mix of product types. These facilities loaded shipments vary from agricultural products, other food, crude minerals, construction materials, chemical products, vehicles, and machinery (table 5.3).

Empty Kilometres

It could see that the sub-urban areas and the remote locations make the most empty kms. The reason for the empty km for sub-urban locations is that these facilities could be at the centre of the supply chain hence making empty tours. While for remote locations the distance travelled by the load vehicle is higher. But when travelling back to these locations is empty as there could be a low number of consumers at these locations. Both these facility locations transport construction materials leading to an increase in the vehicle kilometres.

The facilities in UC and peripheral cities are seen to make lesser empty kms. Due to the complex tours in UC, there is very little possibility of the vehicle travelling empty. The vehicles leaving from peripheral cities travel with chemical products, vehicles, and machines (table 5.3). The movement of these goods is lower in comparison to consumer products. Therefore, it is possible that the low value could be due to the period of the data collection. As the shipment data was collected for only 4 weeks, there is a high probability that during those weeks the transportation of these materials was low.

Number of trips

The number of trips found for each type of logistics facilities can be seen the column E of table 5.6. The medium facilities in the UC make 15 trips in a tour. This is understandable as the logistics facilities in the urban centre are meant for last-mile distribution to the customers. Therefore, it makes a complex tour. The medium facility in remote locations, close to hubs makes the least number of trips. The reason for this was found to be that, these are in the port/airport region therefore consolidation is easier at these points thus making the least number of trips in a tour.

Utilisation Rate

The utilisation found for these different logistics facilities is low. This is due to fact that only the load carried and payload of the vehicle were studied. The study of volume utilisation could help in better understanding the utilisation rate since RDW has a restriction on the weight and volume of the vehicle. The RDW is the organisation that takes care of the registration of motorised vehicles and driving licenses in the Netherlands.

However, the facilities in UC perform the lowest utilisation rate. The small facilities in sub-urban areas (constructed during compact urbanisation policy) and XXL facilities in peripheral cities perform well. In a similar line of reasoning as the number of trips, the facilities in UC have a complex touring making it difficult for them to reach optimal utilisation rate. The reason for a high utilisation rate for the small facilities in sub-urban areas and XXL facilities in peripheral cities could be due to the serving location. It was seen that these facilities have a similar distance to UC and transshipment terminal (TT) making the transportation behaviour very similar in terms of utilisation rate.

5.5. Conclusion

The goal of this chapter was to understand the different indicators for transport efficiency for the classified clusters in chapter 4. Based on the transport efficiency indicators found from the literature, it could be seen that the medium-sized facilities were closer to hubs, old small facilities in the sub-urban areas and the large facilities in peripheral cities are more efficient that the medium facilities in the urban centre, new small facilities in sub-urban centre. A detailed transport efficiency indicators based on types of goods and arrival locations are evaluated and can be found in Appendix C.

6
Conclusion

This chapter offers the concluding remarks on the research gap, goal, and the answer to the research question. Section 6.1 gives an overview of the research done. Subsequently, section 6.2 discusses the findings from the literature study and empirical analysis, which would answer the research question. Finally, section 6.3 discusses the implications for policy makers.

6.1. Research Overview

The location of new logistics facilities is becoming an increasingly popular area of study not only for researchers but also for policy makers. Earlier, these logistics facilities were closer to the urban centre, and in recent years logistics facilities are seen to be moving further away. Each of these logistics facilities has a different type of spatial organisation and catering to logistics activities. The new logistics facilities were expected to have an increased vehicle kilometre, which in turn would lead to high carbon emissions. The main reason for the increase in vehicle kilometre is the spatial location of these logistics facilities.

As for 2030, the Netherlands aims to reduce greenhouse gas emissions by 49% compared to 1990 as per the Paris Agreement and the National Climate Act. About 21% of these emissions are due to freight road transport. There are policies from 2025 to enforce zero-emissions zones. While for other locations, similar regulations are equally important. However, the policy makers need to understand the transportation taking place. Before making any policies, it is foremost to understand which segments of freight road transportation have room for improvement. These improvement areas can be understood by studying the current transport efficiency. Therefore this research aims at bridging the gap between different types of logistics facilities, their movement, and transport efficiency. The goal was to empirically investigate the transport efficiency of on-road vehicles for the different types of logistics facilities.

This research adopted the following steps to achieve the goal and answer the research question. First, a conceptual framework was made to understand transport efficiency. It also helps in understanding the transport behaviour of the logistics facilities with different spatial characteristics. Second, a classification of the logistics facilities was done to understand the topologies. Finally, the transport efficiency of the logistics facilities was analysed empirically based on the shipment data of the Netherlands collected by CBS in 2015.

6.2. Results

This section discusses the results of sub-research questions and the main research question finally. This section consists of two-part. Firstly, the findings from the literature study. Second, the findings of the empirical analysis. Each question is answered and concluded individually.

6.2.1. Findings from Literature Study

An extensive literature study was an important component. It helped in establishing the scope and understanding of the analysis. It formed the basis of the study. It also helped in formulating the concept of transport efficiency. This subsection answer the first 3, sub-questions and was derived from Chapter 3.

Sub Question 1: What are the different factors influencing the logistics facility location?

Differentiating the logistics facilities based on size, distance to the urban centre, sector of the logistics facility, or the hierarchy is the current state of the art. These are some of the suggested ways to distinguish the logistics facilities. Nevertheless, due to the economy of scales, these distinctions don't give an exact measurement of the typology of the logistics facilities. The literature review suggested that the companies plan the location of the facilities based on the distance to Transshipment Terminal, ports, airports, and Urban Centre. Some even suggested centrality being a crucial feature while choosing the location of these logistics facilities. Land and water availability (especially in the Netherlands due to inland shipping) are the factors that are influenced by the size and functionality of the logistics facilities.

Apart from these spatial factors, industry and logistics characteristics also factors that influence the location choice. The business of the logistics facilities, worker availability, land price, distance to the serving area, regulations of the area, vehicle restrictions, etc was found to be some of those factors. With these factors, it is possible to understand the location planning of the logistics facilities.

Sub Question 2: What are the different factors influencing transport efficiency?

Goods transportation to/from a logistics facility is a trade-off between the inventory planning and distribution department. These departments discuss the transportation of goods based on the transport load. The transport load mainly affects the delivery weight, frequency, and distance travelled by the vehicle. The delivery weight, frequency, and distance are the decision of the distribution/delivery side. While inventory planning also influences the distribution, such as the production rate, demand, surface availability.

The fixed costs and variable costs are some of the other factors influencing transport apart from delivery weight, frequency, and distance. The fixed cost includes the cost of the vehicle, fleet size, insurance, driver, mileage of the truck, fuel cost, and cost/ton. All of these factors combined influences transport efficiency. For companies varying in industry sectors, and types of logistics facilities, the measurement of transport efficiency indicators varies.

Sub Question 3: What are the indicators to assess transport efficiency?

The logistics providers try to maximise their transport efficiency by using different indicators. Table 6.1 shows some of the relevant indicators related to the distribution of goods.

Table 6.1: Indicators to understand transport efficiency

Key performance Indicators
Vehicle Utilisation Rate
Vehicle kilometre per day
Vehicle kilometre per trip
Number of stops
Vehicle carrying capacity
Empty Kilometres
Planned v/s actual distance travelled
Level of CO_2 emissions
Number of vehicles in use
Average fuel consumption
Network performance
Carrier performance
Trip duration

Using all the indicators combined with understanding transport efficiency is still a novel concept. A framework for analysing the efficiency of the on-road vehicles was studied. It included a few of the indicators used by the logistics providers to measure their performance. The framework included the indicators: utilisation rate, empty kilometres, and carrying capacity. The ratio of road tonne-km and total vehicle kilometres explains the previously mentioned indicator. Due to the absence of the trip information, an assumption on the number of trips in the framework. The assumed length of a trip is considered based on the total vehicle kilometre divided by the number of trips.

6.2.2. Findings from Empirical Analysis

This section discusses the results of the final sub-research question and the main research question. The empirical findings are discussed in detail in chapters 4 and 5.

Sub Question 4: What are the different types of Logistics facilities in the Netherlands?

An appropriate method found for grouping logistics facilities based on characteristics was cluster analysis. The principal component analysis is a pre-step before clustering. It reduces the variables by grouping the correlated variables. Finally, clustering the logistics facilities resulted in eight clusters for the Netherlands. These eight clusters found could be distinguished based on their size and the location of logistics facilities. The table 6.2 shows the different sizes and location of the logistics facilities. There can be multiple combinations of sizes and locations of these types of logistics facilities.

Table 6.2: Naming of Logistics Facilities

Sizes of the Logistics Facilities	**Locations of Logistics Facilities**
Small Facilities (5,000 - 10,000 m^2)	Urban Centre
Medium Facilities (10,000 - 20,000 m^2)	Sub-Urban Areas
Large Facilities (20,000 - 30,000 m^2)	Peripheral Cities
XL Facilities (30,000 - 40,000 m^2)	Remote Locations
XXL Facilities (40,000 - 50,000 m^2)	
XXXL Facilities (50,000 - 60,000 m^2)	

- Old Medium Facilities in urban centre: These have a surface area of 11,000 m^2 and belong to the oldest category of facilities. These facilities are located in the urban centre. These logistics facilities mainly belong to the food beverages and consumer goods sector.
- Medium Facilities in the urban centre: Facilities in this cluster are located in urban centres. It has a surface area of 12,000 m^2 and was constructed around the 1980s. Freight transportation by road, non-food consumer products, and other specialised wholesale products sectors can be found in this cluster.
- Small Facilities in the sub-urban area (constructed during compact city policy): Small facilities are located in the sub-urban areas of the existing major cities. They were constructed around the 1990s i.e., the time when the Dutch government was trying to implement compact city policy. It included industries such as non-food consumer goods, other specialised wholesale products, and machine and equipment for industry.
- Small Facilities in sub-urban area (constructed during compact urbanisation policy): These facilities were constructed in the 1980s when the Dutch government was trying to implement the compact urbanisation policy. These were located in the sub-urban areas or newer towns. This group of facilities includes a similar type of industry sector as the previous small-facility in sub-urban areas, constructed during the implementation of compact city policy.
- Large Facilities in peripheral cities: The larger facilities were seen around 1995. These are located in the peripheral regions of the cities. Peripheral locations are the areas located outside the urban areas with a low population density. Freight transport by road and transport services are the two main industry sectors that can be found in this cluster.
- XXL Facilities in peripheral cities: These logistics facilities in this cluster are considered important due to their big size and impacts on freight transportation. These are the largest and the newest types of facilities with the construction year of 1995. These are also located in peripheral areas similar to large facilities. 42% of the industry in this cluster belongs to transport services.
- Medium Facilities in remote locations away from hubs: These have a high distance to the transshipment terminals and the ports. These were constructed around the 1990s. They don't have a significant feature in terms of geographical characteristics and logistics sprawling characteristics. Industries such

as other specialised wholesalers and freight transportation by road were seen in these group of logistics facilities.

- Medium Facilities in remote location, close to hubs: Most of the facilities in the remote locations closer to the ports and transshipment terminals. They were constructed around 1995. These logistics facilities have a high land and water availability as well as the lowest $hhkm^2$. The logistics facilities include industry sectors such as transport services and other specialised wholesalers.

Main Research Question: What is the transport efficiency for the different types of logistics facilities in the Netherlands?

Answering the main research question was done based on the topology of the facilities from chapter 4 and the computation of the different transport efficiency in chapter 5. The empirical study was based on the truck diaries database. It was used to compute the indicators and well as the transport efficiency for the different logistics facilities in the Netherlands. The transport efficiency for each of the logistics facilities is discussed below.

- Old Medium Facilities in urban centres have a low utilisation rate, this is due to the low load handled by the logistics facility compared to the payload of the truck. The vehicle moving between these facilities try to organise the distribution in such a way, that it makes only one-third of the vehicle kilometres with no load. Being in the urban centre, these logistics facilities do not make multiple trips on a tour. The low utilisation rate, number of trips, and average empty kilometres make the vehicles travelling from these facilities to have an average transport efficiency. The shipment picks up and drops off are in urban centres, sub-urban areas, and remote locations. Hence, it could be said that these facilities act as consolidation centres to deliver to consumers. It was also seen that the vehicles travelling between these logistics facilities mainly carry agricultural products and live animals.
- Medium Facilities in the urban centres also have a low utilisation rate and empty kilometres, similar to the old medium facilities in urban centres. The low load handling by these facilities compared to the payload of the vehicle makes the utilisation rate low. Due to the location of these facilities, the vehicles leaving them makes the most number of trips in a tour. The high number of trips in a tour would decrease the transport efficiency making it the least efficient. The vehicles mainly travel to other logistics facilities, in this cluster carrying mainly vehicles, machines, and other general cargo. The logistics facilities in this cluster have the lowest efficiency.
- Small Facilities in sub-urban area (constructed during compact city policy) were found to have complicated transportation. These facilities have more empty kilometres than the vehicle kilometres and make multiple trips. Since these facilities handle low loads and have a low payload vehicle, the utilisation rate is decent. The location of these facilities, help in serving the urban areas as well as port areas. The higher empty kilometres and low load handling make these types of facilities less efficient. But, these logistics facilities, make the highest loaded vehicle kilometre. These logistics facilities always end their trips back to the same cluster. These logistics facilities mainly load agricultural products and chemical products.
- Small Facilities in sub-urban areas (constructed during compact urbanisation policy) have a high utilisation rate. These logistics facilities have a lower surface area but a high load handling. The empty kilometre is travelled by the vehicle is similar to the filled kilometre. and making less number of trips. These characteristics have led to the facility to have good transport efficiency. The vehicle tours majorly end in the other small facilities in sub-urban areas. The loading/unloading of shipments from this cluster is mainly in the sub-urban and peripheral areas. The vehicles carry agricultural products, general cargo, vehicles, and chemical products. Since the facilities carry a variety of products these vehicles may belong to third-party logistics providers.
- Large Facilities in peripheral cities handle an average load of goods and are transported in a high payload vehicle. This makes the vehicles leaving these logistics facilities, to have an average utilisation rate. The vehicles of these logistics facilities, make a small number of trips in a tour. They even make the lowest empty kilometres among all the logistics facilities. The low empty kilometres, number of trips, and the average utilisation rate resulted in the average performance of these logistics facilities. Transportation takes place between sub-urban areas and peripheral cities while carrying chemical products,

vehicles, machines, and general cargo. This suggests that these facilities could belong to the middle part of the supply chain.

- XXL Facilities in peripheral cities have similar characteristics as large facilities in peripheral cities in terms of vehicle kilometres and transport load carried by the vehicles leaving this logistics facility. They make smaller tours with a higher load. This would mean that these logistics facilities have a higher transport efficiency, but the higher number of trips makes it difficult. Even with a very high utilisation rate, transport efficiency is low. The main cause is that the average road tonne-km is low. This means the facilities travels for a short distance with a low shipment load in a trip. These logistics facilities end the tour in the same type of logistics facilities. These logistics facilities carry a mix of products and belong to the transport services sector.
- Medium Facilities in remote locations, away from hubs handle a very high transport load on heavy vehicles leading to a good utilisation rate. Among the total vehicle kilometres, half are empty kilometres. These logistics facilities also make a lot of trips in a tour. The low vehicle kilometres also leads to low transport efficiency. Since these logistics facilities are located in remote locations, the vehicle mainly travels between these logistics facilities. They also transport a different category of goods.
- Medium Facilities in remote locations, close to hubs have a good utilisation rate. The good utilisation rate is due to the high load handled by the logistics facilities with a high payload of the vehicle. These logistics facilities also make the least number of trips. About half of the vehicle kilometres are empty. The location of these logistics facilities makes these characteristics interesting. The availability of hubs nearby helps in consolidation/de-consolidation freight. All these characteristics combined lead to high transport efficiency. The vehicle leaving these logistics facilities travel to urban centres, sun-urban areas, peripheral cities, and in the remote location as well. These logistics facilities transport goods such as crude minerals, construction materials, chemical products, vehicles, machines, and other goods.

Studying these different types of logistics facilities, led to an understanding that the geographical and spatial characteristics influence freight activity.

Firstly, the analysis of distinguishing logistics facilities showed that categorising the facilities based on spatial and on geographical locations could help in understanding the freight planning of the companies better. The study considered the distance to the Urban centre, Transshipment Terminal, ports, airports, ramps (infrastructure), land availability, water availability, household per kilometre square, construction year, and surface area of the facility. Adding a few logistics characteristics such as market availability, the objective of the logistics facility, and position in the supply chain could improve the categorisation of the logistics facilities.

Secondly, the transport efficiency analysis showed that the combination of the vehicle kilometres in a trip, load handled in a trip and empty kilometres is important. These factors influence transport efficiency. It was seen that the average load handled in the trips was lowest in urban centres, followed by sub-urban areas, peripheral cities, and highest in remote locations. The average shipment distance was seen as the lowest in the urban centre, followed by peripheral cities, remote locations, and then sub-urban locations. The average empty kilometre was also seen to have a variation as average shipment distance. Finally, the comparison between the old and new logistics facilities in the urban, sub-urban areas, peripheral cities, and remote locations showed that the older facilities were more efficient.

Finally, the transport efficiency analysis, showed that the combination of the vehicle kilometres in a trip, load handled in a trip and empty kilometres is important. These factors influence transport efficiency. However, studying these different types of logistics facilities, led to an understanding that the comparison of transport efficiency is difficult. This is due to the significant difference in terms of their functionality, the kind of goods that need to be transported, and their position in the supply chain. However, a comparison of the facilities within the clusters can be done to understand their behaviour.

6.3. Implications for Policy Makers

The truck diaries database is available for the Netherlands, and it is one of the most extensive freight data available. For transport planners and policy makers to extract usability from the data is very important. This section discusses the implications for policy makers based on the results.

- The types of location from the logistics facilities found were the urban centres, sub-urban areas, peripheral cities, and remote locations. Overall, the most common case found was with the medium size of the logistics facilities. Predominantly, the location of these logistics facilities is around populated areas.

- Empty kilometres for the different types of logistics facilities showed that 25% of the vehicle kilometres are empty kilometres. In some cases, it was higher. The sub-urban areas have higher empty kilometres as it serves both the upstream and downstream part of the supply chain.
- Payload of the vehicle performed a bit differently than expected. The XXL facilities were seen to have the lowest payload vehicle while the old small facility had a high payload vehicle. However, no accurate reason for this behaviour was found. But, the logistics facilities in the remote locations used the highest payload vehicle.
- The location of the logistics facilities in the supply chain influences the vehicle kilometres in a trip. The distance travelled when the facilities belong to the urban centre or remote locations are lower compared to sub-urban areas and peripheral locations. The reason for the high vehicle kilometre in these locations is that the serving areas are higher.
- Number of trips were found to be high in urban centres, as these facilities make more complicated tours. The other facilities located away make simpler tours. The remote locations, away from hubs had more trips than expected. This is due to the spatial location, these logistics facilities were located in the Groningen region. The companies located in this area need to make multiple tours to keep with their planning.
- The utilisation rate was the ratio of the load handled by the facilities and the payload of the truck. But, in most cases, the payload of the vehicle was not utilised. One of the reasons could be, that RDW has constraints on the volume and load of the vehicle. This research only considered the load and not the volume of the vehicle.
- Transport efficiency was seen to be varied and comparison between these is not possible. However, the facilities with low values indicate that there is room for improvement. The medium facility in an urban centre and remote location, away from hubs could improve their transport efficiency.

7

Discussion and Recommendations

In this chapter, the results are discussed. Section 7.1 first discussed the logistics facility, followed by transport efficiency, and ends with a discussion on methodology. Section 7.2 reflects on the assumptions. The chapter concludes with recommendations (section 7.3), it comprises of some scientific and practical recommendations.

7.1. Discussion

This research focused on the topology of the logistics facilities based on the different spatial and logistics characteristics and their transport performance. The transport efficiency indicators this research evaluated focused on the logistics facilities from the size of 5,000 m^2.

Clustering analysis helped in grouping similar types of logistics facilities. Transport efficiency was analysed subsequently. Since studying transport efficiency still novel. There was little to no literature on this type of analysis. However, four indicators were combined to make an analytical model study transport efficiency. In the next sections, a discussion on logistics facilities, followed by logistics sprawling, and discussing transport efficiency is presented.

7.1.1. Logistics Facilities

Logistics facilities are complex to understand. No two facilities are similar to each other. This research helped in understanding some of the main aspects based on which most of the facilities can be distinguished. The diversity of logistics facilities not only results from the geographical characteristic, centrality, and the sector but also the objective of these facilities, employees, service regions, and business around. The number of facilities has been growing over the years. The constructing of new logistics facilities still takes place around UC as well as remote locations, because these help in the last mile delivery and internationally. The companies are trying to make their supply chain as efficient as possible.

There were four main locations (urban centre, sub-urban areas, peripheral cities, and the remote location) with regards to geography and urban structure for facility location. One of the most interesting characteristics was that four out of eight facilities belong to medium size facilities, two were small facilities, and the others to large and XXL. One of the interesting points of the XXL facilities was the location. In most of the cases, it was seen that these XXL facilities weren't located in a remote location. This could be because of the hub availability, as the ports are in Rotterdam and Amsterdam. More than half of the population lives in these provinces, making it highly urbanised. Thus, the large facilities are around the cities.

The segregation of the logistics facilities was done to only eight different types of facilities as after that the difference in the topology was very minute. These facilities are not the only type of facilities, since there is still a degree of variation among them. There could be other types of facilities, such as large facilities in sub-urban areas or remote locations. Furthermore, there could be more factors influencing the facility location that was not considered. For instance, the customer base location, the supplier location, employees availability, objective of the facility, land prices, or the location of the facility in the supply chain. Hence, it would be too simple, to say that these are the only categories of logistics facilities as well as the factors.

Another key aspect is to understand logistics facilities pattern changes dynamically taking urban patterns into account. This study assumed that the UC, land, infrastructure, water, and ports were always there and didn't change. More logistics and business characteristics would also help in getting a better understanding of the logistics facility type better.

7.1.2. Logistics Sprawling

Logistics sprawling is an area of increasing interest by research. Researchers suggested that the older facilities are located in the urban areas (closer to the population) while the newer ones further away. Based on it, the expectation for the Netherlands was also the same. The correlation study was done between the construction year, surface area, and distance to urban centres to check. However, no explicit relationship was seen among them. One of the reasons for this could be the data for the many other really small facilities that are not available. The other being no explicit study was done to understand logistics sprawling.

The logistics facilities constructed around 1995, were on average were bigger in size compared to the others but not located in remote locations. These facilities were around the urbanised regions or called peripheral cities in this research. Based on the construction year it was seen that earlier there were old medium facilities in UC, followed by medium facilities in UC, small facilities in sub-urban areas, medium facilities in remote locations, away from hubs, small facilities in sub-urban areas, and later the large, XXL facilities in peripheral cities, and medium facilities in a remote location, close to hubs. One of the reasons for this changing pattern could be the changing pattern of urban centres over the years. It could be said that the facilities were moving further away but in recent years the bigger logistics facilities are at an intermediate distance to reach centrality. Another factor that needs to be understood is the changing demand and innovations in the supply chain makes it complicated to understand the changing pattern.

7.1.3. Transport efficiency

The eight logistics facilities were tested for the different transport efficiency indicators found in the literature. It was seen that there isn't any facility that performs poorly on all the indicators. However, the medium facility in an urban centre performs lower in transport efficiency, utilisation rate, shipment distance, and the number of trips. It is naive to say that the transport efficiency of these types of logistics facilities is poor compared to the other facilities since it is difficult to compare as these serve different logistics segment. Companies try to reach an optimal performance throughout their supply chain, hence in some parts of the tours/trips, the efficiency could be low. These facilities are located in the urban centre, so the main purpose of these facilities is to deliver to multiple locations. Delivery to multiple locations would mean that the truck leaving these facilities would have to make multiple stops. It is interesting to see that these facilities for the trips it makes, perform well with respect to vehicle kms and empty kms. The reason for the low utilisation rate could also be because there, is a mixture of different types of goods being carried through this type of facility.

The comparison between the similar type of logistics facilities could give a better understanding of the transport efficiency. Inspecting the medium facilities in UC (Cluster 2) with old medium facilities in UC (Cluster 1), it was noted that both have a similar empty kms and utilisation rate of the vehicle. The older facilities make fewer trips with agricultural products and vehicles, machines and general cargo carried over a long distance. Due, to the long-distance and high shipment load the transport efficiency is also high. According to the literature, the older facilities should have lower efficiency, but in this case, it is not true. The reason for this could their position in the supply chain is not known, since the freight flow also depends on it. It can not be concluded that the old facilities can be positioned higher in the supply chain since the data is not representative of a company. Since the data is on an aggregate level. The last mile deliveries will always have less efficiency compared to the first leg of the trip.

There are two types of small facilities in the sub-urban area, one is built during compact city policy while the other in compact urbanisation policy. It was expected that the facility built during compact city policy would perform better. One of the reasons for low transport efficiency could be that the facilities were towards the urban centre than the other. It could also be seen in the number of trips these facilities made. However, it can not be proved since the other facilities are away from the TT and ramp compared to the new small-sized facilities in sub-urban areas.

Examining newer facilities large facilities in the peripheral cities showed that, they have average values for the other indicators. This would seem logical since they would be located at the centre of the supply chain. They would be facilitating the transshipment terminals as well as the smaller facilities so distribution to customers. The newer facilities are planned accordingly to reach the maximum potential. The other new facility is the XXL facilities in peripheral cities. Currently, these are the most discussed facilities as it is expected these could negatively impact road freight transport. XXL facilities indeed have a low transport efficiency, but they perform well on utilisation rate, vehicle kms, and empty kms. These facilities should have some similar characteristics to large facilities, but the shipment distance for these facilities is low. The reasons could be that the XXL facilities are a little closer to the TT and ports, and they also use trucks with a lesser payload. Since, the truck operation is composed of the vehicle carrying capacity, payload utilisation, and empty running, the reason holds up.

The medium facilities in a remote location, closer to hubs are newer compared to the other facilities. The high transport efficiency could be due to the high positioning of these logistics facilities in the supply chain as they are located close to the hubs. The low vehicle utilisation rate could be due to RDW weight and volume regulation. These types of facilities were expected to perform better than the other facilities located closer to the UCs. This is also because the consolidation at these facilities is easily and efficiently done. The other medium facility in a remote location, away from the hubs performs significantly differently. The medium facilities in remote locations, away from hubs have a similar utilisation rate to the medium facilities in a remote location, close to the hubs. The low transport efficiency suggests that they travel with a low total load. Hence, it could be said that the facilities of this type pick up and delivers shipments from/to smaller sized facilities.

Improving the efficiency of freight transport has been an objective for the government for some time now. It does come with a lot of challenges. In logistics facilities multiple actors are present and all the facets should be working at the optimal performance. To improve efficiency companies need to work collaboratively, leading to data sharing. To understand the efficiency of the logistics facilities, multiple areas need to be looked into. The complexities of the supply chain, make it challenging, yet interesting to study. This study helped in understanding the different transport & logistics indicators. However, it is difficult to say which transport efficiency indicator for a logistics facility can be improved further. Since the clusters have a different composition of commodities handled, this has an impact on the measured efficiency. Therefore it is not possible to compare the efficiency between clusters

7.2. Reflection on Assumptions

This section reflects on the assumptions made throughout this research. It also provides solutions that could help in reducing assumptions. The main issue because of which these assumptions were made was due to insufficiency in the database. Some of the databases were not available due to difficulty in the collection, some still in progress of completion or due to time constraints, some of the assumptions were made. The list below shows the assumptions that were made, with recommendations to reduce them.

- The *supply chain was not considered*, due to data insufficiency. This can be solved, by interviewing the companies in the database to check what is their position in the supply chain. The other solution could be to make a model for distribution structure and use those to find the position of these logistics facilities in the supply chain.
- The *indicators for transport efficiency were given equal importance*, due to time availability. This can be solved by a literature review to understand for a particular industry sector which indicators are important.
- *Number of trips* in a tour, were calculated based on the number of locations the truck visited. This was done, as the data didn't include the trips (vehicle routing). The number of trips assumptions gives the minimum number of trips the vehicle makes in a tour. While it could make more trips due to load restrictions or optimal routing. A vehicle routing problem can solve this assumption.
- The *data given was true and was used as it is.* When the weights of shipments or locations that were not mentioned were excluded from the study.
- The *RDW accepted payload for a truck was used to calculate utilisation rate.* Since around 40% of the data of the payload was missing, the RDW accepted payload was used. A proper collection and data

processing is needed to get the exact payload. This could have led to a difference in utilisation rate, as the actual vehicle could have a higher or lower payload.

- *Hubs were always present.* Since the year of construction was considered to study sprawling and the topology, the changing TT, and the port location was not studied. Adding a variable regarding the construction year of the hubs could help to refine the study.
- The *distance taken into consideration was planer distance, not infrastructural.* This was done to reduce the computational time, as in the Netherlands the infrastructure is developed and the on/off ramps are close. Hence, it shouldn't make a lot of difference in the distance calculation. To improve this, the shortest path problem can help in calculating the exact distance.
- The *Urban Centre position didn't change over time.* This assumption was made to simplify the problem. It can be solved by taking the population density of the Netherlands for every year and map it with the construction year of the logistics facilities.

7.3. Recommendations

The government needs to be aware of the nature of the logistics facilities and their transportation characteristics. This study provided an overview of these. The analysis and experience with the database resulted in the recommendations. This chapter discusses some recommendations stemming from this research.

7.3.1. Scientific Recommendations

This research adopted a combination of classifying the logistics facilities followed by analysing transport efficiency. There are multiple ways to classify logistics facilities and analyse the indicators which can help in understanding transport efficiency. This study looked into a few of them. For the classification of logistics facilities and analysis of transport efficiency performed, some of the aspects could lead to a better and more extensive analysis.

Classification of Logistics Facilities

- Firstly, there should be a dynamic analysis of the spatial pattern. This would give a better understanding of the changing location pattern of the logistic facilities.
- The objective of these logistics facilities are important to know to differentiate the logistics facilities. This differentiation would add high value to the characteristics of the logistics.
- Similarly, there must be an addition of land price, market proximity, and worker availability variables. These would also add high value while differentiating.
- The high variation among the industry sector and surface area makes it difficult to capture all the data points. Therefore, clustering could be done for each industry sector.
- Using hierarchical clustering doesn't always give the optimal number of groups. Therefore, a latent class analysis could also be used to group these logistics facilities
- The calculation of the distance between various locations should be studied point to point while also considering the infrastructure,

Analysing Transport Efficiency

- Firstly, all the indicators to understand transport efficiency should be taken into consideration. Indicators such as the number of vehicles in use, network performance, carbon emissions, and average fuel consumption by the vehicles.
- Similarly, while defining the scope some of the variables that were not used (vehicle cost, cost of the driver, mileage, etc.) would also help in understanding the efficiency better.
- All indicators were given equal importance, but some indicators may be more important for a particular industry sector. Therefore, it is important to understand the difference in each type of sector.
- With the vehicle routing, and understanding the trip, and calculating the indicators for each trip would give a more accurate view of the transport efficiency.

- A vehicle has a volume and a load restriction by the RDW and the vehicle itself. It is important to check the volume utilisation of the vehicle as well.
- It is also important to check which part of the supply chain, do these facilities belong to say something about the efficiency.

Future Research

In addition to the recommendations discussed above, there are some recommendations for the research question itself. Further, this research could focus on including carbon emissions, therefore giving more insights into making transportation of some logistics facilities greener. It would be interesting to see how the transport efficiency performs in itself and also in combination. It is also crucial to study the interaction between the transportation side and inventory planning, and how inventory planning affects the performance of the vehicle. Furthermore, a case study on each type of logistics facilities could give more insights into transport efficiency.

Another direction that could be taken, is to model the transportation behaviour of a particular industry sector and to validate with the existing truck diary database. The database could help in validating different freight models. Finally, it is also useful to analyse transport efficiency using a different conceptual model.

7.3.2. Practical Recommendations

The results from the analyses helped in identifying some locations for improving transport efficiency. Apart from the scientific recommendation, some other recommendations for policy makers to focus on, to increasing transport efficiency and planning for the future are:

- Firstly, the freight model should be adapted. The traditional methods of considering vehicles travel from origin to destination are not true. Therefore, it is recommended to see the number of trips performed by the vehicle for a particular group of logistics facilities.
- An extensive up-to-date database of the different logistics facilities would help in understanding the changing patterns over time.
- To reduce the carbon emission, the facilities in sub-urban areas should be prioritised. As these facilities are located in the middle of the supply chain, it makes a lot of empty kilometres.
- A detailed look into the medium-size facilities in the remote location away from hubs are mainly located in the Groningen region. It was these that those logistics facilities also have very low transport efficiency.
- Since XXL facilities are new, it is expected to have a high negative impact. There is a needs to understand that these facilities are performing better on average compared to the other logistics facilities.

There is an important role for the authorities to fully understand and take action for all the logistics facilities. Companies also need to understand that their planning should be optimal.

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A

Distance to Urban Centre

This appendix shows the average distance of logistics facilities to the urban centre for the time period of 1830 till 2015 for different levels of urbanisation.

Zone	Number of Facilities	Distance to UC (km)
1	12	5.50
2	1	5.99
3	0	0
4	6	2.23
5	5	1.35
AVERAGE		2.02

Table A.1: Before 1935

Zone	Number of Facilities	Distance to UC (km)
1	89	0.76
2	12	2.48
3	23	2.41
4	45	2.09
5	115	1.61
AVERAGE		1.87

Table A.2: 1935 - 1976

Zone	Number of Facilities	Distance to UC (km)
1	130	0.81
2	37	2.78
3	31	1.69
4	73	2.29
5	259	1.65
AVERAGE		1.84

Table A.3: 1976 - 1995

Zone	Number of Facilities	Distance to UC (km)
1	100	0.88
2	23	2.73
3	30	2.20
4	60	2.28
5	297	1.69
AVERAGE		1.95

Table A.4: 1995 - 2005

Zone	Number of Facilities	Distance to UC (km)
1	57	0.97
2	12	2.98
3	16	2.39
4	36	2.51
5	212	1.93
AVERAGE		2.16

Table A.5: 2005 - 2015

B

Spatial Analysis

The spatial analysis was executed using ArcGIS pro. It helped to generate a distance matrix between logistics facilities and UC, TT, and ramps (infrastructure). The distances calculated were based on the planer distance on the map, the complete infrastructural network was not taken into consideration. This was done because the Netherlands has an extensive infrastructure, hence the difference would be very minute. The average distance to UC was found to be 1.6 kilometres with a standard deviation of 1.43 kilometres. The maximum distance was 14.26 kilometres. While the average distance to on/off ramps was 0.36 kilometres with a standard deviation of 0.32 kilometres. The maximum distance to a ramp was found to be 3.43 kilometres. The average distance to the transshipment terminal was 469 kilometres with a standard deviation of 57.17 kilometres. The transshipment terminals used in the study are the inland terminals, container terminals, and rail terminals in the Netherlands. The maximum distance to a ramp was found to be 633 kilometres (table B.1). Due to the high variation between the distances, it can be said that there is heterogeneity in the logistics facilities, hence reliable segregation of the facilities is needed.

	Distance To UC (km)	**Distance to TT (km)**	**Distance to Ramp (km)**
Mean	1.66	469.08	0.36
Median	1.29	462.89	0.27
Std. Deviation	1.43	57.17	0.33
Range	14.26	633.39	3.43
Minimum	0	0	0
Maximum	14.26	633.39	3.43

Table B.1: Descriptive statistics of spatial characteristics

Exploration of the logistics facilities was done for different time periods. It was seen that there was an increase in logistics facilities over the year in the remote areas (less than 500 $hhkm^2$). Simultaneously, there has been the construction of the facilities in urban centres. Scatter plots (Figure B.1) show the relationship between the construction year of the facilities with the distance to the urban centre. The colour of the dots indicates the different surface areas of the facilities. From this, we can understand that there is no direct relationship between the construction year, distance to the urban centre, and the size (surface area) of the facility. But, we can observe from Figure B.2 that the facilities made in the last decade have a distance higher than 2 kilometres to the on/off ramps.

The spatial movement of logistics facilities in the Netherlands has been measured over the following variables: construction year, distance to urban centres, distance to transshipment terminals, and distance to on/off ramps.

An exploratory statistical analysis was done on the mentioned variables. Table B.2 explains the Coefficient of Variation (CV) or the relative standard deviation. CV concerning the distance to the urban centre was as high as 0.77 without clustering the logistics facilities. This meant that there is a high dispersion in the distance to the UC. The CV for the distance corresponding to the different periods has been higher than the

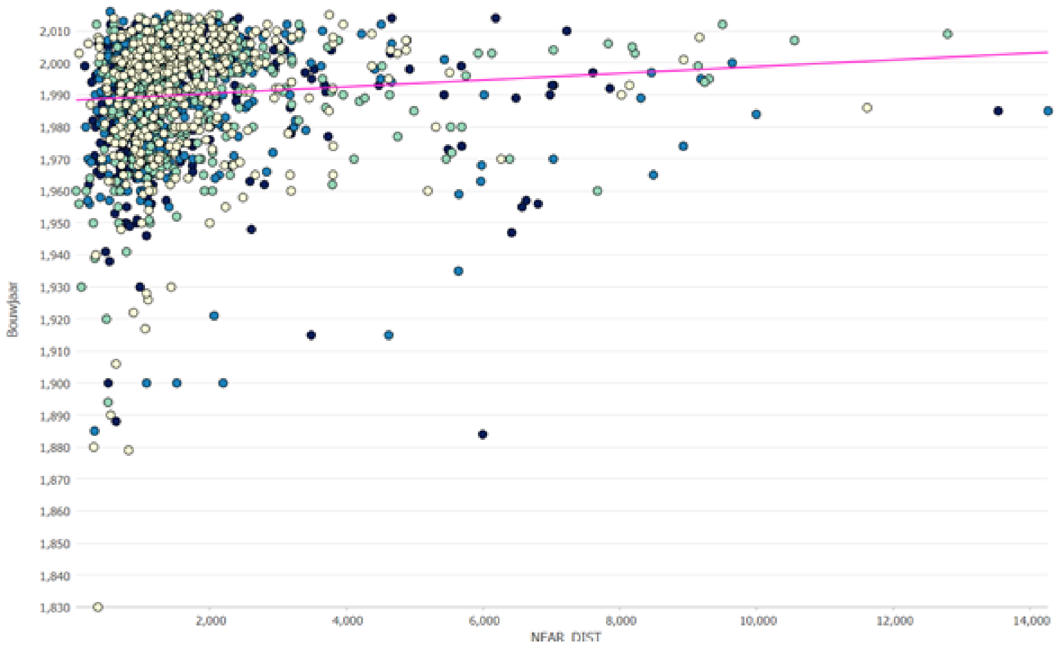

Figure B.1: Scatter plot between construction year and distance to UC

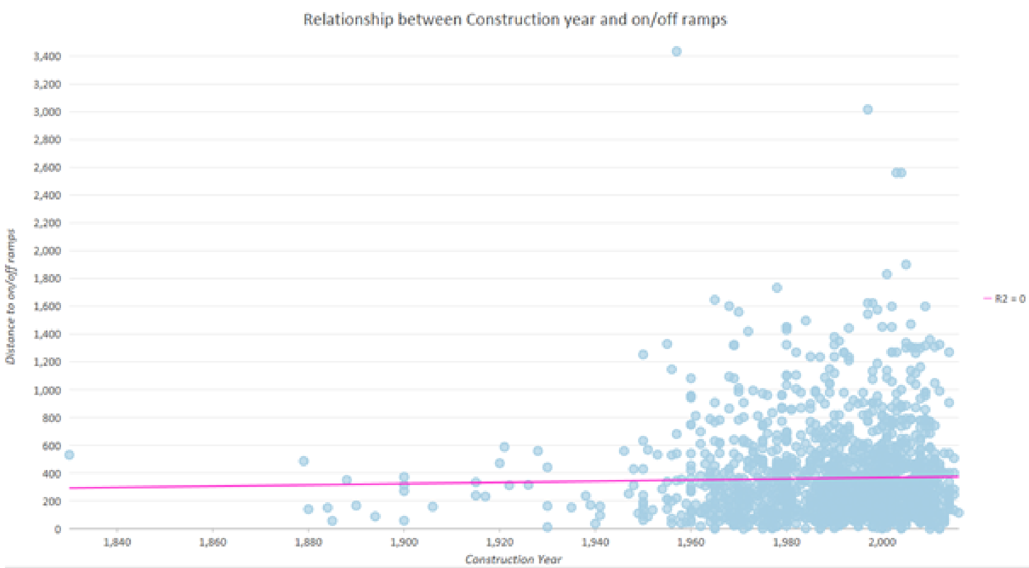

Figure B.2: Scatter plot between construction year and distance to on/off ramps

last period. While theCV for distance to TT has been low (0.11) for all the periods. CV for distance to the ramp is also high (0.87). The volatility of these factors has been decreasing but it is still considered high. It is likely, that different patterns of facility locations mat occur. For, that reason a clustering/grouping is done based on logistics facilities.

Each of the individual variables was compared to find if there was any significant difference in the logistics facilities. Since no single variable was significant all the distance variables were tested together to find if combining them would give a better result. Hence, All the logistics facilities were compared for all the variables (distance to UC, TT, ramps) and it was seen that there was no significant difference between the facilities when all the variables were joint. Wilk's λ = 0.426, F(16,5114.792)= 103.055, p= .00 and partial η squared = 0.192. A separate ANOVA was conducted for each dependent variable with each ANOVA evaluated at an α level of 0.025. There was a significant difference between household density with distance to UC (F= 68.6), distance to the ramp (F=7.37), and $hhkm^2$ (F=466.53). There was no significant difference between $hhkm^2$

Time Period	Distance to UC	Distance to TT	Distance to Ramp
>1935	1.05	0.13	0.59
1935-1976	0.97	0.11	0.99
1976-1995	0.95	0.12	0.84
1995-2005	0.78	0.11	0.92
2005-2016	0.77	0.11	0.87

Table B.2: CV for different time periods for distance to UC, TT and ramp

to TT, $F(4,2689263303) = 0.978$, $p = 0.419$ and partial η squared = 0.002. Since, directly it was seen that there is no significant difference between the facilities, a clustering analysis needed to be done.

C
Transport Efficiency

This appendix presents the transport efficiency indicators for different goods type in each cluster (table C.1). It also includes the transport efficiency indicators for the tour between clusters (arrival cluster) (table C.2).

Table C.1: Indicators for the different NSTR in each cluster

	NSTR	Average vehicle kms	Average load handled by the facility	Average Payload of Truck	Average number of trips	Average Load handled in a trip	Average shipment distance in a trip	Utilisation Rate	Road tonne per km	Transport Efficiency
Cluster 1	**0**	57	6	21	4	1.51	15.55	26%	23.5	0.41
	9	238	8	29	4	1.90	54.31	29%	103.4	0.44
Cluster 2	**1**	87	7	24	22	0.31	3.91	29%	1.2	0.01
	9	73	7	25	20	0.37	3.63	30%	1.3	0.02
Cluster 3	**0**	230	13	22	11	1.16	21.36	56%	24.9	0.11
	1	201	12	23	8	1.51	25.44	53%	38.3	0.19
	8	211	12	25	8	1.50	25.53	51%	38.3	0.18
	9	201	11	23	7	1.51	27.61	48%	41.7	0.21
Cluster 4	**0**	149	17	16	8	2.22	19.71	102%	43.7	0.29
	9	186	18	30	5	3.70	38.84	59%	143.6	0.77
Cluster 5	**8**	175	15	31	5	2.95	34.74	10%	102.5	0.59
	9	164	16	31	5	3.00	31.47	51%	94.5	0.58
Cluster 6	**0**	83	11	20	18	0.61	4.67	54%	2.8	0.03
	8	131	14	21	11	1.24	11.46	69%	14.3	0.11
	9	121	10	20	11	0.94	10.94	51%	10.3	0.08
Cluster 7	**0**	138	15	32	10	1.52	13.65	48%	20.8	0.15
	1	133	18	32	11	1.65	12.42	55%	20.5	0.15
	8	192	15	32	10	1.56	20.12	46%	31.3	0.16
	9	141	12	30	12	1.01	11.67	41%	11.8	0.08
Cluster 8	**6**	212	16	28	5	3.34	44.75	57%	149.5	0.70
	8	133	18	28	3	5.15	38.47	63%	197.9	1.48
	9	123	18	30	4	4.73	31.89	62%	150.9	1.23

Table C.2: Indicators for the different departure and arrival clusters

	Arrival Cluster	Average vehicle kms	Average load handled by the facility	Average Payload of Truck	Average number of trips	Average Load handled in a trip	Average shipment distance in a trip	Utilisation Rate	Road tonne per km	Transport Efficiency
Cluster 1	**3**	69	6.82	27.92	4	2	19	24%	35	0.51
	7	79	15.24	40.01	7	2	12	38%	28	0.36
Cluster 2	**5**	91	6.94	29.55	4	2	20	24%	31	0.35
	2	94	5.62	22.97	20	0	5	24%	1	0.01
	3	133	7.20	30.23	4	2	30	24%	47	0.36
Cluster 3	**5**	119	3.53	23.11	4	1	31	15%	29	0.24
	2	94	10.04	32.25	5	2	18	31%	34	0.36
	3	151	9.82	20.73	10	1	15	47%	15	0.10
	4	160	18.51	22.80	5	4	32	81%	116	0.72
	6	57	4.22	23.72	5	1	12	18%	10	0.18
Cluster 4	**5**	162	22.08	39.25	3	7	54	56%	396	2.45
	3	70	6.63	30.50	5	1	14	22%	20	0.28
	4	286	2.56	41.82	3	1	95	6%	81	0.28
Cluster 5	**5**	157	24.98	37.49	8	3	21	67%	69	0.44
	2	47	14.18	32.23	4	4	12	44%	41	0.89
	3	126	8.76	30.32	4	2	30	29%	62	0.50
	6	292	16.90	22.67	8	2	39	75%	86	0.29
Cluster 6	**5**	105	11.20	32.41	4	3	28	35%	86	0.82
	3	100	12.03	22.80	4	3	24	53%	69	0.69
	6	87	12.92	19.65	18	1	5	66%	3	0.04
Cluster 7	**6**	134	9.26	40.40	6	2	22	23%	34	0.25
	3	118	11.87	29.07	5	3	26	41%	69	0.58
	7	130	15.65	39.95	9	2	14	39%	23	0.17
	6	164	11.36	32.45	9	1	18	35%	21	0.13
Cluster 8	**3**	123	7.04	32.20	4	2	32	22%	61	0.49
	8	161	10.71	23.15	3	3	49	46%	162	1.00

D
Truck Diary Database

The figure D.1, shows the details of the truck diary database provided by CBS which was used for this research.

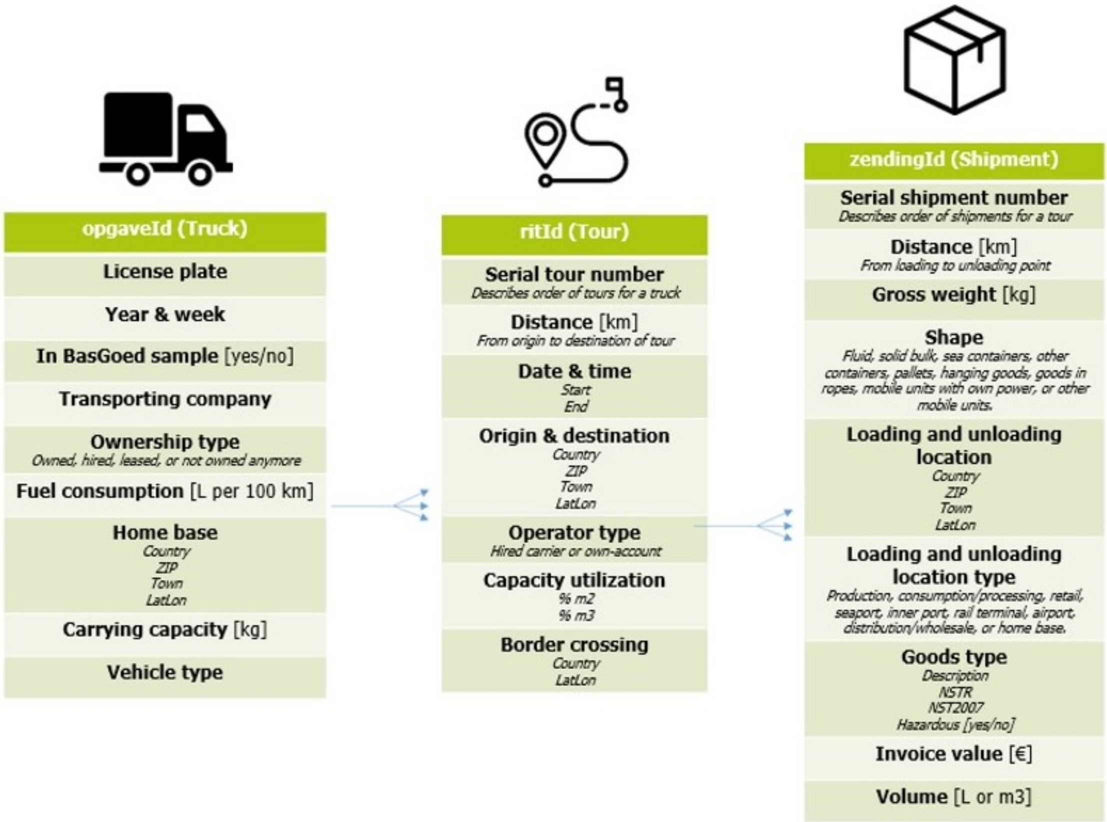

Figure D.1: Type of information available from CBS (Mohammed et al., 2020)

E

Scientific Paper

This appendix includes the scientific paper.

Exploring the transport efficiency for different types of logistics facilities

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ABSTRACT

The synergic effect between the spatial organisation and freight transport is crucial for transport planners to understand. It will help in improving freight transport planning. The absence of freight data has made such a study difficult. This research aims to understand the relation between spatial organisation and freight transportation by using the 1681 logistics facility database and the database of 2.65 million shipments of the Netherlands collected by CBS in 2015. The logistics facilities are categorised based on different spatial and logistics characteristics. The indicators of freight activity for the logistics facilities are studied, and the transport efficiencies are analysed subsequently. The analysis concluded on three main points. First, there are eight main types of logistics facilities in terms of spatial characteristics. Second, spatial characteristics have an impact on freight activity. Finally, the transport efficiency of the different logistics facilities can not be directly compared due to their objective and position in the supply chain.

1. Introduction

Around the mid-1980s there were discussions on the relationship between transport and spatial organisation. However, most of these studies relate to passenger transport. There has been little to no comparable research to understand the synergy between the spatial organisation and freight transport activity. The research of Allen et al. (2012) suggested that the logistics management of road freight transport operations was affected by the geographical location, in turn affecting the efficiency of road freight journey to, from, and within urban areas.

The spatial distribution of the logistics facilities was observed across many countries (Allen et al., 2012, Cidell, 2011, Sakai et al., 2015). The location of these logistics facilities is becoming an increasingly popular area of study not only for researchers but also for policy makers. The spatial organisation and logistics activities of the logistics facilities differ significantly.

The study of freight transport and the geography of logistics facilities remains relatively under-researched. Some researches addressed that the new logistics facilities are creating an increase in vehicle kilometres, leading to high carbon emissions. These studies, however, focus primarily on developments on the location or freight activity in the urban areas rather than the relationship between spatial structure and freight activity. This is due to the absence of freight data, as it requires shipment data of the different logistics facilities and their geographic characteristics. The research by Sakai et al. (2017) was an only study based on freight data. It focused on the efficiency of migrated logistics facilities using the Tokyo Metropolitan Freight Survey (TMFS) from 2003 and 2013. The analysis showed higher inefficiencies in outward migrated logistics facilities.

This study tries to capture the different logistics facilities in terms of spatial patterns in the Netherlands. It also examines the transport efficiency (road freight transport efficiency) for different spatial location of logistics facilities. Rijkswaterstaat (Directorate-General for Public Works and Water Management of the Netherlands) collected the database of the several logistics facilities within the Netherlands. A shipment database of the Netherlands similar to TMFS was collected by the Statistics Netherlands/ Centraal Bureau voor de Statitiek (CBS) in 2015 for the Netherlands which is also used in this study.

The rest of the paper is drafted as follows: the section 2 focuses on literature review. In section 3, the data and methodology of the analysis are discussed. Section 4 discusses the results of the analysis and findings subsequently. Finally, section 5 concludes the paper with a summary and the notable findings.

2. Literature Review

We performed a literature review to understand the spatial characteristics of logistics facilities that determine the location choice. It also helped in understanding the different indicators of transport efficiency.

2.1. Logistics Facility

In this section, first, we provide an overview of the changing location of the logistics facilities and the factors that influenced them over the past decade. Then we briefly discuss the categorisation of the logistics facilities.

2.1.1. Logistics Facility Location

The restructuring of the logistics facilities has resulted in a geographically fragmented supply chain, which implies geographically separated locations of suppliers, producers, distributors, and consumers (Rodrigue, 2008). The fragmentation is an attribute of the economy of scales in freight production and distribution systems. The freight distribution system has also seen a decrease in the transport costs due to advancement in transport technology and transportation infrastructure improvements. It has also eased the spatial reorganisation process (Hall et al., 2006). These factors also have facilitated the emphasises on reliability and high throughput of goods transportation (Hesse and Rodrigue, 2004). High throughput movement, rather than storage, has become the goal of logistics, and demand for centralised freight distribution system (Cidell, 2011, Rodrigue, 2008). The economy of scale has led to the facilities moving out of the urban centres causing a de-concentration of the logistics facilities. This phenomenon was first explained by Dablanc (2009) and is known as logistics sprawling.

Studies on the location of the logistics facilities and the factors of the movement were found during the literature study (Dablanc et al., 2014, Dablanc and Ross, 2012, Ewing et al., 2003, Woudsma et al., 2008). However, studies related to the movement of goods with different locations has not been carried out due to the insufficient data availability of freight flow.

Combination of many variables such as population density, land use, degree of centrality, and street accessibility has led to the changes in location (Ewing et al., 2003).

Woudsma et al. (2008) also tried to examine the relationship between urban structure development from a perspective of the logistics sector. Woudsma et al. (2008) found that accessibility and market conditions influences the location choice. Major highways and airports in the urban area are also crucial for the logistics development.

Wagner (2010) explained that the location of the logistics facility depends on factors such as centrality with the service areas, location of other facilities, or transfer depot, land availability, land price, access to infrastructure, and traffic volumes with the region. The location of these logistics facilities influences both private and public stakeholders. It impacts the truck traffic pattern as well as the well-being of individuals. For instance, logistics activities tend to create issues such as noise, air quality, safety, and congestion (Dablanc et al., 2014, Lindsey et al., 2014).

Some researchers found access to retail and facilities, population density, geographical area, distance to the urban centre, transport infrastructure, operational cost, economic impact, and environmental regulation to be the reason of changing location pattern (de Carvalho et al., 2019, Wiśnicki and Kujawski, 2019, Xydianou, 2019).

2.1.2. Categorisation of Logistics Facility

Differentiating logistics facilities is challenging as the function, industry sector, objective, location in the supply chain, the size varies. McKinnon (2009) tried to differentiated the logistics facilities based on the function of the facility. While some research works have attempted to introduce a difference between the logistics sector Heitz et al. (2019), Hesse and Rodrigue (2004) tried to distinguish based on the services provided by the logistics facilities. Wiegmans et al. (1999) classified the terminals based on surface area of the logistics facilities.

According to Raimbault et al. (2012), the facilities could also be distinguished by location: service terminal, distribution centres, and inland port. Higgins et al. (2012) tried to categorise the logistics facilities based on hierarchy: satellite terminal, distribution centre, and gateway terminal. Based on the location of the logistics facilities in the supply chain, the logistics facilities can be distinguished (Cui and Hertz, 2011).

This research tries to incorporate these characteristics while trying to differentiate the logistics facilities, since the location of the logistics facilities doesn't entirely depend on the urban structure (de Carvalho et al., 2019).

2.2. Freight Movement

The relation between the shipment pattern, location, and characteristics of facilities should be taken into consideration while analysing the effect of spatial distribution. Relationship between shipment patterns, location, and characteristics of facilities was recognised by Giuliano et al. (2016). The author also found that if the logistics activities were locally oriented, there would be more vehicle movements (vehicle kilometre travelled). But, if logistics activities were decentralised, there was no proof that it would result in high vehicle movements.

Aljohani and Thompson (2016) studied logistics sprawling and found a hike in freight flows due to increased frequency and low-weight deliveries. Sakai et al. (2017) study suggested that even though the average distance travelled had increased, the delivery efficiency would increase. The study also suggested the distance between the facility and the urban centre will have an impact on efficiency. The study excluded several factors such as congestion effects, vehicle routing, and type of vehicle. This research was one of a kind due to the extensive data collected in the Tokyo Metropolitan Area (TMA).

2.3. Transport Efficiency

Köksal and Aksu (2007) points out that the efficiency of the logistics sector is a significant issue in global trade. Logistics has an impact on the manufacturing and organisation's performance. Logistics influences the manufacturer's ability to satisfy customers and overall performance (Tracey, 1998). The Supply Chain Management (SCM) practices and logistics capabilities lead to an improvement in the strategies, which can result in an overall improvement in a firm's performance (Sezhiyan et al., 2011).

Researchers have been studying the elements of the supply chain to increase functioning efficiency. However, the change in the performance included parameters of the transportation process, which is not yet fully discovered (Kush et al., 2018, Tracey, 2004). Companies desire to reach economy of scale by consolidating, postponement, and transshipment of freight. The size of the shipment oscillates due to the external impacts and customer demand. Either the vehicles travel in Full truckload (FTL) or Less-than-truckload (LTL) (Stadtler et al., 2015). The study of Prasad and Sounderpandian (2003) showcased the different characteristics of transportation that influence the supply chain and location planning. The transportation cost, accessibility, shipping patterns, warehouse locations, routing constraints, the ratio of infra to inter-company traffic, carrier qualifications, intermodal systems, and services of third party freight forwards are some of the transportation characteristics have an influence over supply chain.

Transport planning affects inventory planning. The production rate, demand rate, maximum load per shipment, transport lead timed, cycle time, shipment quantity, inventory holding cost, and the cost of the shipment are the various variables that help in the planning (Stadtler et al., 2015). Ivanov et al. (2019), Kush et al. (2018) found that the load on the vehicle, vehicle utilisation, distance travelled, trip duration, and empty kilometres are useful indicators to understand the transport efficiency for different types of logistics facilities.

2.4. Aim of this Research

While the movement of logistics facilities have been studied (Davydenko and Tavasszy, 2013, Wagner, 2010). An analysis is essential to understand the relationship between the different location and transport performance. The new location due to logistics sprawling of the logistics facilities itself may not necessarily be a problem. As such, it is critical to understand how the different logistics facilities perform. This study tries to address these gaps by analysing the transport efficiency of the different logistics facilities.

3. Methodology

Section 3.1 describes the different data used in this research and the steps taken in the analysis subsequently. Section 3.2 discusses the differentiation of the urban centre. Section 3.3 describes the method used for segregating the logistics facilities subsequently, and finally, section 3.4 shows a framework to understand transport efficiency and the various indicators.

3.1. Database

This research included three types of databases. First, the geospatial data of the Netherlands (section 3.1.1). Second, the logistics facility database (section 3.1.2). Third, the shipment database (section 3.1.3).

3.1.1. Geospatial Data of the Netherlands

In 2015, Rijkswaterstaat collected information on the population demographics and regional statistics of land use for the Netherlands. The database discusses all the information on district-level data. It includes the population, land area, water availability, geography of the district, road network, and some other information. This database helped in defining the urban centres and finding the distances to various locations for the analysis.

3.1.2. Logistics Facility Database

The logistics facility database included data of 1681 distribution centres in the Netherlands from 1835 till 2016. This database was collected by Rijkswaterstaat. Information on the location (6-digit accuracy postcode), surface area, and industry sector (SBI Code) was the information available. The sizes of these logistics facilities varied from 5,000 m^2 to 100,000 m^2. Figure 1 shows the frequency of different kinds of the industry sector in the Netherlands.

3.1.3. Shipment Database

Microdata of shipment information was collected by CBS was used in this research. The data was collected by obligatory survey for transport companies to report on their vehicle hence allowing a high volume of data with high density. CBS used an innovative XML-interface to automatically extract inputs from companies' transport management systems (TMS). In total, CBS extracted 2.65 million shipment data from the year 2015, which contains rich information regarding loading and unloading locations, commodities carried, and vehicles used (Mohammed et al., 2020). Mohammed et al. (2020) also linked the data between the location of the loading/unloading of trucks and firm activities, making it easier to study the transport efficiency of the different logistics facilities.

3.2. Defining Urban Centres

In a polycentric country like the Netherlands it is important to determine the Urban Centre (UC). The UC was defined based on the household density of 2015 for the different neighbourhoods. The most used definition of urban centres is municipalities with more than 2,500 households per kilometre square. Dubie et al. (2018), Strale (2019), Xydianou (2019) used similar methodologies. The Netherlands' urban area was divided into 5 different regions based on the population density (Table 1). The areas with the highest population densities are considered as urban centres.

Table 1
Different level of urbanisation

Household per kilometre square	Urbanisation Level
More or equal to 2,500	Urban Centre
1,500 – 2,500	Sub-Urban Area
1,000 – 1,500	Peripheral Cities
500 – 1,000	Rural Areas
Less than 500	Remote Location

The number of households in each neighboured for 2015 with the land area were used to differentiate the urban centre. Table 2 shows the share of level of urbanisation in the Netherlands.

Table 2
Percentage share of different level of urbanisation

Urbanisation Level	Percentage Share
Urban Centre	23%
Sub-Urban Area	5%
Peripheral Cities	6%
Rural Areas	13%
Remote Location	53%

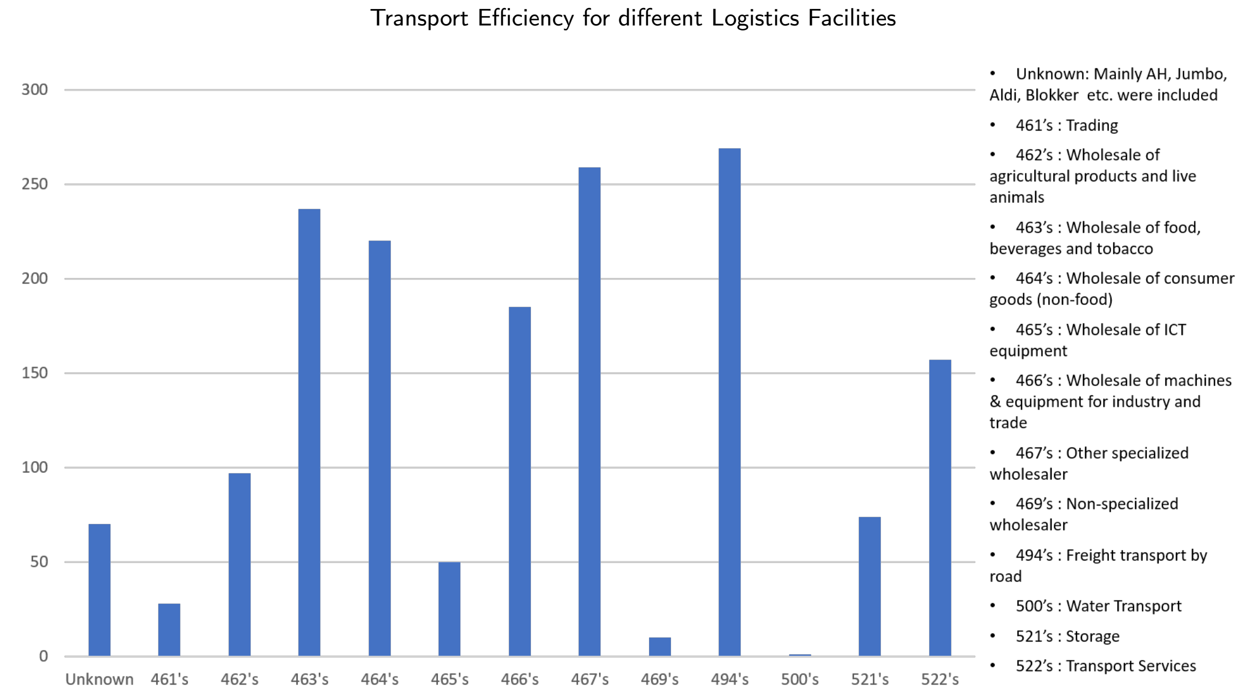

Figure 1: Frequency of different industry sector

3.3. Cluster Analysis

We quantified and described the topology of logistics facilities in the Netherlands based on spatial and logistic indicators. Categorising the logistics facility was a two step process. First, the Principal Component Analysis (PCA) was carried out. It relies on the fact that the variables have a considerable variance and are significantly interrelated. PCA is a statistical method that dimensionally reduces the initial database by identifying principal components uncorrelated to each other (Jaadi, 2019).

Succeeding PCA was the Hierarchical Clustering Analysis (HCA). It dealt with the grouping of logistics facilities based on the components extracted from PCA. HCA provides a realised cluster. The objective was to segregate the facilities homogeneously internally and with each other simultaneously. Researches have seen that there is a relation between the logistics facilities' location and urban structure. Chhetri et al. (2014), Cidell (2010), Rodrigue (2020) saw that there is a preference for a specific location.

3.4. Framework for analysing Transport Efficiency

An analytical model to calculate transport efficiency was created by Mckinnon (2007), later adapted by Allen et al. (2012) to calculate the efficiency of the on-road vehicles. The ratio of tonne-kilometres to vehicle kilometres performed reflects the road freight transport efficiency. Higher numbers indicate more efficient operations. Adaptation of the framework by Allen et al. (2012), was used for the analysis of transport efficiency was done in this research (figure 2).

The conceptual framework presented in figure 2 explains the relation between the different aspects of this study. The framework uses the shipment weight and trip kilometres to find the road tonne-km of a trip. The ratio of tonne-kilometres to vehicle kilometres performed by vehicle reflects the efficiency of vehicle where higher numbers indicate more efficient operations (Allen et al., 2012). The road tonne-km divided by the total vehicle kilometres also indicates the vehicle carrying capacity, payload utilisation rate and empty kilometres. If a trip in the tour travels with no shipment/load, then the transport efficiency of that leg would be 0. The in-

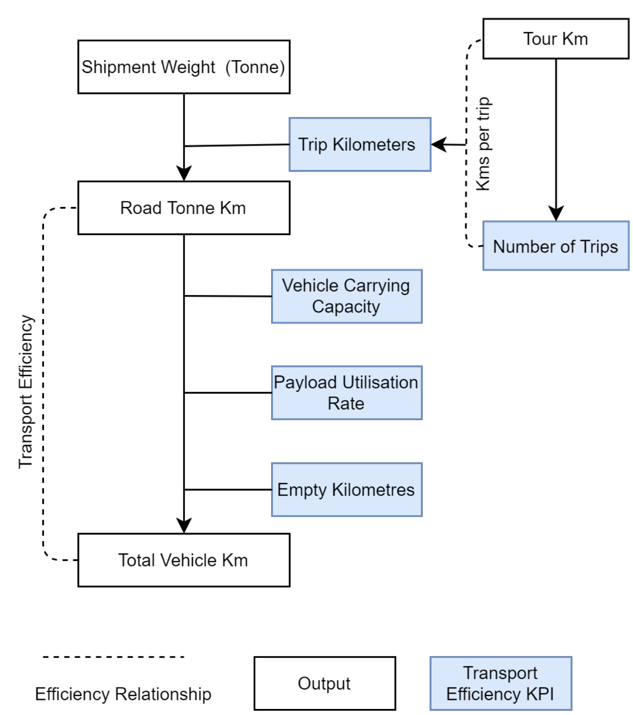

Figure 2: Analytical framework for Transport Efficiency. Source: adapted from Allen et al. (2012), Mckinnon (2007)

Table 3
Characteristics for different topology of logistics facilities

Cluster	Surface Area (m^2)	Construction Year	Distance to UC (km)	Distance to TT (km)	Distance to Port (km)	Distance to Ramp (km)	HHKm2	Land	Water
1	11026	1950	0.46	463	25.59	0.29	19957	124	38
2	12947	1980	0.78	455	24.57	0.25	13676	144	5
3	8529	1990	1.67	463	33.09	0.29	1242	237	8
4	9460	1985	1.70	456	31.07	0.47	2824	711	52
5	20335	1995	1.64	458	31.75	0.40	726	271	14
6	41979	1995	1.76	442	29.89	0.49	918	347	20
7	11474	1990	2.13	568	116.12	0.34	2184	381	17
8	12086	1995	2.66	461	11.33	0.69	556	2179	454

dicators, empty kilometres, and the payload utilisation rate would also reflect the same.

The above-explained method was to be performed for each trip of the tour. Since the database didn't give any information on the individual trip leg. Average distance was calculated by dividing total tour length with the minimum number of trips. This assumption calculates transport efficiency a little different than calculating for each trip.

The minimum number of trips was calculated by adding the number of departure location of the vehicle with the arrival location of the vehicle and the total unique logistics facilities the vehicle visits subtracted by 1.

4. Results

Section 4.1 first presents the different topologies of the logistics facility and visualises the spatial characteristics of the facilities with respect to all the logistics facilities. Section 4.2 discusses the transport efficiency subsequently.

4.1. Logistics Facilities topology

This section discusses the topology of logistics facilities. Facilities which resulted from the cluster analysis can be seen in table 3 with the characteristics of each topology.

The clusters were named based on the size of the logistics facility and the location. Buck Consultants Internationals (2020) looked into the XXL logistics facilities and also identified facilities with surface area more than 40,000 m^2 as XXL size. Hence, the table 4 explains the naming for differnet sizes of the logistics facilities.

Table 4
Naming of Logistics Facilities

Name of the Logistics Facilities	Size of Logistics Facilities
Small Facilities	(5,000 - 10,000 m^2)
Medium Facilities	(10,000 - 20,000 m^2)
Large Facilities	(20,000 - 30,000 m^2)
XL Facilities	(30,000 - 40,000 m^2)
XXL Facilities	(40,000 - 50,000 m^2)
XXXL Facilities	(50,000 - 60,000 m^2)

The name of the locations were segregated into urban centres, sub-urban areas, peripheral cities, and remote locations. The urban centres are highly dense areas, and the distance to UC is less than 1 km. Sub-urban areas are the areas just outside the UC. These areas are a little less populated compared to the urban centres and are at a distance of 1 to 2 kms to the UC. The extended cities are similar to sub-urban areas with a lesser population density. Remote locations are 2 kms away from the UC. Figure 3, shows the different locations.

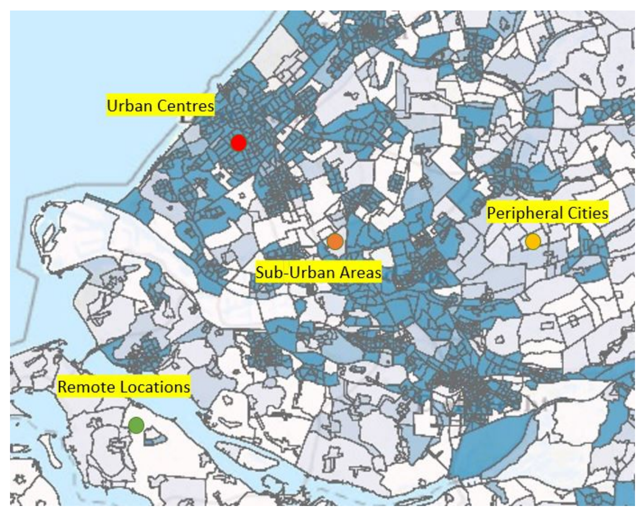

Figure 3: Example of Urban Centre, Sub-Urban Areas, Peripheral Cities & Remote Locations

Therefore. the 8 clusters found were named as follows:

1. Old Medium Facilities in Urban Centre (Figure 4)
2. Medium Facilities in Urban Centre (Figure 5)
3. Small Facilities in Sub-Urban Areas (constructed during compact city policy) (Figure 6)
4. Small facilities in Sub-Urban Areas (constructed during compact urbanisation policy) (Figure 7)
5. Large Facilities in Peripheral Cities (Figure 8)
6. XXL Facilities in Peripheral Cities (Figure 10)
7. Medium Facilities in Remote Locations, away from hubs (Figure 10)
8. Medium Facilities in Remote Locations, close to hubs (Figure 11)

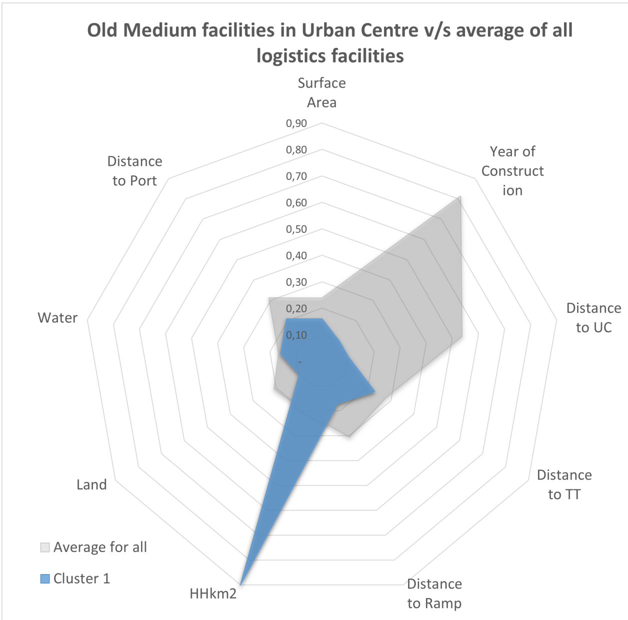

Figure 4: Spatial characteristics of cluster 1 in comparison to the average of all the logistics facilities

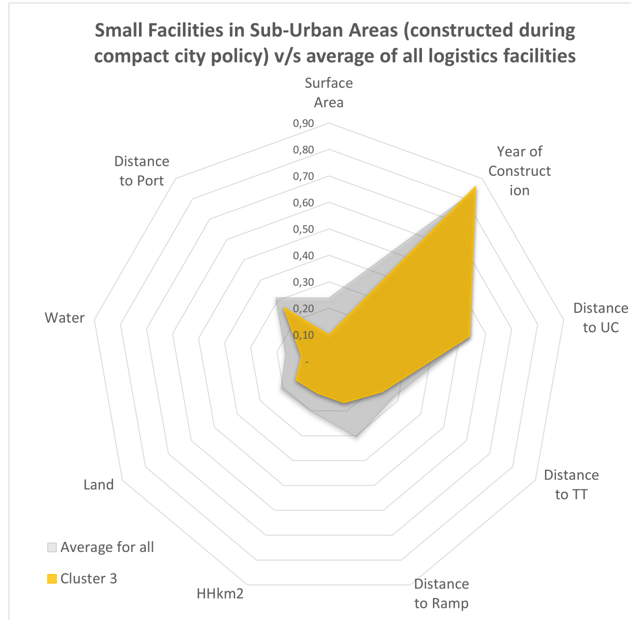

Figure 6: Spatial characteristics of cluster 3 in comparison to the average of all the logistics facilities

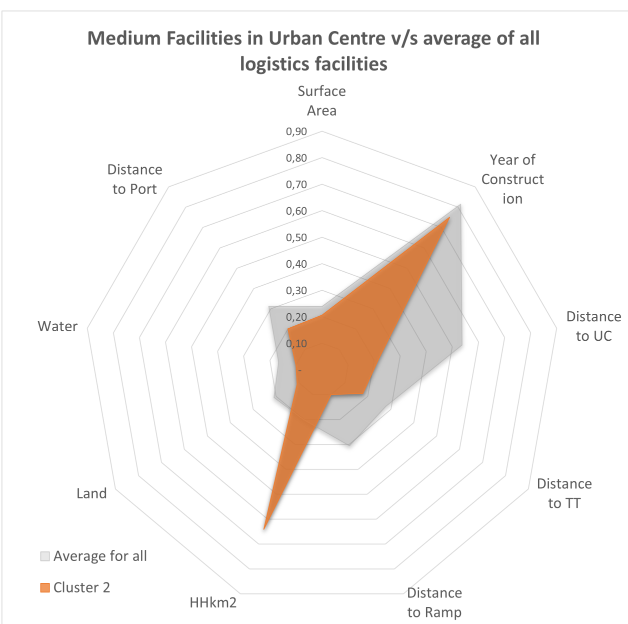

Figure 5: Spatial characteristics of cluster 2 in comparison to the average of all the logistics facilities

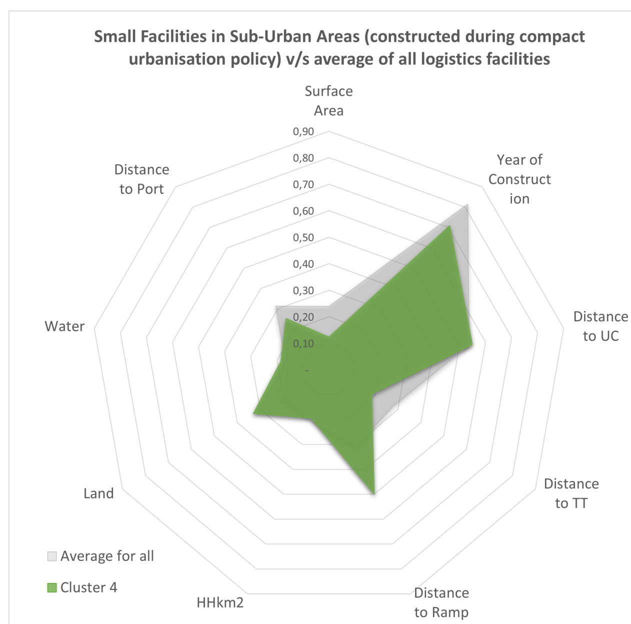

Figure 7: Spatial characteristics of cluster 4 in comparison to the average of all the logistics facilities

4.2. Transport Efficiency of the logistics facilities

In this section, we will examine transport efficiency. It should be noted that all the variables to understand transport efficiency for the logistics facilities can be found in table 5.

4.2.1. Vehicle kilometres

The table 5 shows the vehicle kilometres for different types of logistics facilities in 2015. The data showed that the medium facility in urban centres and medium facilities in remote locations which are both close and away from hubs generates the least vehicle kilometres. It is likely due to direct shipments from the remote locations to the destination and last-mile delivery in urban centres. Meanwhile, small facilities in sub-urban areas (constructed during compact city and compact urbanisation policy) generated more vehicle kilometres than others. The reason could be due to being in the middle of the supply chain, it facilitates the upstream and downstream supply chain.

The freight journey of the filled vehicle kilometres is average from large and XXL facilities peripheral cities and also

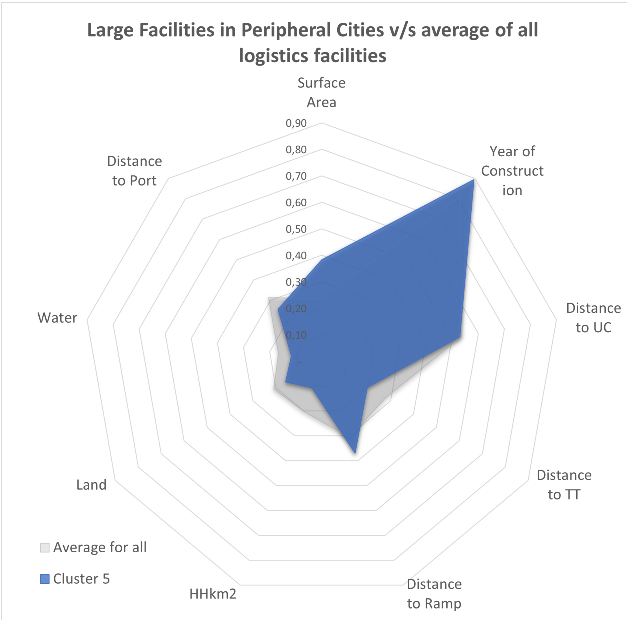

Figure 8: Spatial characteristics of cluster 5 in comparison to the average of all the logistics facilities

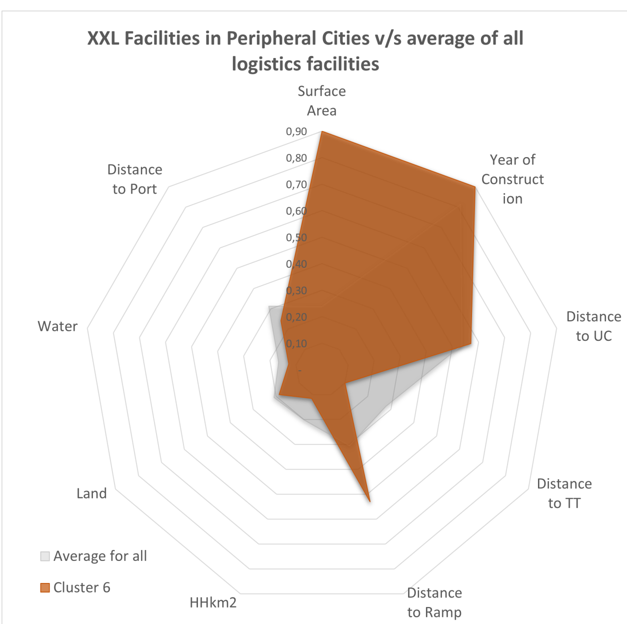

Figure 9: Spatial characteristics of cluster 6 in comparison to the average of all the logistics facilities

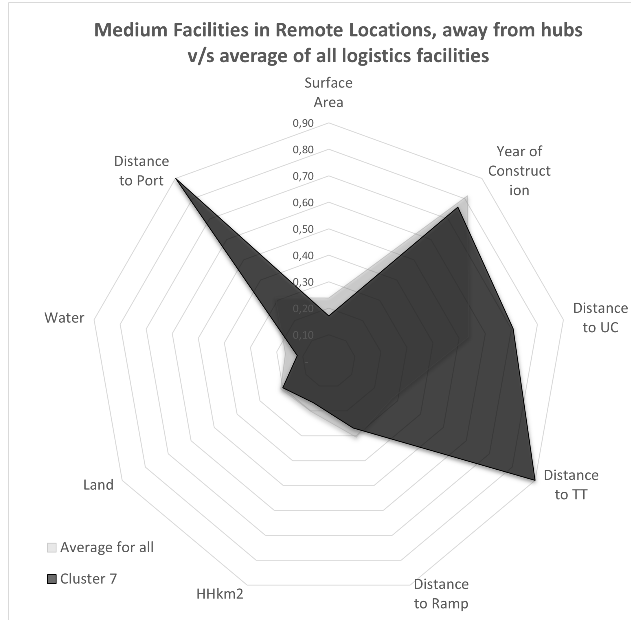

Figure 10: Spatial characteristics of cluster 7 in comparison to the average of all the logistics facilities

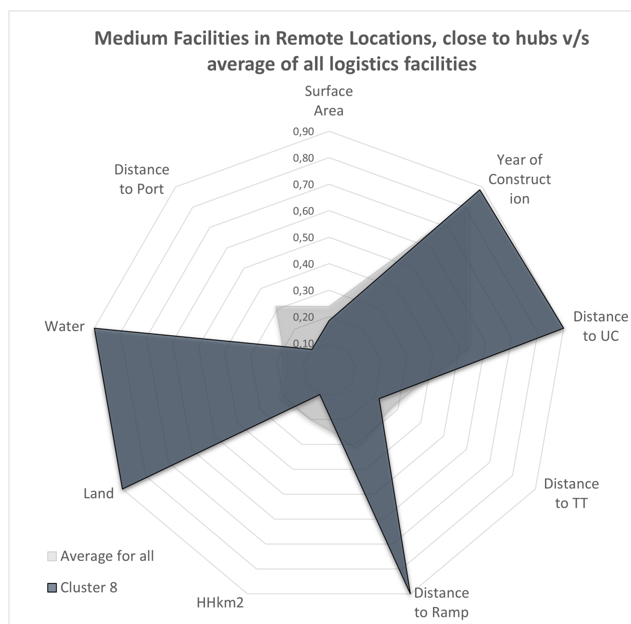

Figure 11: Spatial characteristics of cluster 8 in comparison to the average of all the logistics facilities

for old medium facilities in UC. It could likely be because these facilities have specific tasks to perform.

4.2.2. Load handled by logistics facilities

The relationship between the load handled by a facility was seen to have proportional relationship to the distance from UC. The facilities located in the UC carry lower loads compared to the facilities in the remote location. This is due to the area these facilities serve. The pick up/delivery points for remote location is higher compared to the urban centre.

However, one of the facilities performed differently. The small facilities in the sub-urban areas (constructed during compact urbanisation) were found to have a high load handling. One such reason found was that these facilities carry a mix of product types. These facilities loaded shipments vary from agricultural products, other food, crude minerals, construction materials, chemical products, vehicles, and machinery (table 6).

Table 5
Transport Efficiency for different topology of logistics facilities

Clusters	Avg. vehicle kms (A) (kms)	Avg. load handled by a facility (B) (tonnes)	Avg. empty kms (C) (kms)	Avg. payload of Truck (D) (tonnes)	Avg. number of Trips (E) (nos.)	Avg. load handled in a trip (F = B/E) (tonnes)	Avg. shipment distance in a trip (G = A/E) (kms)	Utilisation Rate (H = B/D*100)	Avg. road tonne km (I = F*G) (tonne-km)	Transport Efficiency (J= I/A)
1: Old Medium Facilities in UC	159	8	60	30	4	1.93	37.54	27%	72.38	0.46
2: Medium Facilities in UC	120	7	65	25	15	0.45	8.09	27%	3.66	0.03
3: Small Facilities in sub-urban area (compact city policy)	193	9	300	23	6	1.53	31.12	41%	47.47	0.25
4: Small Facilities in sub-urban area (compact urbanisation policy)	190	17	125	27	4	4.01	46.07	60%	184.78	0.97
5: Large Facilities in Peripheral cities	168	12	60	30	4	2.84	38.45	41%	109.24	0.65
6: XXL Facilities in Peripheral cities	155	14	65	21	6	2.27	25.03	65%	56.76	0.37
7: Medium Facilities in remote Locations, away from hubs	143	16	90	31	9	1.82	16.05	53%	29.28	0.20
8: Medium Facilities in remote Locations, closer to hubs	143	16	100	30	3	4.74	41.26	54%	195.76	1.37

Table 6
Percentage share of product type in each cluster

	Agricultural product and live animals	Other food products and animal feed	Solid mineral fuels	Petroleum oils and petroleum products	Ores, metal waste roasted iron molars	Iron, steel and non-ferrous metals	Crude minerals; construction materials	Chemical products	Vehicles, machines and other goods (general cargo)
Cluster 1	63%	5%	0%	0%	0%	0%	0%	10%	21%
Cluster 2	4%	6%	0%	0%	0%	0%	0%	6%	82%
Cluster 3	28%	10%	0%	0%	0%	0%	1%	37%	23%
Cluster 4	32%	13%	0%	0%	0%	0%	4%	25%	26%
Cluster 5	0%	13%	0%	0%	0%	1%	9%	33%	45%
Cluster 6	29%	15%	0%	0%	0%	0%	2%	21%	34%
Cluster 7	39%	15%	0%	0%	0%	0%	1%	17%	27%
Cluster 8	11%	8%	0%	0%	0%	0%	23%	32%	26%

4.2.3. Empty Kilometres

We could see that the sub-urban areas and the remote locations make the most empty kms. The reason for the empty km for sub-urban locations is that these facilities could be at the centre of the supply chain hence making empty tours. While for remote locations the distance travelled by the load vehicle is higher. But when travelling back to these locations is empty as there could be a low number of consumers at these locations. Both these facility locations transport construction materials leading to an increase in the vehicle kilometres.

The facilities in UC and peripheral cities are seen to make lesser empty kms. Due to the complex tours in UC, there is very little possibility of the vehicle travelling empty. The vehicles leaving from peripheral cities travel with chemical products, vehicles, and machines (table 6). The movement of these goods is lower in comparison to consumer products. Therefore, it is possible that low value could be due to the period of the data collection. As the shipment data was collected for only 4 weeks, there is a high probability that during those weeks the transportation of these materials was low.

4.2.4. Number of trips

The number of trips found for each type of logistics facilities can be seen the column E of table 5. The medium facilities in the UC make 15 trips in a tour. This is understandable as the logistics facilities in the urban centre are meant for last-mile distribution to the customers. Therefore, it makes a complex tour. The medium facility in remote locations, close to hubs makes the least number of trips. The reason for this was found to be that, these are in the port/airport region therefore consolidation is easier at these points thus making the least number of trips in a tour.

4.2.5. Utilisation Rate

The utilisation found for these different logistics facilities is low. This is due to fact that only the load carried and payload of the vehicle was studied. The study of volume utilisation could help in better understanding the utilisation rate since RDW has a restriction on the weight and volume of the vehicle. The RDW is the organisation that takes care of the registration of motorised vehicles and driving licenses in the Netherlands.

However, we could see that the facilities in UC perform the lowest in utilisation rate. The small facilities in sub-urban areas (constructed during compact urbanisation policy) and XXL facilities in peripheral cities perform well. In a similar line of reasoning as the number of trips, the facilities in UC have a complex touring making it difficult for them to reach optimal utilisation rate. The reason for a high utilisation rate for the small facilities in sub-urban areas and XXL facilities in peripheral cities could be due to the serving location. It was seen that these facilities have a similar distance to UC and transshipment terminal (TT) making the transportation behaviour very similar in terms of utilisation rate.

4.2.6. Transport efficiency

Figure 2 shows the relationship between the indicators and output. Transport efficiency is the ratio of tonne-kms to vehicle kilometres performed by the vehicle. The transport efficiency for these logistics facilities varies from 0.03 for medium facilities in UC to 1.37 (Medium facilities in remote locations, close to hubs). The low transport efficiencies in some of the logistics facilities could be seen due to a shorter trip length or the empty running.

The clusters with high transport efficiency are cluster 4 (small facilities in sub-urban areas (compact urbanisation policy)) and cluster 8 (medium facility is remote locations, closer to internal hubs). These facilities perform quite similarly over all indicators. However, the reason behind the similar performance is still not clear, apart from the fact that these facilities carry a similar type of products.

5. Conclusion

This study used extensive freight shipment data to investigate the freight activity of the different types of logistics facilities. The findings suggest that geographical and spatial characteristics influence freight activity. Regardless of the richness of the data, it also has limitation. The lack of vehicle routing data (trip information) would capture the efficiency of individual trips to different geographic locations. Despite these limitations, the analysis shed light on the relationship between the location of the logistics facilities and shipment patterns. Firstly, the analysis of distinguishing logistics facilities showed that categorising the facilities based on spatial and on geographical locations could help in understanding the freight planning of the companies better. The study considered the distance to the Urban centre, Transshipment Terminal, ports, airports, ramps (infrastructure), land availability, water availability, household per kilometre square, construction year, and surface area of the facility. Adding a few logistics characteristics such as market availability, the objective of the logistics facility, and position in the supply chain could improve the categorisation of the logistics facilities.

Secondly, the average load handled in the trips was lowest in urban centres, followed by sub-urban areas, peripheral cities, and highest in remote locations. The average shipment distance was seen the lowest in the urban centre, followed by peripheral cities, remote locations, and then sub-urban locations. The average empty kilometre was also seen to have a similar variation as average shipment distance. The comparison between the old and new logistics facilities in the urban, sub-urban areas, peripheral cities, and remote locations showed that the older facilities were more efficient.

Finally, the transport efficiency analysis, showed that the combination of the vehicle kilometres in a trip, load handled in a trip and empty kilometres is important. These factors influence transport efficiency. However, studying these different types of logistics facilities, led to an understanding that the comparison of transport efficiency is difficult. This is due to the significant difference in terms of their functionality, the kind of goods that need to be transported, and their position in the supply chain. However, a comparison of the facilities within the clusters can be done to understand their behaviour.

The freight transport factors are only a small part of the supply chain of a product. The complexity results in a potentially far greater set of factors that influence freight transport activity.

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