UNIVERSIDAD
NACIONAL
DE COLOMBIA

The Role of Truck Stops in Urban Freight Planning Using GPS Data

Diana Isabel Alarcón Bohada, C.E

Universidad Nacional de Colombia
Facultad de Minas, Departamento de Ingeniería Civil
Medellín, Colombia
2024

The Role of Truck Stops in Urban Freight Planning Using GPS Data

Diana Isabel Alarcón Bohada, C.E

Tesis presentada como requisito parcial para optar al título de:

Maestría en Ingeniería – Infraestructura y Sistemas de Transporte

Director:

Carlos Alberto Gonzalez-Calderon, PhD.

Codirector:

Iván Darío Cárdenas Barbosa, PhD.
John Jairo Posada Henao, PhD.

Línea de Investigación:

Transporte de Carga

Grupo de Investigación:

Semillero de Transporte de Carga y Logística (FTL)

Universidad Nacional de Colombia

Facultad de Minas, Departamento de Ingeniería Civil

Medellín, Colombia

2024

Dedicatoria

A mi madre, por ser mi fuerza inquebrantable y por creer en mí incluso cuando mis sueños parecían imposibles.

A mi abuelita, por enseñarme a nunca dejar de luchar incansablemente por los propósitos. Q.E.P.D

A mi familia, porque, aunque la distancia nos separe, siempre celebran mis logros como si estuvieran a mi lado.

A mis amigos, por ser siempre un apoyo incondicional. Y, especialmente, a mi mejor amiga, quien ha sido como una hermana durante 15 años, alentándome en los momentos más difíciles y regalándome el amor más puro a través de mi sobrino.

A mis profesores, por guiarme no solo en el camino hacia ser una profesional competente, sino también por inspirarme a ser una mujer fuerte y llena de poder.

Declaración de obra original

Yo declaro lo siguiente:

He leído el Acuerdo 035 de 2003 del Consejo Académico de la Universidad Nacional. «Reglamento sobre propiedad intelectual» y la Normatividad Nacional relacionada al respeto de los derechos de autor. Esta disertación representa mi trabajo original, excepto donde he reconocido las ideas, las palabras, o materiales de otros autores.

Cuando se han presentado ideas o palabras de otros autores en esta disertación, he realizado su respectivo reconocimiento aplicando correctamente los esquemas de citas y referencias bibliográficas en el estilo requerido.

He obtenido el permiso del autor o editor para incluir cualquier material con derechos de autor (por ejemplo, tablas, figuras, instrumentos de encuesta o grandes porciones de texto).

Por último, he sometido esta disertación a la herramienta de integridad académica, definida por la universidad.

Diana Isabel Alarcón Bohada

Nombre

Fecha 22/10/2024

Agradecimientos

Quiero expresar mis agradecimientos a mis profesores Carlos A. Gonzalez-Calderon y John Jairo Posada-Henao de la Universidad Nacional de Colombia por ayudarme a explotar mis capacidades, por impulsarme a dar aún más de lo que creía poder dar, por abrir mi mente al mundo de la investigación, por darme la oportunidad de trabajar hombro a hombro en diferentes proyectos que me ayudaron a incrementar los conocimientos en esta área, por apoyarme en cada proceso para poder desarrollar y culminar este gran proyecto

Quiero agradecer también al profesor Iván Darío Cárdenas-Barbosa de la Universidad Tecnológica de Chalmers en Suecia quien desde el primer momento estuvo dispuesto a trabajar conmigo desde la distancia, quien me dio la oportunidad de aprender de su valiosa experiencia y quien me ha aportado significativamente para abrir mi mente ante otras perspectivas del conocimiento.

Quiero agradecer al profesor Joris Beckers de la Universidad de Amberes en Bélgica quien me abrió las puertas de esta universidad para terminar mi trabajo y a su vez compartirlo con los tomadores de decisiones de cada ciudad para que fuera visible y aplicable. A su vez me dio su asesoría y su apoyo en el proceso final de esta investigación.

A la Universidad Nacional de Colombia porque ha sido mi segunda casa en estos últimos 10 años, me formó como ingeniera civil, como especialista en vías y transporte y ahora como Magister. También porque me apoyo económicamente para poder continuar con mis estudios de posgrado y poder difundir mis investigaciones en otras ciudades y países.

Al grupo de investigación FTL – Freight Transport and Logistics Research Group por inculcarme el amor a la investigación, pero sobre todo por darme grandes amigos para toda la vida.

Resumen

El papel de las paradas de camiones en la planificación del transporte urbano utilizando datos GPS.

El transporte de mercancías es fundamental para la economía de un país, pero también genera externalidades negativas, como la congestión causada por paradas de camiones en aceras y carreteras. Para abordar estos problemas y mejorar la planificación, es necesario contar con datos precisos y accesibles. A pesar de los avances en tecnologías como el Sistema de Posicionamiento Global (GPS), que permite el seguimiento en tiempo real de la ubicación, velocidad y tiempo de los vehículos, muchos estudios previos han basado sus análisis en datos limitados o muestras pequeñas. Este estudio aborda esa brecha mediante el uso de una base de datos completa proporcionada por el sistema de cobro por circulación del gobierno, que incluye información detallada sobre todos los camiones que ingresan a las ciudades de Bélgica. Además, se incorporan datos actualizados de zonas residenciales y comerciales, lo que permite desarrollar una metodología robusta para analizar la duración, ubicación y tipo de paradas de camiones en áreas urbanas. Al examinar la correlación entre estos factores, se identifican los elementos que contribuyen a conflictos con peatones y otros vehículos. Los hallazgos no solo ofrecen soluciones prácticas para mejorar la logística urbana y reducir los impactos negativos, sino que también aportan directrices para políticas públicas que optimicen la gestión del transporte de mercancías en entornos urbanos.

Palabras clave: Paradas de camiones, Planificación de Carga, Rutas GPS de camiones.

Abstract

The Role of Truck Stops in Urban Freight Planning Using GPS Data

Freight transport is essential for a country's economy, but it also creates negative externalities, such as congestion caused by truck stops that block sidewalks and roads. To address these problems and improve planning, accurate and accessible data is necessary. Although technologies like the Global Positioning System (GPS) allow real-time tracking of vehicle location, speed, and time, many previous studies have used limited data or small samples. This study addresses that gap using a complete database provided by the government’s circulation fee system, which includes detailed information on all trucks entering cities in Belgium. Additionally, updated data on residential and commercial areas is included, allowing the development of a solid methodology to analyze the duration, location, and type of truck stops in urban areas. The study identifies elements contributing to conflicts with pedestrians and other vehicles by examining the correlation between these factors. The findings offer practical solutions to improve urban logistics and reduce negative impacts and provide guidelines for public policies that can optimize freight transport management in urban environments.

Keywords: Truck stops, Freight planning, GPS truck routes.

Content

List of Figures

Pág.

List of Tables

List of symbols and abbreviations

Symbols with Latin letters

Symbol	Term	Und SI	Definition
d_{time}	Dwell time	seg	Stop time set for the threshold
$dx_{(k)}$	Distance	m	Distance value for each GPS point that corresponds to a truck.
i	Position	1	Position of GPS points within the stipulated range.
L_x	Trajectory of a truck or unique ID.	1	Path for x number of trucks
Lx_k	Trajectory of a truck or unique ID	1	Trajectory for an x number of trucks and each trajectory contains k GPS points
R	Earth Radius	Km	Equation 3-2
S	Flag for identification of stops	1	Within the algorithm, assign zero or one as appropriate. See Figure 3-1
tx_k	Time	seg	Time value for each GPS point that corresponds to a truck or trajectory. See Equation 3-1
vx_k	Speed	$\frac{km}{h}$	Recalculated speed for each pair of points for each truck or trajectory. See Equation 3-4
$vx_{k(i)}$	Speed at position i	$\frac{km}{h}$	

Symbols with Greek letters

Symbol	Term	Und SI	Definition
δ	Speed	$\frac{\text{km}}{h}$	Threshold set for near-zero speed
$\Delta\lambda$	Longitude	radians	Difference between the longitudes of two points GPS-
$\Delta\sigma$	Great circle Equation		See Equation 3-3
Δt	Time difference	seg	Change over time
Δx	Spatial difference	radians	Change in spatial coordinates
ϕ_k	latitudes	radians	Latitudes of K points GPS. See Equation 3-3.

Abbreviatures

Abbreviature	Term
EU	European Union
GPS	Global Positioning System
OBU	On Board Unit

1. Introduction

Freight transport is a vital part of every country's economy. During the COVID-19 pandemic, a global crisis happened, but since then, the economy has been growing again. The world's Gross Domestic Product (GDP) grew by 3.4% between 2021 and 2022, with 2.7% growth in advanced economies and 4% in developing economies. Global trade also increased by 2.3% (International Transport Forum, 2023)

One of the sectors that has grown the most is road freight transport. Its value is expected to increase from $98.948 billion USD in 2023 to $105.960 billion USD in 2024, with a growth rate of 7.1%. The market will likely keep growing at 6.5% per year in the future (The Bussiness Research Company, 2024). In the European Union (EU), road transport made up 24.6% of all freight transport in 2021 (Statistical Office of the European Union - Eurostat, 2024). This shows how vital road freight transport is and highlights the challenges its continuous growth brings.

Freight transport is mainly connected to cities because they are the main places where goods are produced and consumed. Cities are the heart of the economy, where many products are made, distributed, and sold. Therefore, the efficiency of road freight transport in these urban areas is essential to ensure the smooth movement of goods. These cities are putting much pressure on freight systems because of their high demand. That's why improving freight transport efficiency in these areas is essential to maintain the economy and improve the quality of life. Many authors highlight this relationship. For example, Cui et al., (2015) said that "efficient freight transport is essential for the proper functioning of urban transport networks and also contributes to the development of industry and the economy." Ortuzar & Willumsem, (2011) also wrote, "A percentage of goods arrive in urban areas for distribution; therefore, it is essential to gather all available information to develop a plan for efficient and balanced freight transport." Urban logistics, which aims to optimize deliveries in cities, can reduce costs and environmental impact while improving the quality of life.

However, it is also essential to focus on the negative impacts of urban freight transport, like pollution, accidents, congestion, noise, and emissions (Cui et al., 2015; Sakai et al., 2020; Z. Yang et al., 2023). To address these problems, it is necessary to integrate freight transport with urban planning.

One of the biggest challenges in urban freight transport research is collecting reliable data. Good mobility data is needed for urban planning but getting accurate and affordable information can be challenging. Researchers often have to use costly data or models based on assumptions. Some cities have cameras and sensors to collect data, but much is outdated or ignored. On top of that, human behavior can be unpredictable, making studies even harder.

Fortunately, GPS technology has helped solve this problem. GPS data is now recognized as a valuable tool that helps companies understand their transport operations better while taking into account environmental and cost factors (Bø & Mjøsund, 2022)

All of this leads us to the research question:
How can GPS data from truck routes in cities be used to improve freight transport planning and make logistics processes more efficient in commercial areas?

This research has several objectives. First, it will show how GPS data from On-Board Units can be analyzed. Second, it will map truck routes and identify stops in two cities in Belgium using a method adapted to the available information. Then, it will examine the relationships between stop locations and durations, the origin and destination of trips, and the number of stops per truck. Finally, this will help to create alternatives to improve city planning and logistics processes. This research is innovative because it uses GPS data to address significant challenges in urban freight transport. It will analyze stop durations, locations, and types, giving valuable insights into freight operations. The research will also identify the factors causing conflicts between trucks, vehicles, and pedestrians, showing where urban logistics can be improved.

1.1 Objectives

1.1.1 General Objective

To propose public sector initiatives for planning urban freight transportation based on GPS data of truck routes, focusing on analyzing stops in residential zones and identifying commercial areas to optimize logistics processes.

1.1.2 Specific Objectives

- To identify truck routes using a georeferencing tool, identifying origin–destination pairs and recurring points (e.g., logistics centers), and specifying the nature of the stops.

- To perform a geospatial analysis that covers the location, duration, and activity of truck loading and unloading, identifying commercial zones in urban areas.

- To compare with thriving practices in other locations through comprehensive data analysis to effectively improve freight transportation management in urban areas.

2. Background

Urban and transportation planning studies have focused on people's mobility in cities for several years. Various modes of transportation have been analyzed, and routes have been optimized to reduce travel times. Freight transportation has always been a crucial factor in the economy and functioning of all countries worldwide. It is now receiving the attention it deserves; thus, research on this topic is increasing daily. There is a growing interest in urban planning based on the relationship between people and cargo, recognizing the importance of ensuring everyone has the necessary elements for living. Whether passenger or cargo-oriented, urban planning should use data analysis to demonstrate qualitative/quantitative decisions. This analysis should also enable the management of urban transportation initiatives and policies. One of the most complex issues in executing this type of research is data collection; it can be achieved through surveys of people and experts involving questions that identify behaviors and elements (Lægran et al., 2023).

Bjørgen & Ryghaug, (2022) conducted a documentary analysis, taking Norwegian cities as a case study, and conducted several interviews with logistics operators, receivers, urban planners, and authorities to understand policy implementation and changes. These resources have laid the foundation for freight transportation studies. However, it's essential to note that these projects often require significant time and financial resources, which can limit their scope in terms of budget and personnel. Nowadays, with technological advancements, new alternatives have been implemented to collect large-scale information more efficiently and with fewer resources. One of these methods, upon which this research is based, is GPS data (Global Positioning System). However, these data require transformation and analysis, depending on their quantity, often necessitating more advanced processing tools that may not be accessible to everyone. Consequently, researchers like Camargo et al., (2017) have presented tools and techniques to transform low-frequency GPS data from commercial sources into complete trajectories within the network.

Among the studies identified is that of researchers, Akter et al., (2018) who extract and analyze cargo truck activity patterns from anonymous GPS data collected from private operators. These data have also been studied to determine factors that improve traffic efficiency and safety, one of them being the traffic flow of trucks. Wang et al., (2020) propose a novel truck traffic flow prediction method using GPS data from the road network.

The proposed method consists of two phases: expansion and prediction, for which the methods of long short-term memory (LSTM) and closed recursive unit (GRU) neural networks were used. Another factor studied is the prediction of demand to determine distribution routes: You & Ritchie, (2019) implemented a revised form of entropy maximization based on truck routes to model and better understand the behavior of the drayage truck trips at the San Pedro Bay Ports (SPBP) complex in Southern California.

Another essential factor that this research will closely analyze is identifying truck stops in urban areas and their nature. One of the most studied, modified, and applied research methodologies in this regard is Gingerich et al., (2016) which uses entropy to identify primary and secondary stops. They designed a distance measurement to determine holidays occurring in a dataset, organized them, placed an initial point (P1), and compared point-to-point distances concerning P1. This comparison is done using a threshold distance where it's observed when points deviate from this threshold. When this happens, points within this threshold are classified as dwell time. They determine the threshold distance and intervals of time that determine the nature of stops. Demissie & Kattan, (2022) developed a heuristic-based approach to determine truck stops, validated with known points of interest. They used a speed threshold of 10 km/h to determine which vehicles were stopped, accelerating, or in a state of rest.

Mjøsund & Hovi, (2022) have two points to consider, one of which is giving continuity to what was previously mentioned. They used the methodology of Gingerich et al., (2016) but modified the threshold distance (a smaller one = 50 meters) as it is focused on downtown areas. On the other hand, the researchers take seven cities in Norway as a case study. They use demographic density to classify the site in the center of these cities and the surrounding area. To identify stops, they superimposed a map on the GPS points where the stops are placed, and a time interval is used again to group them and make them “easier” to recognize.

The researchers Holguín-Veras et al., (2020) they developed an algorithm based on travel velocity and acceleration using attributes such as the truck route, the type of merchandise, duration, and distance to crucial network locations. It is identified as a mechanical procedure because it is based on the physics of driving patterns. The results were compared with support vector machines, random forests, and k nearest neighbors, indicating that this algorithm is more accurate than these methods.

These methodologies reflect adjustments based on experience and adaptation of previously established methods, with varied results in terms of precision. However,

precision remains a debated issue due to the variability in GPS data, which can differ in the number of points, collected information, accuracy, and time differences in recordings. Holguín-Veras et al., (2020) addresses this challenge by using more precise acceleration data with per-second records, which offers high precision compared to methods using data every 30 seconds, as in the present study. The high variability in acceleration and the large number of GPS records introduce significant errors in stop identification.

A notable area for improvement in existing studies is that speed thresholds have been defined primarily based on practical experience. This research aims to improve this aspect by considering accuracy in determining vehicle stops and analyzing speed, distance, and time with values close to zero while accounting for GPS accuracy errors. Additionally, rather than observing only the average speed between two points, the methodology considers previous and subsequent speeds to identify whether the vehicle is stopped, decelerating, or accelerating. This approach also helps identify stops caused by congestion by analyzing speed jumps, providing a clearer view of vehicle behavior.

Critical information is needed in different areas to plan urban regions effectively. Demographic data about population growth, density, and migration patterns are essential to predict future infrastructure needs. Land use and zoning data help guide space allocation and use restrictions. Understanding transportation networks, including traffic flows and public transit, is essential for mobility planning. Environmental impact assessments and current infrastructure conditions are necessary for sustainable development and expansion. Economic data on employment and business trends support decisions on zoning and development, while public services data ensure that healthcare, education, and safety are adequately provided. Finally, community input is crucial to align planning initiatives with local priorities.

Despite the consensus that combining all these factors is needed to implement effective logistics and urban planning policies, researchers acknowledge that complete information is often lacking. Depending on the available data, researchers adapt their approaches. For example, Jaller et al., (2015) used data from around 400 receiving companies and 400 transporters in New York City. Due to the lack of detailed data, the authors developed models for freight trips produced (FTP, truck trips/day) and freight trips attracted (FTA, deliveries/day) for different industrial sectors, using the North American Industry Classification System (NAICS). The study concluded that large traffic generators (LTG)

create highly concentrated traffic impacts but also offer opportunities for urban logistics strategies.

In other studies, such as (Lindawati et al., 2014; Sharma & Singh, 2023 and Kin et al., 2024), literature reviews, surveys, and interviews were used to analyze urban logistics practices. However, limitations were found, such as small samples and lack of participation from administrative staff, which reduced the applicability of the results.

One of the main challenges, as mentioned by Cui et al., (2015), is to improve data collection and databases. This is necessary to understand urban freight transport better and improve planning processes, regulation, and management. Our research addresses this gap using a complete database that includes all trucks entering the cities, thanks to the government's circulation fee system. Additionally, updated residential and commercial area data allow us to propose more specific policies and initiatives for problematic areas. Although previous studies have analyzed GPS data with good results, their applicability is often left for future research or based on small data samples that do not provide a broad perspective.

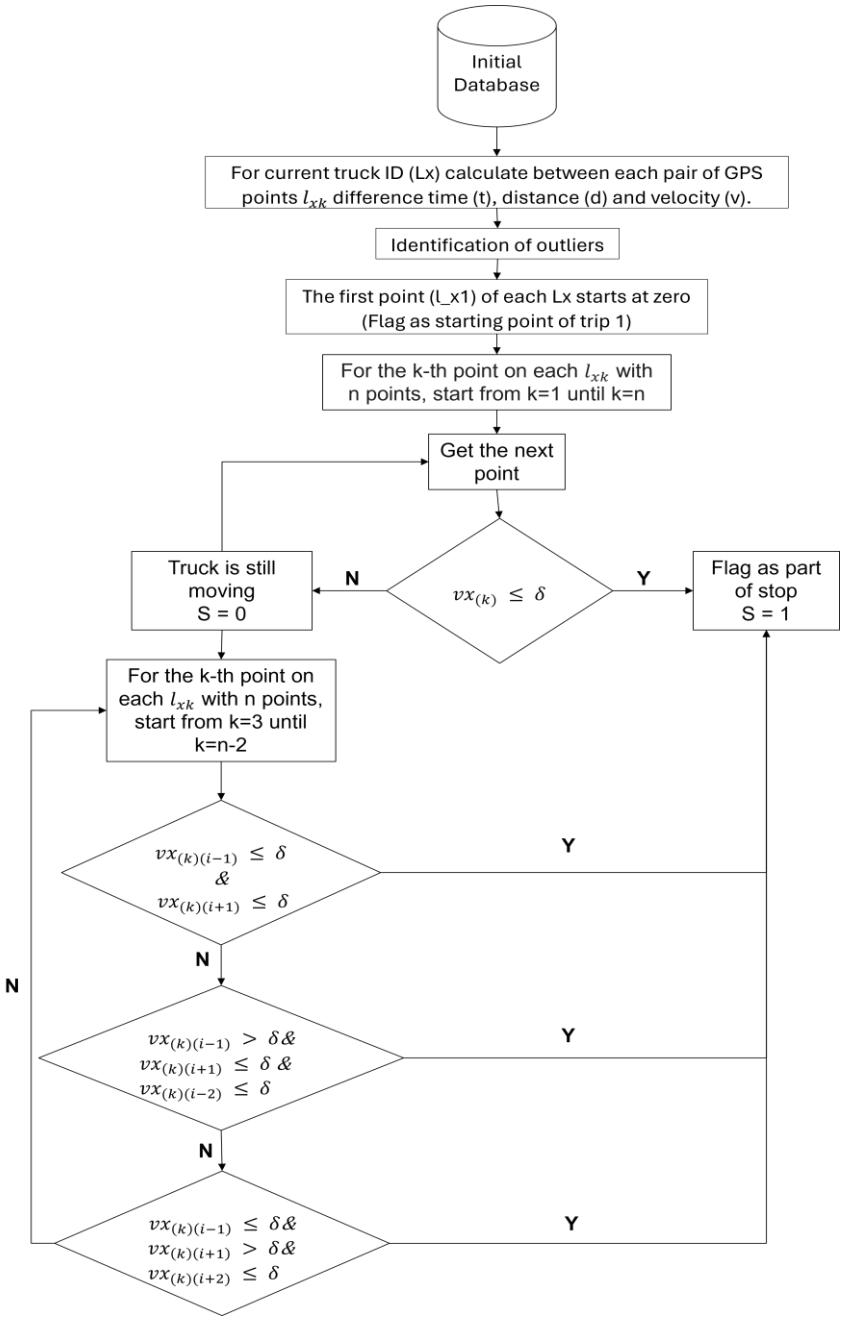
3. Methodology for GPS data processing and stop identification

The methodology of this study is organized into two fundamental steps. First, a data cleaning process is carried out to identify outliers and remove those without explanation. This stage is crucial, as outliers can introduce uncertainty due to GPS data imprecision, which could negatively affect the results' validity. Second, a detailed approach is developed to identify stops. This process involves implementing various conditions and using speed and the time difference between successive points as critical variables. This systematic approach aims to ensure accurate and reliable identification of stops in the transport data analysis.

In this research, GPS data from trucks (see www.viapass.be for details (Viapass, 2011)), taken every 30 seconds, are analyzed. The positions of the trucks were recorded over five days (Monday to Friday) in November 2021. The database includes GPS coordinates for each truck ID (each ID represents a different truck), along with the timestamp and date of each GPS point, the current speed of the truck, its direction, the country of registration, the Euro value (a reference to pollution class in Europe), and the Maximum Permissible Weight (MTM), which indicates the maximum weight a particular truck can carry.

Figure 3-1 presents an overview of the methodology used for identifying truck stops, depicted as a flowchart. Each process stage illustrated in the diagram is detailed throughout this section.

Figure 3-1: Overview of the methodology for identifying truck stops.



3.1 Data Cleaning

The initial database contains 389,982,879 GPS points corresponding to 770,044 IDs, which equates to the number of trucks. We will denote each truck (x) with its GPS

trajectory data. Lx, where $x \in \{1, 2, 3, \dots, j\}$, with j being the number of unique IDs or the number of trucks. In turn, each $Lx = \{ lx_1, lx_2, \dots, lx_k\}$ with $k \in \{1, 2, 3, \dots, n\}$, where n is the total number of GPS points for each truck. Each lx_k has values of time (t), distance (d), and velocity (v) ($(lx_{(k)} = (tx_{(k)}, dx_{(k)}, vx_{(k)}))$. To perform data cleaning, the first step is to calculate, using Equation 3-1, the time difference between GPS points for each truck (lx_k), using the date and time from the database.

$$tx_{(k)} = tx_{n+1} - tx_n \qquad \text{Equation 3-1}$$

Subsequently, the distance traveled between the GPS points of each truck. lx_k, is calculated using the latitude and longitude coordinates from the initial database. This calculation uses the great-circle equation (Equation 3-2) to determine the shortest distance between two points on the Earth's surface.

$$dx_{(k)} = R * \Delta\sigma \qquad \text{Equation 3-2}$$

Where:

$d = distance\ between\ the\ two\ points\ lx_k\ along\ the\ great\ circle$

$R = Earth\ Radius$

$$\Delta\sigma = arcos\ (sin(\phi 1)\ sin(\phi 2) + cos(\phi 1)\ cos(\phi 2)\ cos(\Delta\lambda)) \qquad \text{Equation 3-3}$$

Where:

$\phi 1\ y\ \phi 2\ are\ the\ latitudes\ of\ the\ two\ points\ lx_k\ in\ radians$

$\Delta\lambda\ is\ the\ difference\ between\ the\ longitudes\ of\ the\ two\ points\ lx_k\ in\ radians$

The above calculations calculate the speed from these data with Equation 3-3.

$$Vx_{(k)} = {tx_{(k)}}/{dx_{(k)}} \qquad \text{Equation 3-4}$$

Where:

$d = distance\ calculated\ in\ Equation\ 3-2$

$t = time\ difference\ calculated\ in\ Equation\ 3-1$

After these calculations, it is necessary to remove duplicate, missing, or unreasonable data. Following this premise, outliers are identified and eliminated. According

to Viapass, trucks change their ID every 24 hours to protect information, so it is verified that no total travel time exceeds this limit. Additionally, Euro values are analyzed, ensuring they do not exceed Euro 6. If any ID shows errors, they are corrected, or the entire ID is removed if all points are erroneous.

A speed limit of 250 km/h is established to identify points that exceed this limit. If an ID has multiple errors, it is completely removed; if there is only one outlier, two conditions are reviewed: if the error is at index 1, meaning at the point. lx_2, the first point lx_1 is removed; otherwise, the specific point lx_k is eliminated. Finally, the time (t), distance (d), and velocity (v) of the removed points are recalculated, and it is verified again if there are speeds exceeding 250 km/h. If outliers reappear in corrected IDs, the entire ID Lx will be removed for lack of reliability.

At the end of this cleaning process, 2.5% of the GPS points and 2.1% of the truck IDs were removed from the original database (Table 3-1). This procedure highlights the importance of data cleaning in managing the inconsistencies in a large amount of information. Maintaining a critical attitude regarding the quality of the data obtained from the sensors is essential.

Table 3-1: Retained information after the central filtering, cleaning, and validation steps.

	GPS Points		**Trucks ID's**	
	Number	**Percentage (%)**	**Number**	**Percentage (%)**
INITIAL DATABASE	389,982,879	100	770,044	100
Identification of outliers: total travel time	383,524,673	98.34	761,600	98.90
Identification of outliers: Euro value	380,728,705	97.63	754,763	98.02
First identification of outliers: velocity	380,614,407	97.60	754,596	97.99
Second identification of outliers: velocity FINAL DATABASE	380,357,938	97.53	754,214	97.94

3.2 Stop Identification

Analyzing the data and verifying the velocities has identified two types of cases in stop identification:

Case 1 occurs when several consecutive points show a velocity and initial distance that are zero or near zero. In this case, it is assumed that the truck slows down to a stop without turning off the vehicle, thus continuing to emit a signal and register GPS points.

Case 2 This is more clearly identified when there is a considerable time difference between points.

Given these cases, methodologies created and implemented by various researchers were studied, and it was decided to establish a proprietary method based on observed behaviors, data quantity, and inherent GPS errors. In Case 1, with several consecutive points, it must be determined whether it is a stop or, for example, a case of congestion. For this, the main variables considered are speed and time.

To identify periods when trucks are stopped, consecutive GPS points where the change in spatial coordinates (Δx) over time (Δt) is zero ($dx_{(k)} = 0$) are initially marked, indicating no movement. However, due to inherent inaccuracies in GPS measurements, some points exhibited minimal but non-zero velocities that could be misinterpreted as movement. Therefore, a threshold was introduced to account for these minor inaccuracies. Specifically, a near-zero speed threshold was defined, below which trucks are considered stopped. This threshold ensures that small GPS fluctuations do not affect stop event identification.

To define an appropriate threshold for determining when trucks are stopped, GPS point velocities separated by less than 50 meters were analyzed, a distance assumed to be short enough to represent nearly stationary conditions. Graphing these velocities showed that speeds for points within very close proximity (specifically less than 5 meters) were

predominantly low. Indeed, 97.5% of the velocities for points less than 5 meters apart were below 0.5 km/h.

This observation established a threshold δ=0.5 km/h to define near-zero velocities, assuming that movements below this threshold could be attributed to GPS inaccuracies rather than actual truck movement. However, it is essential to examine this logic critically.

Firstly, choosing 50 meters as a "short distance" could still include minor movements that are not accurate stops, particularly in urban environments with dense traffic. Additionally, while 97.5% of the velocities for very close points fall below δ, this threshold could exclude legitimate low-velocity movements, such as maneuvers or prolonged driving in congested areas. Therefore, while our data statistically support the threshold δ, it may require further refinement and validation against actual stop events to ensure its accuracy and reliability in different contexts. This threshold is necessary to run Algorithm 1 to flag (S=1) points suspected of being stops or part of a stop initially. Points that do not meet the conditions will be flagged as S=0.

Algorithm 1:

Being $Lx = \{ lx_1, lx_2, \dots, lx_k\}$ and $lx_{(k)} = \left(tx_{(k)}, dx_{(k)}, vx_{(k)}\right)$ with $k \in \{1, 2, 3, \dots, n\}$

$k = 1;$

$\boldsymbol{if}\ vx_{(k)} \leq \delta$

$S = 1; classify\ as\ a\ possible\ stop$

$\boldsymbol{else}$

$S = 0; Classify\ as\ a\ possible\ moving$

$\boldsymbol{End\ While}$

When it is already marked with a flag, I check the points that have S=0 and algorithm 2 is executed.

Algorithm 2:

Being $i = \ position\ of\ GPS\ points\ within\ the\ stipulated\ range$

$Between\ k = 3\ and\ k = n - 2$

$\boldsymbol{if}\ vx_{(k)(i-1)} \leq \delta\ \boldsymbol{and}\ vx_{(k)(i+1)} \leq \delta$

$S = 1; classify\ as\ a\ possible\ stop$

$\boldsymbol{else}$

$\boldsymbol{if}\ vx_{(k)(i-1)} > \delta\ \boldsymbol{and}\ vx_{(k)(i+1)} \leq \delta, \boldsymbol{and}\ vx_{(k)(i-2)} \leq \delta$

$S = 1; classify\ as\ a\ possible\ stop$

else

$vx_{(k)(i-1)} \leq \delta\ \&\ vx_{(k)(i+1)} > \delta,$

$\&\ vx_{(k)(i+2)} \leq \delta$

$S = 1; classify\ as\ a\ possible\ stop$

else

$S = 0; Classify\ as\ a\ possible\ moving$

End While

The threshold mentioned earlier is established to account for these minor inaccuracies. Specifically, we define a near-zero speed threshold below which trucks are stopped. Consequently, values marked with the flag S=1 are potential stops. When observing the behavior of velocities before and after each point analyzed in the algorithm, consecutive '1's are found, indicating that the vehicle is stationary in the exact location while emitting a signal. For this reason, these points are combined, and time, distance, and velocity are recalculated, followed by the execution.

To analyze this condition, the authors examine the time difference to stipulate a threshold for the time considered a stop. Previous research has shown variations in methods based on specific study needs, such as those of Gingerich et al., (2016) uses a threshold distance of 250 meters for stop identification and then applies an average speed threshold of 1 km/h and a dwell time of 15 minutes to eliminate stops that may be due to congestion. X. Yang et al., (2014) employs an average speed of 14 km/h and adjusts the dwell time to 10 to 20 minutes based on observations and secondary data. Mjøsund & Hovi, (2022) builds on the methodology of the author Gingerich et al., (2016) but adjusts several parameters for urban areas. Specifically, it reduces the distance threshold to 50 meters, increases the average speed to 8 km/h, and shortens the stop duration to 5 minutes. This reduction in stop duration is noteworthy, as Mjøsund & Hovi, (2022) operates in urban environments across different cities in Oslo, where traffic conditions and stop characteristics can vary from non-urban areas.

Conversely, Demissie & Kattan, (2022) evaluates various time thresholds across different cities in Canada, finding a threshold of 5 minutes for stops. This finding is significant

because many studies define a stop as any duration exceeding 10 minutes, considering both urban and non-urban stops. However, a deeper analysis of stops in metropolitan areas reveals that deliveries can occur within 5 to 10 minutes. Therefore, a 5-minute threshold for stops has been adopted in alignment with the described methodology (Table 3-2). With this information, this time, called $, the\ study\ is\ set$ in this study at 5 minutes.

Table 3-2: Dwell times according to previous studies.

Author	D time (min)
Adam et al., (2021)	10
Mjøsund & Hovi, (2022)	5
Demissie & Kattan, (2022)	5
Our research	5

Therefore, it must be analyzed whether the time difference ($tx_{(k)}$) of the analyzed point lx_k is greater than or equal to d_{time}, if this is the case, it will also be marked as S=1. In the other instances where none of the four conditions are met, it will be marked as S=0. This condition does not mean that the truck did not stop, but it does indicate that the stop may have another nature (congestion, traffic lights, among others).

After identifying the stops, we extract the necessary information for the specific case study. In this case, stops in the urban areas of one or more cities will be analyzed. All IDs with at least one of their points located within the boundary of the specific city to be explored are extracted. It is important to note that each ID corresponds to a different truck. These IDs are referred to as 'tours'.

To understand the context, we refer to two complementary 'tour definitions. Ortuzar & Willumsem, (2011) defines a tour as "A set of linked sojourns and trips," and Holguín-Veras et al., (2014) describes it as " the sequence of stops freight carriers undertake to pick up or deliver cargo and then return to the home bases." This context is necessary to understand that the stops identified with the previous algorithms and conditions shape the GPS trajectories, redefining them as 'tours.' These 'tours' define the 'trips' each truck takes.

4. Case study

As mentioned in previous chapters, GPS data from trucks (see www.viapass.be for details (Viapass, 2011)), collected every 30 seconds, were analyzed. The positions of the trucks were recorded over five days (Monday to Friday) in November 2021. This GPS data is recorded because in 2016, the three regions of Belgium – Flanders, Wallonia, and Brussels – decided to implement a kilometer-based tax. Instead of taxing truck ownership, the tax is based on usage, allowing for a fair distribution of infrastructure costs, including environmental impacts. This system applies to all heavy goods vehicles weighing more than 3.5 tons and to N1/BC class vehicles, regardless of whether they are empty, fully loaded, or carrying private goods. To ensure proper recording, every vehicle must have an on-board unit (OBU) that stays active while driving on Belgian roads. The OBU device tracks the kilometers traveled and sends the total to the billing center, which issues detailed invoices regularly.

Belgium is located in the west of Europe and shares borders to the north with the Netherlands, east with Germany and Luxembourg, and the south and west with France. Although its area is 30,688 km², making it a small country, its location has made it an important economic and urban center in Europe.

The geography of Belgium is divided into three central regions: Lower Belgium, which is below 100 m above sea level; Central Belgium, which is between 100 and 200 m above sea level; and Upper Belgium, which ranges from 200 m to more than 500 m above sea level (Belgian Federal Government, 2024).

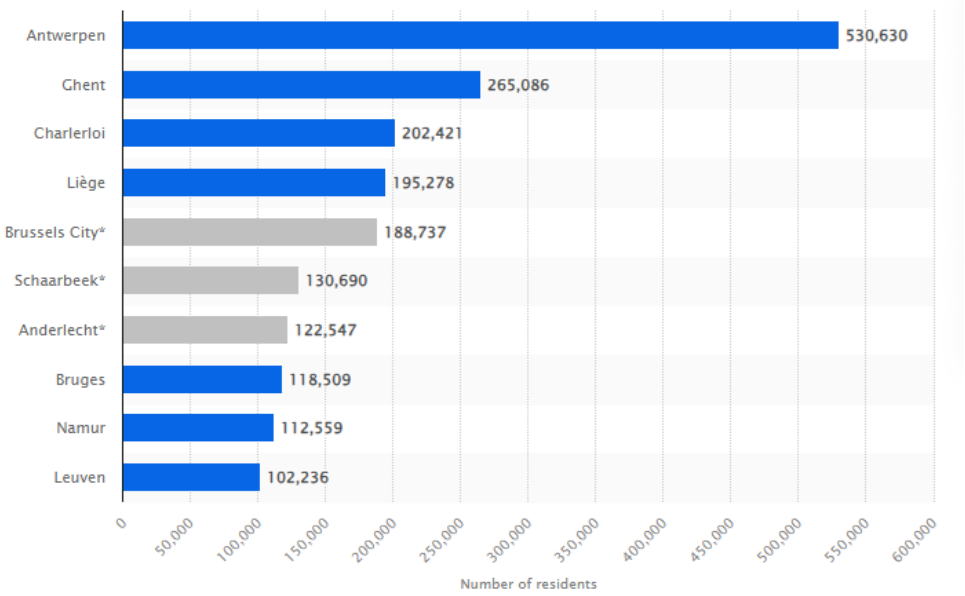
As of January 1, 2024, Belgium's legal population was 11,763,650. Between January 1, 2023, and January 1, 2024, the Belgian population grew by 66,093, representing an increase of 0.57%. This population growth has been slightly higher than the average of the last ten years, which is 0.53%. These figures come from the official statistics of Statbel, the Belgian statistical office (Statbel, 2024).

The geographical location of Belgium can be seen in figure 4-1.

Figure 4-1: The geographical location of Belgium.

In turn, it is mentioned that this research aims to analyze urban areas; for this reason, two main cities in the country were chosen: Antwerp and Ghent. In 2022, the most populated cities in Belgium were Antwerp, Ghent, Charleroi, Liège, and Brussels. Antwerp and Ghent, located in the Flanders region, were the most populated cities in the country that year. In regional terms, Flanders has 6.8 million people, and about 800,000 live in these two cities. Interestingly, Brussels, the capital, was not at the top of the list. This is because of how the population is counted, as Brussels comprises 19 municipalities. Only three of them—Brussels City, Schaerbeek, and Anderlecht—appeared in the ranking (Figure 4-2). These 19 municipalities form the core of the Brussels agglomeration, also known as "le Grand Bruxelles," which includes 36 towns in total. In 2019, over a million people lived in this Brussels-Capital region, making it the most populated agglomeration in Belgium, even more significant than Antwerp's agglomeration. (Statista Research Department, 2024)

Figure 4-2: The cities and municipalities with the highest population in Belgium in 2022



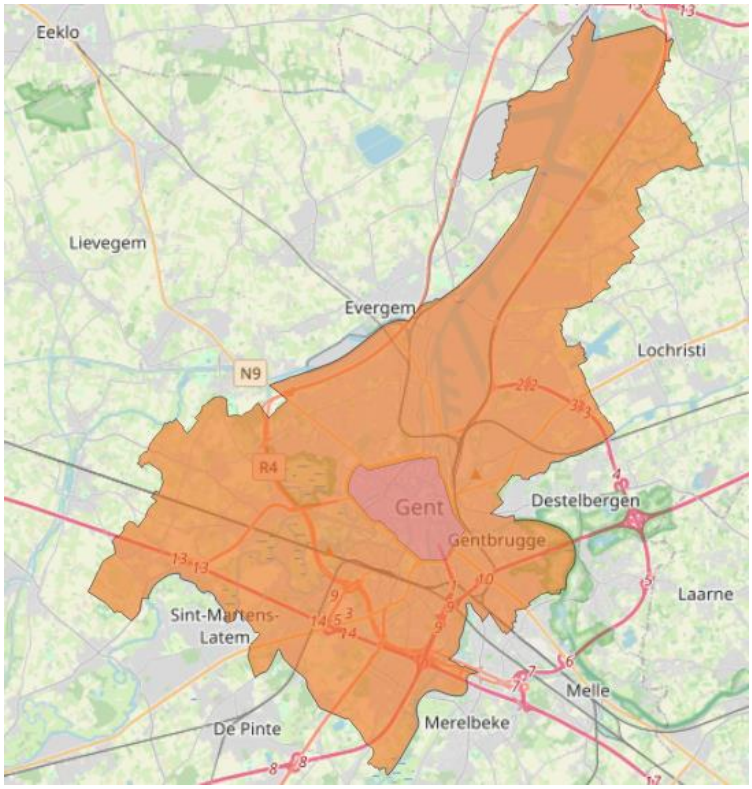
Source: (Statbel, 2024)

4.1 Ghent.

According to the last census in 2021, Ghent had 263,700 residents, with an estimated population of about 270,000 by 2024. The city covers 157.8 km² and has a population density of approximately 1,709 people per km² (Brinkhoff, 2024). As mentioned earlier, Ghent is the second-largest city in Flanders. With around 78,000 students, it is also the most prominent student city and continues to grow. The town has a pedestrian-friendly center and 400 km of bike lanes. One major cultural event is the Ghent Festival, which lasts ten days and attracts around two million visitors annually.

It is also important to mention the North Sea Port, a cross-border port formed by the merger of the Dutch Sealand Ports and the Belgian port of Ghent. This port is a critical economic hub, employing more than 100,000 people and handling about 71.5 million tons of cargo yearly, generating 14 billion euros in added value (EUROCITIES, 2024b). Image 4-3 shows the geographical location of Ghent, with the city center also highlighted.

Figure 4-3: The geographical location of Ghent.



After reviewing the general data of the city and the reasons why it was chosen as one of the study cases, the analysis of the results from applying the methodology in Chapter 3 begins. First, the tours that had at least one point within the city's boundary were processed. Using the applied methods, the stops for each tour in the town and the city center were identified. Table 4-1 summarizes the number of tours, trucks, and stops in the city and the center of Ghent.

Table 4-1: Number of tours, trucks, and stops in the city and the center of Ghent.

Day	Tours / Total Trucks	Total stops		Ghent stops		Center Ghent stops	
		Trucks	Num. Stops	Trucks	Num. Stops	Trucks	Num. Stops
15	30.592	27.505	147.028	8.198	19.936	388	698
16	32.484	29.094	150.352	8.498	20.133	415	769
17	32.787	29.539	152.346	8.467	19.594	389	682
18	31.488	28.780	152.244	8.552	20.141	411	779
19	28.506	25.810	141.019	7.756	18.359	392	734

It is essential to analyze the information about the stops to understand the behavior of trucks within the city, starting with their duration. Knowing the stop duration is critical for logistics management and urban planning because it affects several essential aspects. The length of stops impacts logistics efficiency and traffic congestion since long stops can disrupt the flow, especially in busy areas. It also affects the use of public space, as in commercial and residential areas, these stops can cause blockages and make it harder for pedestrians, cyclists, and private vehicles to move. Additionally, there's an environmental and sustainability impact because trucks that stop for long periods produce more pollution, especially with the engine running.

For these reasons, the distribution of stops throughout different hours of the day on various days of the week is examined. The aim is to identify the hours when stops are most frequent. Figure 4-4 shows the number of stops recorded per hour for each study day in Ghent, while Figure 4-5 displays the same information but focuses on the city center.

Figure 4-4: Number of Stops by Hour of Day- Ghent

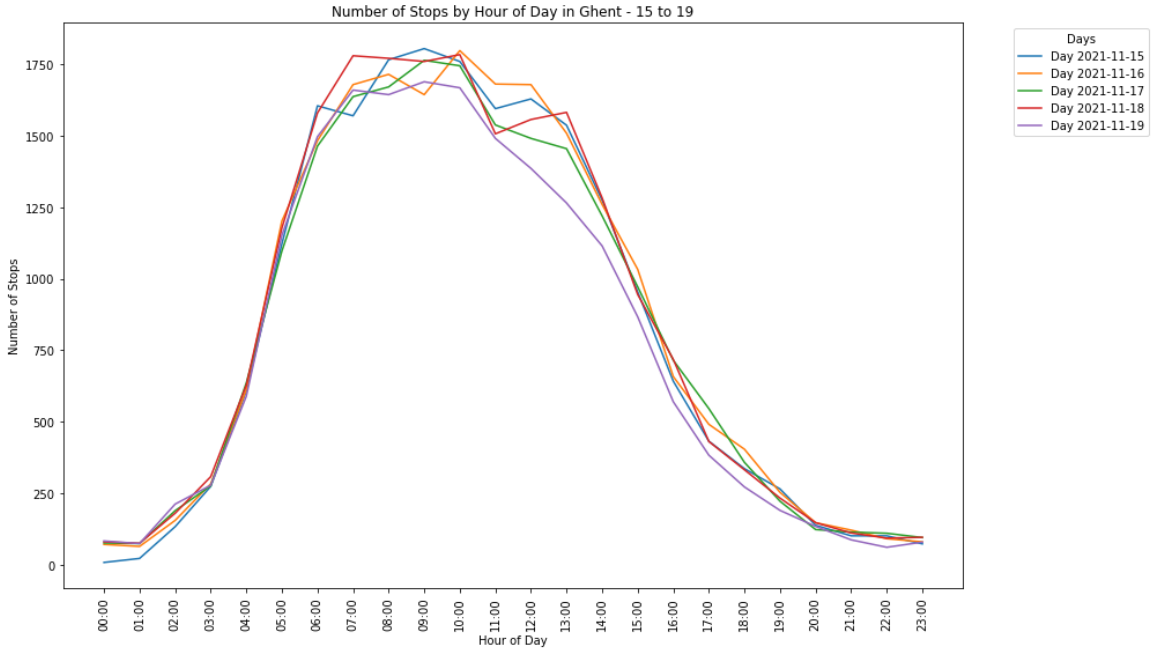
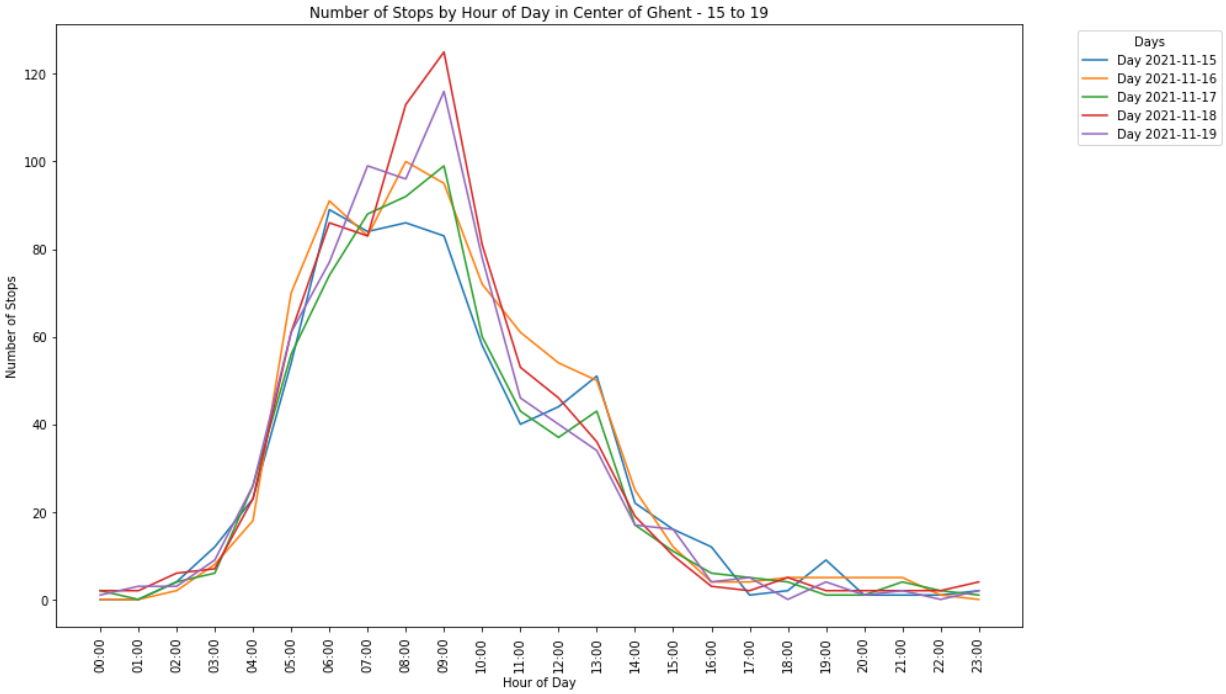


Figure 4-5: Number of Stops by Hour of Day- Center of Ghent



In both figures, it can be seen that stops gradually increase from the early hours of the day, reaching their peak between **07:00 and 10:00**. Afterward, there is a steady decrease, with most stops concentrated in the first half of the day, mainly between **05:00 and 14:00**. After **14:00**, the number of stops drops considerably and remains low for the rest of the day. In the center of Ghent, stops seem to spread more throughout the day, whereas the curve is more compact in the rest of the city. Figure 4-6 y 4-7 provides a numerical concentration of these stops for a more detailed view.

Figure 4-6: Number of Stops by Hour of Day - Ghent

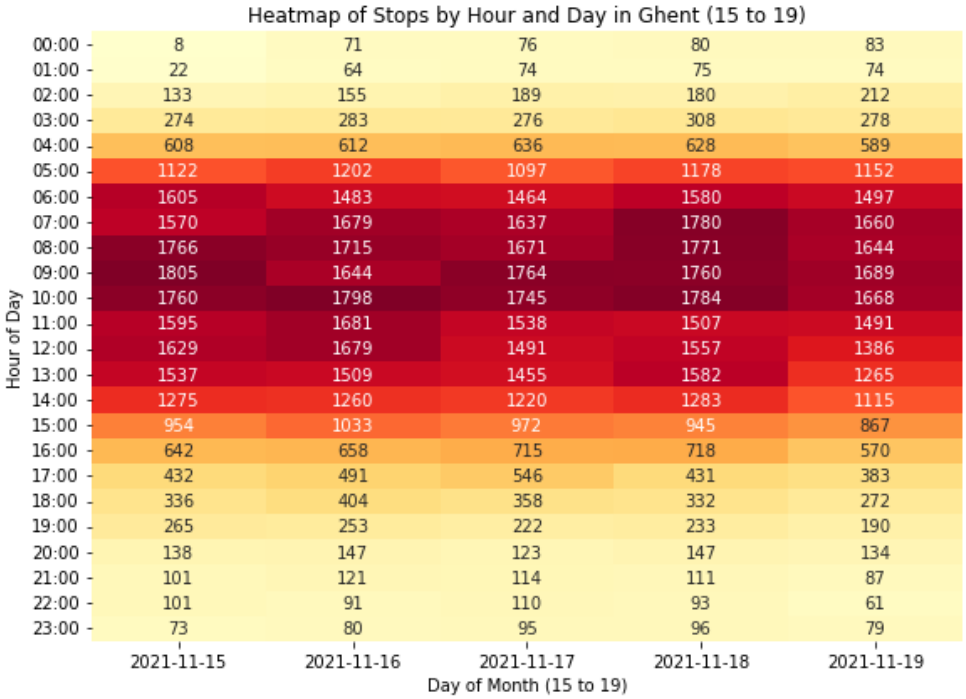


Figure 4-7: Number of Stops by Hour of Day – Center of Ghent

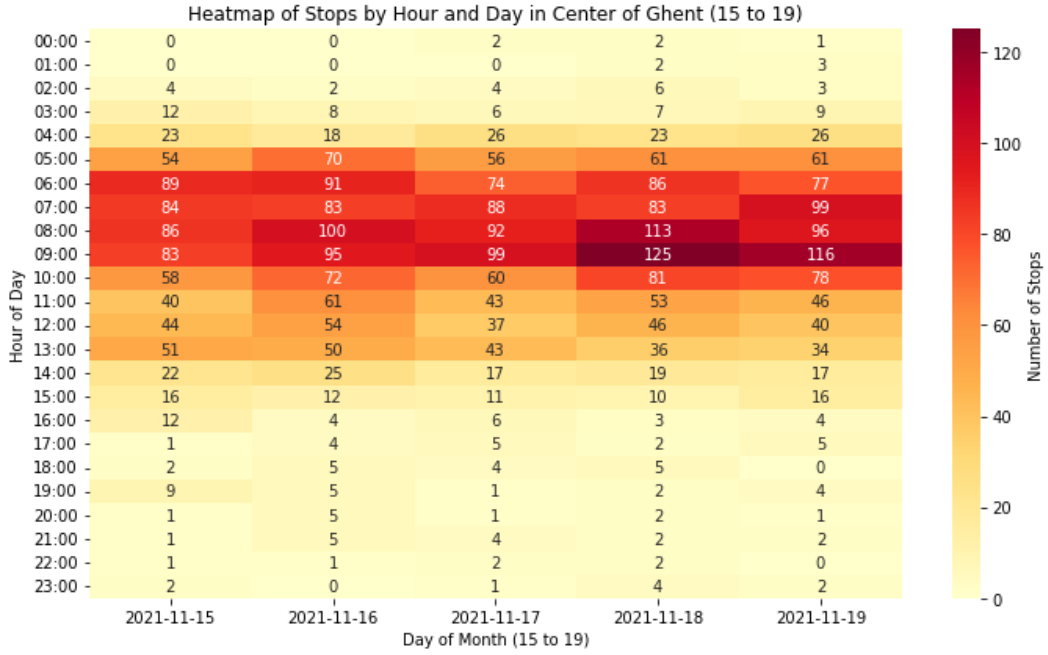


Figure 4-6 shows the number of stops at different hours for each day of the week in Ghent, while Figure 4-7 presents the same information but focuses on the city center. As mentioned earlier in the visual analysis, in the city, stops are mainly distributed between

6:00 and 11:00, where around 50% of total stops occur during this time frame. Similarly, between 6:00 and 10:00, 50% to 60% of the stops are concentrated in the city center.

It is worth noting that the highest values in the city are recorded on Mondays, Wednesdays, and Fridays at 8:00. At the same time, on Tuesdays and Thursdays, the peak occurs at 9:00. In the city center, Monday reaches its maximum at 6:00. However, there is no significant difference between 6:00 and 9:00. Tuesday has its highest value at 8:00. For the rest of the week, the peak is at 9:00, with Thursday showing a much higher concentration compared to other days. It's important to highlight that, in both cases, the highest values are observed at **8:00 and 9:00.**

It's important to note that the number of stops doesn't necessarily indicate the number of trucks present. Therefore, it's vital to analyze the relationship between the two. This will help us determine if, during a specific hour, there are several trucks making few stops or if it's the opposite scenario. To aid in this analysis, figure 4-8 presents the number of trucks recorded per hour for each study day in Ghent, while Figure 4-9 does the same for the city center.

Figure 4-8: Number of Trucks by Hour of Day- Ghent

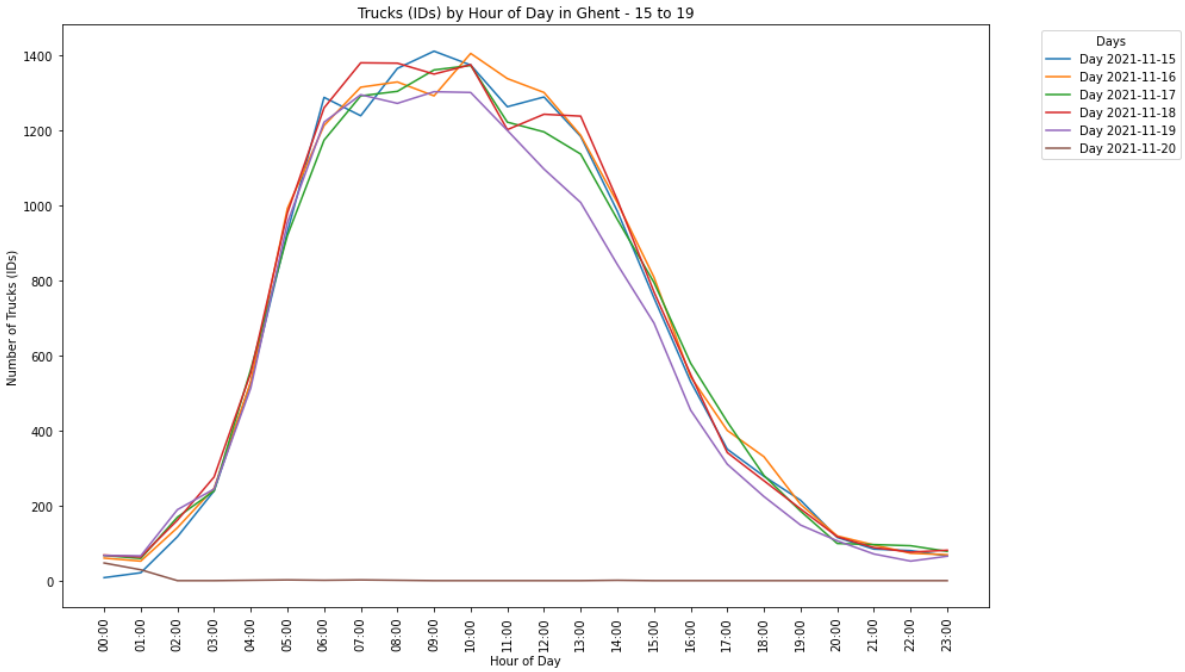
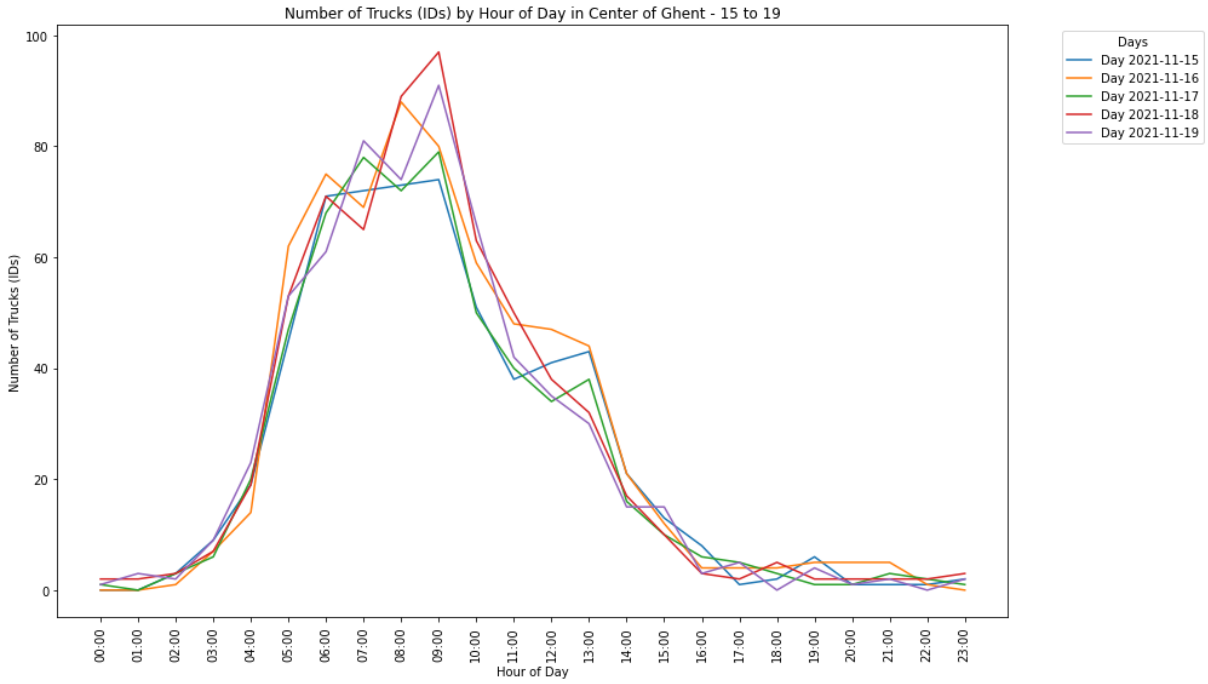


Figure 4-9: Number of Trucks by Hour of Day- Center of Ghent



A similar pattern can be seen when comparing Figures 4-4 and 4-5 with the new Figures 4-8 and 4-9. This confirms that the stops are made by different trucks, supporting the initial hypothesis that trucks enter a specific area at the same time, within an hour interval, to carry out activities that require them to stop. For a more detailed analysis, Figure 4-10 y 4-11 presents the numerical concentration of the number of trucks.

Figure 4-10: Number of Trucks by Hour of Day- Ghent

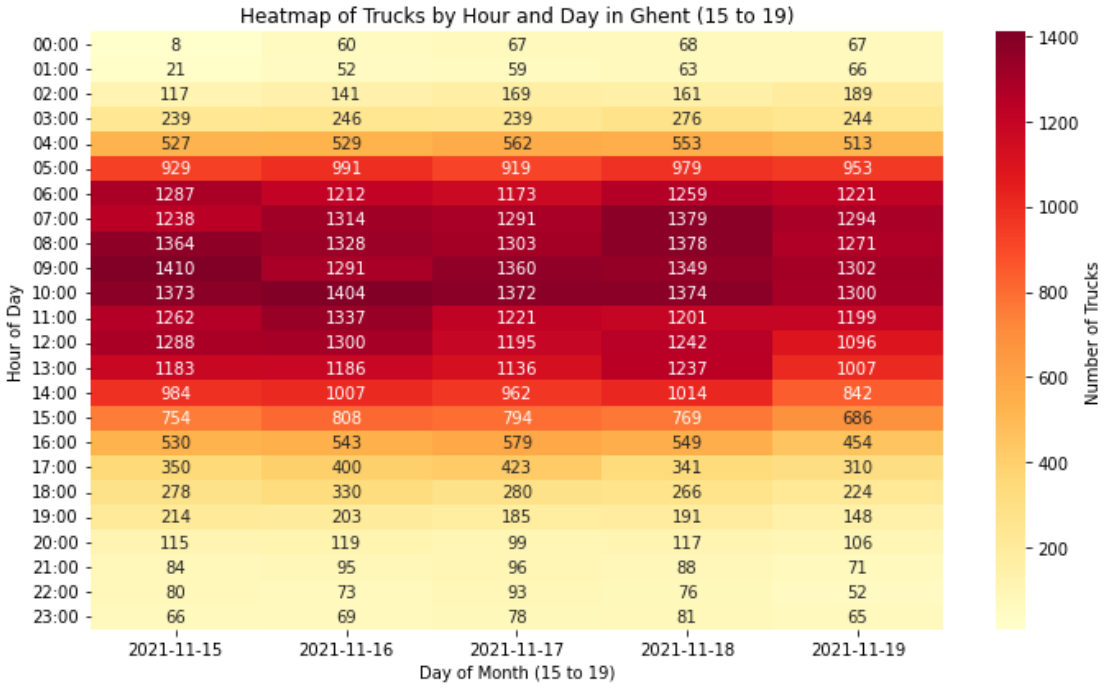


Figure 4-11: Number of Trucks by Hour of Day- Center of Ghent

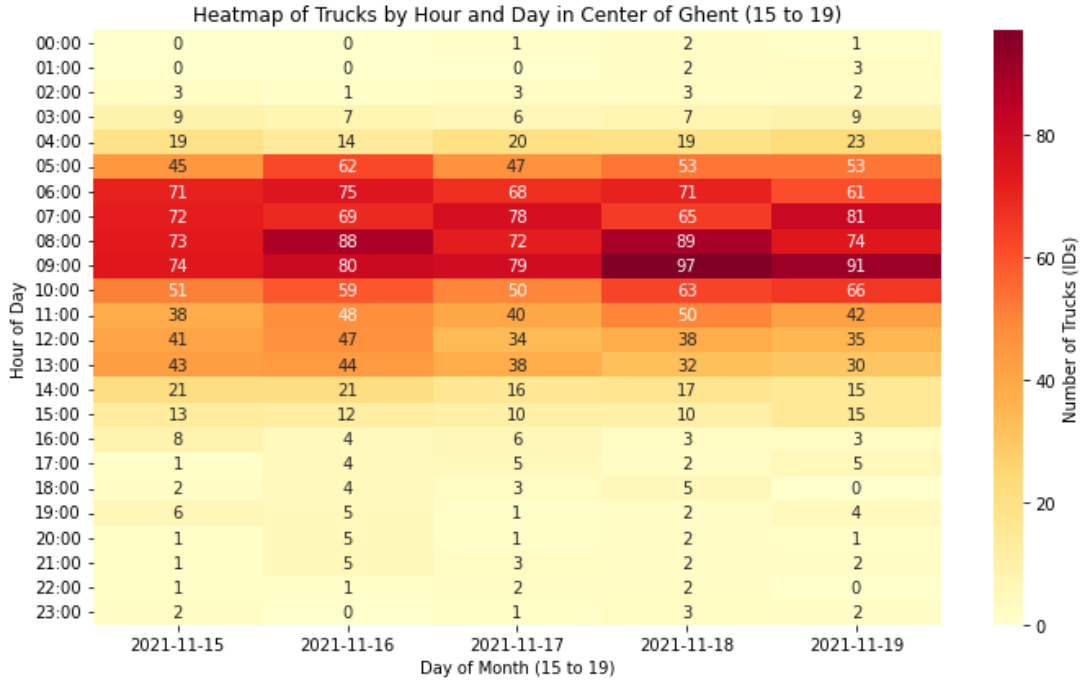


Figure 10 shows the number of trucks recorded at different hours of the day for each day of the week in Ghent, while Figure 11 provides the same information but focuses on the city

center. Comparing this data with the stop figures, it is evident that in Ghent, most trucks are concentrated between 9:00 and 10:00 a.m., except for Thursday, when the highest concentration is at 7:00 a.m. However, there is no significant difference compared to the number recorded at 10:00 a.m. Similarly, in the city center, Mondays show a uniform pattern from 6:00 to 9:00 a.m., Tuesdays peak at 8:00 a.m., and the rest of the days peak at 9:00 a.m. In this case, the hours with the most stops also have the highest concentration of trucks. This leads to a new preliminary hypothesis: most trucks make between one and two stops at different times throughout the day.

The number of trucks making a certain number of stops was calculated to verify the hypothesis. In Figure 4-12, a bar chart is presented, where the x-axis shows each day of the week, and the y-axis shows the number of stops per truck. This figure presents data for Ghent, while Figure 4-13 shows the same information but focuses on the city center.

Figure 4-12: Number of Stops per Truck per Day- Ghent

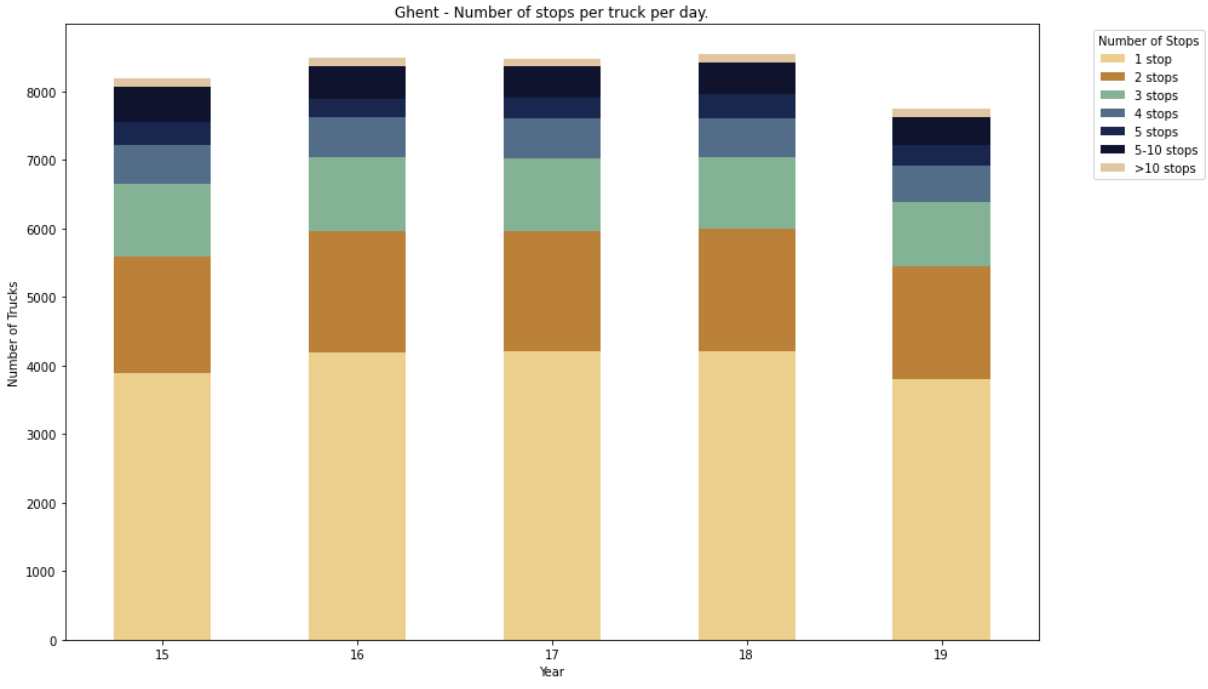
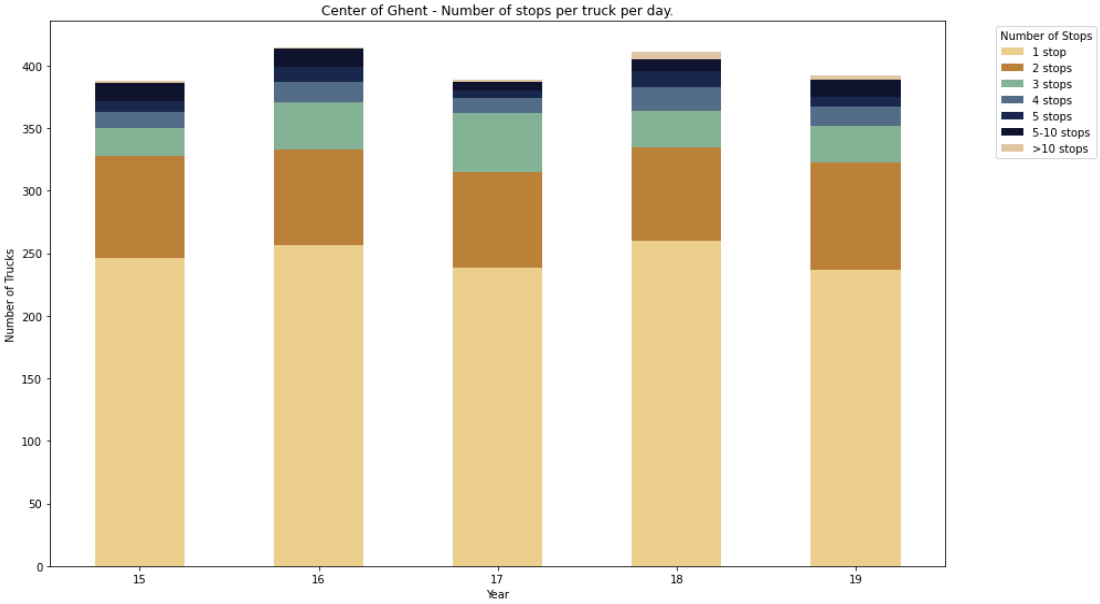


Figure 4-13: Number of Stops per Truck per Day - Center of Ghent



As observed, most trucks make one (1) or two (2) stops, confirming what was suggested in the previous analysis. To quantify this information, Table 4-2 y 4-3 displays the number of trucks falling into each category.

Table 4-2: Number of Stops per Truck per Day – Ghent

	1 stop	%	2 stops	%	3 stops	%	4 stops	%	5 stops	%	5-10 stops	>10 stops
15	3882	**47%**	1713	**21%**	1050	**13%**	578	**7%**	333	**4%**	516	126
16	4187	**49%**	1772	**21%**	1073	**13%**	594	**7%**	272	**3%**	462	138
17	4214	**50%**	1743	**21%**	1065	**13%**	582	**7%**	307	**4%**	454	102
18	4203	**49%**	1792	**21%**	1052	**12%**	562	**7%**	347	**4%**	473	123
19	3806	**49%**	1643	**21%**	943	**12%**	532	**7%**	292	**4%**	416	124

Table 4-3: Number of Stops per Truck per Day – Center of Ghent

	1 stop	%	2 stops	%	3 stops	%	4 stops	%	5 stops	5-10 stops	>10 stops
15	246	**63%**	82	**21%**	22	6%	13	3%	9	14	2
16	257	**62%**	76	**18%**	38	9%	16	4%	12	15	1
17	239	**61%**	76	**20%**	47	12%	12	3%	6	7	2
18	260	**63%**	75	**18%**	29	7%	19	5%	13	9	6
19	237	**60%**	86	**22%**	29	7%	15	4%	8	14	3

Table 4-2 shows the data for the city of Ghent, while Table 4-3 presents the data for the city center. On average, 49% of trucks in the city and 62% in the city center make only one (1) stop. For two (2) stops, 21% of trucks in the city and 20% in the city center follow this pattern. About 12% of trucks in the city and 8% in the city center make three (3) stops, while the remaining percentage, corresponding to 18% in the city and 10% in the center, make more than three (3) stops. These percentages are reflected in the concentrations seen in the respective intervals and with green underlined in the tables. These results support the initial hypothesis, and it can also be noted that in the city center, there is a higher concentration of trucks making one or two stops compared to the rest of the city.

As mentioned in the previous analysis, analyzing how long these stops last is essential. For this reason, the number of stops is examined within different time intervals: less than 10 minutes, between 10 and 20 minutes, between 20 and 30 minutes, between 30 minutes and 2 hours, and more than 2 hours. Figure 4-14 shows the distribution of these time intervals on the x-axis and the number of stops on the y-axis. Each day of the week is represented by a different color in this figure.

Figure 4-14: Number of Stops Durations Per Week - Ghent

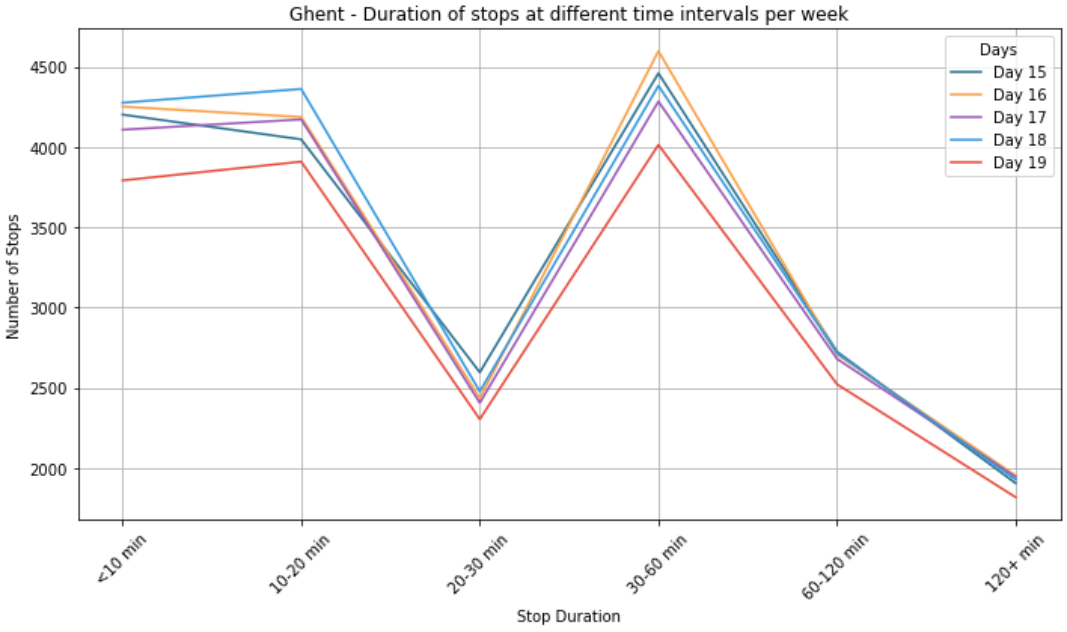


Table 4-4 summarizes the data from the graphs. It shows that between 63% and 65% of the stops are within three intervals: less than 10 minutes, between 10 and 20 minutes, and between 30 minutes and 1 hour. While the differences are insignificant, most stops last between 30 minutes and 1 hour. These percentages are reflected in the concentrations observed in the respective intervals and with a green underline in the tables.

Table 4-4: Number of Stops Durations Per Day - Ghent

Time stops	Day 15		Day 16		Day 17		Day 18		Day 19	
	Stops	%	Stops	%	Stops	%	Stops	%	Stops	%
<10 min	4202	21.1%	4252	21.1%	4108	21.0%	4276	21.2%	3792	20.7%
10-20 min	4048	20.3%	4187	20.8%	4172	21.3%	4362	21.7%	3909	21.3%
20-30 min	2596	13.0%	2435	12.1%	2406	12.3%	2477	12.3%	2304	12.5%
30-60 min	4460	22.4%	4598	22.8%	4284	21.9%	4382	21.8%	4014	21.9%
60-120 min	2725	13.7%	2708	13.5%	2680	13.7%	2716	13.5%	2522	13.7%
120+min	1905	9.6%	1953	9.7%	1944	9.9%	1928	9.6%	1818	9.9%

Now, the same analysis has been done for the city center area. Figure 4-15 shows the time interval distribution, like the previous analysis. This figure shows each day of the week in a different color.

Figure 4-15: Number of Stops Durations Per Week - Center of Ghent

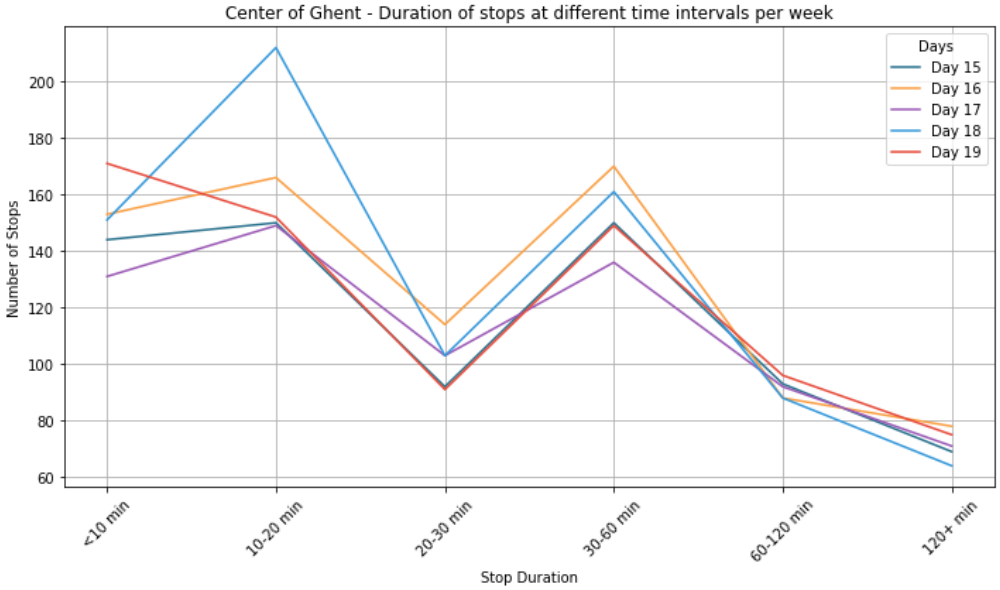


Table 4-5 summarizes the data from these graphs. It shows that 63% and 65% of the stops are at the same three-time intervals. Although the differences are slight, the stops are between 10 and 20 minutes on most days, except for Friday, when most stops are less than 10 minutes. These percentages are reflected in the concentrations observed in the respective intervals and with a green underline in the tables.

Table 4-5: Number of Stops Durations Per Day – Center Ghent

Time stops	Day 15		Day 16		Day 17		Day 18		Day 19	
	Stops	**%**	**Stops**	**%**	**Stops**	**%**	**Stops**	**%**	**Stops**	**%**
<10 min	144	20.6%	153	19.9%	131	19.2%	151	19.4%	171	23.3%
10-20 min	150	21.5%	166	21.6%	149	21.8%	212	27.2%	152	20.7%
20-30 min	92	13.2%	114	14.8%	103	15.1%	103	13.2%	91	12.4%
30-60 min	150	21.5%	170	22.1%	136	19.9%	161	20.7%	149	20.3%
60-120 min	93	13.3%	88	11.4%	92	13.5%	88	11.3%	96	13.1%
120+ min	69	9.9%	78	10.1%	71	10.4%	64	8.2%	75	10.2%

It can also be seen that, generally, the city's highest number of stops happens on Tuesdays and Thursdays. However, Friday is one of the days with the most stops in the city center. Finally, the origin and destination of tours stopping in Ghent and those stopping only in the city center are analyzed.

Figure 4-16: Percentage of Internal and External Starting and Final Points - Ghent

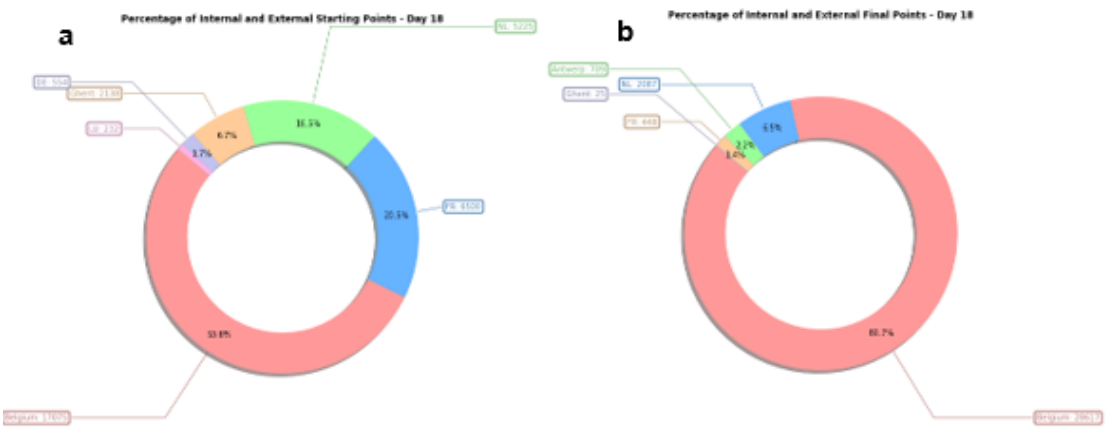


Figure 4-16 (a, b) shows the Starting Points (a) and Final Points (b) of the trips stopping in the city of Ghent on the 18th, which is selected because it is the day with the most tours. All other days show the same behavior. Figure 4-16(a) shows that approximately 54% of the trips start in Belgium, meaning they begin at different points, excluding Ghent and Antwerp. In second place, 21% of the trips begin at the borders with France, and 17% start in the Netherlands. Figure 4-16(b) shows that approximately 90% of the trips end within Belgium.

Figure 4-17: Percentage of Internal and External Starting and Final Points – Center of Ghent

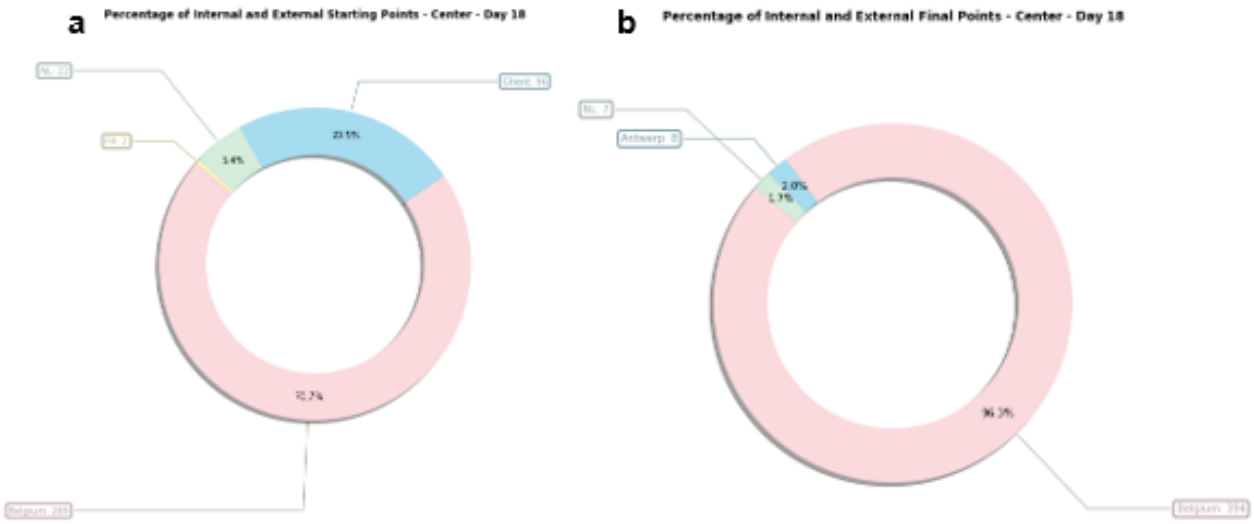
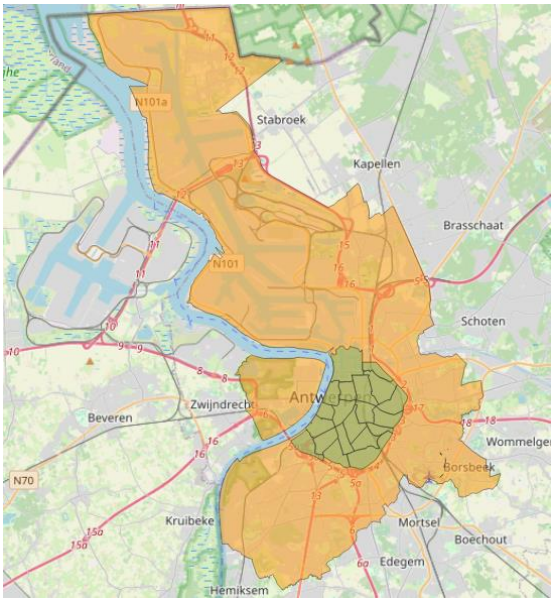


Figure 4-17 (a, b) shows the Starting Points (a) and Final Points (b) of the trips stopping in the center of Ghent on the 18th, with all other days showing the same behavior. In Figure 4-17(a), it can be seen that around 71% of the trips start within Belgium, while 24% start in the city of Ghent itself, which is an important detail. Figure 4-17(b) shows that 96% of the trips end within Belgium.

4.2 Antwerp.

According to the last census in 2021, Antwerp had 529,417 residents, with an estimated population of about 544,759 by 2024. The city covers 204.3 km² and has a population density of approximately 2,666 people per km² (Brinkhoff, 2024). The biggest city in Flanders, Antwerp, located on the River Scheldt with direct access to the North Sea, is home to the Port of Antwerp-Bruges, the second largest in Europe after Rotterdam. This port, which handles containers and chemicals as its primary industries, receives over 60,000 inland and sea-faring vessels yearly. It is 80 kilometers inland and a crucial gateway between the sea and the hinterland. In addition to its logistical importance, the port attracts international researchers and serves as a center for specialized maritime training, reinforcing Antwerp's role as a hub of marine expertise.(EUROCITIES, 2024a). Image 4-18 shows the geographical location of Ghent, with the city center also highlighted.

Figure 4-18: The geographical location of Antwerp.



After reviewing the general data of the city and the reasons why it was chosen as one of the study cases, the analysis of the results from applying the methodology in Chapter 3 begins. First, the tours that had at least one point within the city's boundary were processed. Using the applied methods, the stops for each tour in the town and the city center were identified. Table 4-6 summarizes the number of tours, trucks, and stops in the city and the center of Antwerp.

Table 4-6: Number of tours, trucks, and stops in the city and the center of Antwerp.

Day	Tours / Total Trucks	Total stops		Antwerp stops		Center Antwerp stops	
		Trucks	Num. Stops	Trucks	Num. Stops	Trucks	Num. Stops
15	42.578	38.549	200.240	13.349	41.562	1.036	2.134
16	44.153	39.736	201.195	13.971	41.468	1.070	2.072
17	44.630	40.381	206.393	15.015	44.070	1.165	2.267
18	44.033	39.752	204.197	13.834	41.538	1.098	2.187
19	39.156	35.597	190.461	12.746	38.897	996	2.044

For the same reasons presented in section 4, the distribution of stops throughout different hours of the day on various days of the week is examined. The aim is to identify the hours when stops are most frequent. Figure 4-19 shows the number of stops recorded per hour for each study day in Antwerp, while Figure 4-20 displays the same information but focuses on the city center.

Figure 4-19: Number of Stops by Hour of Day- Antwerp

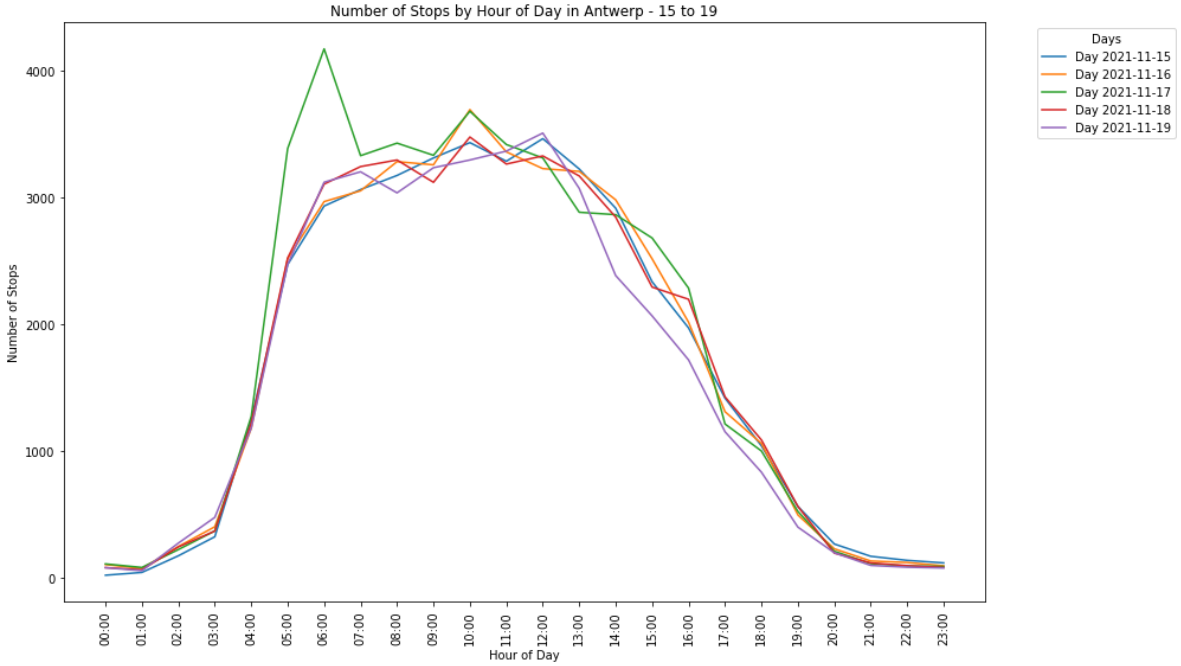


Figure 4-20: Number of Stops by Hour of Day- Center of Antwerp

The figures show a pattern in the number of stops throughout the day, both in the city of Antwerp and in the city center. The highest concentration of stops is between **5:00 and 12:00** in Antwerp and **7:00 and 10:00**, with a significant peak in the city at **6:00**. In the city center at **8:00**. After this peak, the number of stops gradually decreases, with a noticeable drop after 14:00, reaching its lowest point after 20:00. Although the days show slight variations, like a higher number of stops on November 17th, the overall pattern remains consistent. In the center of Antwerp, the total number of stops is lower than the entire city. Still, it follows the same time pattern, suggesting that logistical activities in the center happen similarly, though on a smaller scale. For a more detailed view, Figure 4-21 y 4-22 provides a numerical concentration of these stops.

Figure 4-21: Number of Stops by Hour of Day – Antwerp

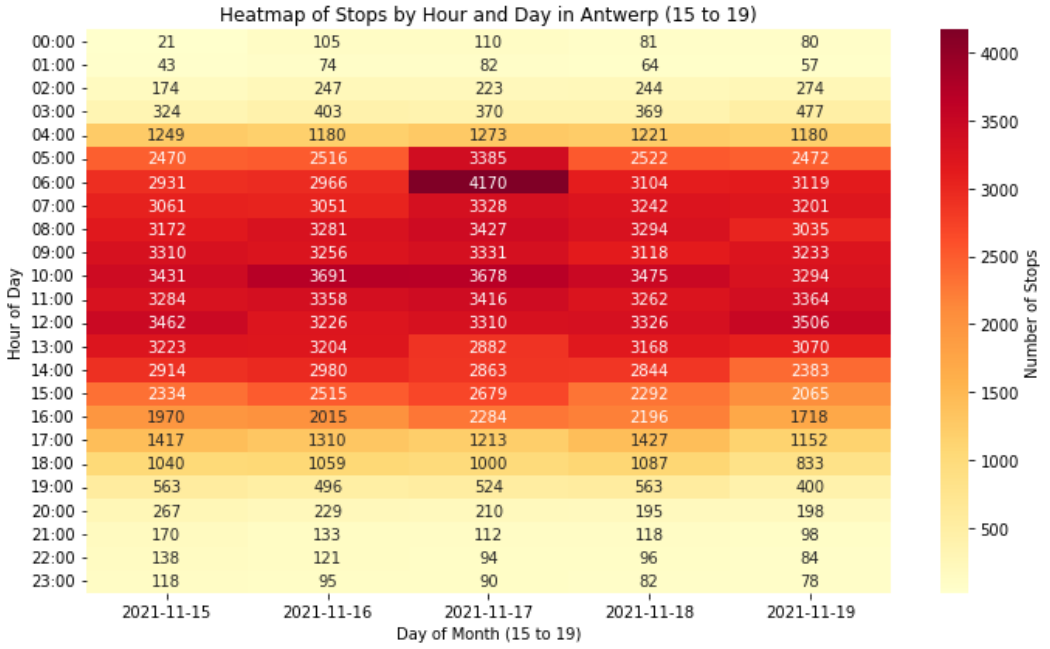


Figure 4-22: Number of Stops by Hour of Day – Center of Antwerp

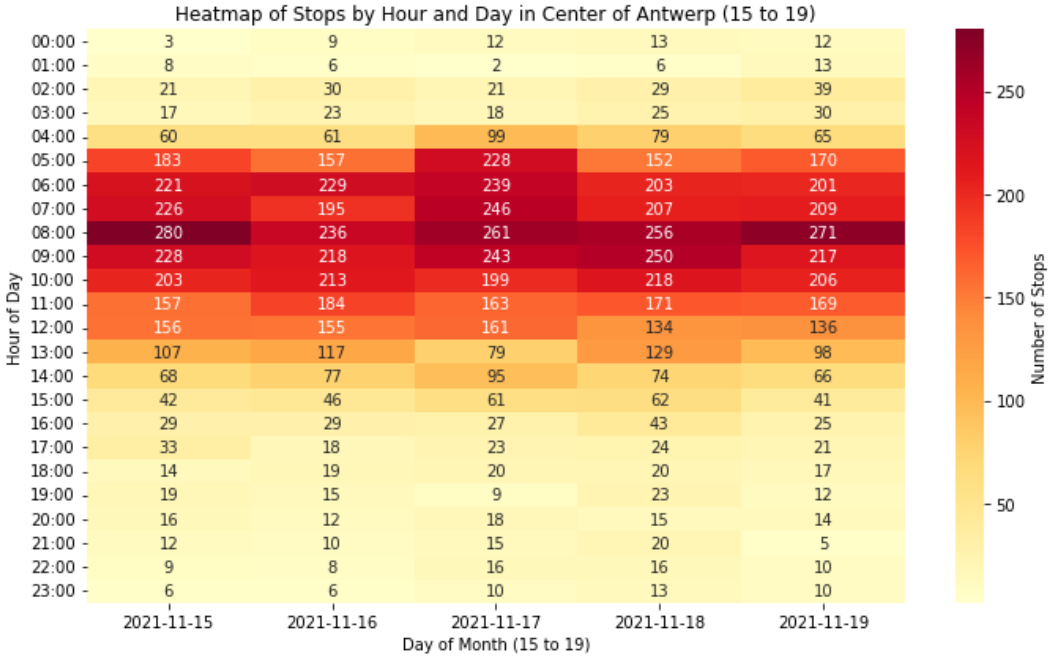


Figure 4-21 shows the number of stops at different hours for each day of the week in Antwerp, while Figure 4-22 presents the same information but focuses on the city center. As mentioned earlier in the visual analysis, in the city, stops are mainly distributed between

5:00 and 12:00, where around 62% of total stops occur during this time frame. Similarly, in the city center, between 7:00 and 10:00, on average, 42% of the stops are concentrated.

It is worth noting that the highest values in the city are recorded on Mondays and Fridays at **noon**, while on Tuesdays, Wednesdays, and Thursdays, the peak occurs at **10:00**. In the city center, the city center, every day of the week shows the highest concentration of stops at **8:00.** Unlike in Ghent, where the peak times were the same across all cases, there is a difference in peak hours between the city and the center in Antwerp.

It's important to note that the number of stops doesn't necessarily indicate the number of trucks present. Therefore, it's vital to analyze the relationship between the two. This will help us determine if, during a specific hour, there are several trucks making few stops or if it's the opposite scenario. To aid in this analysis, figure 4-8 presents the number of trucks recorded per hour for each study day in Ghent, while Figure 4-9 does the same for the city center.

Figure 4-23: Number of Trucks by Hour of Day- Antwerp

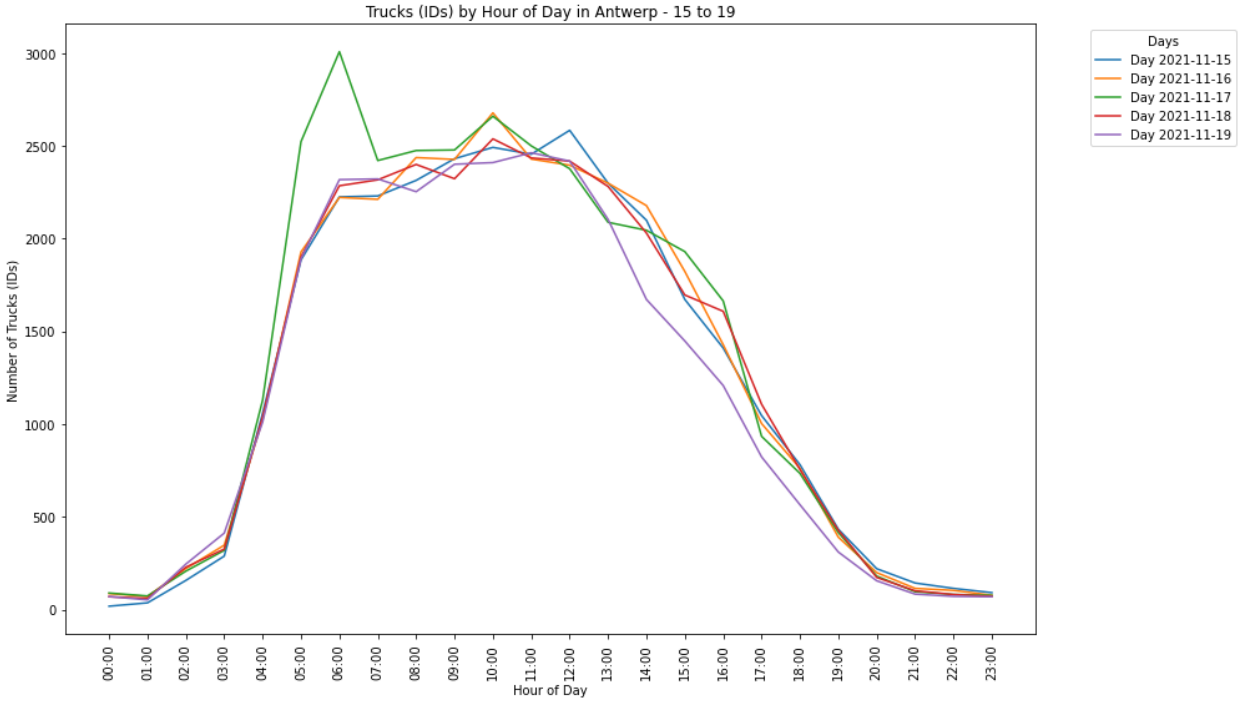
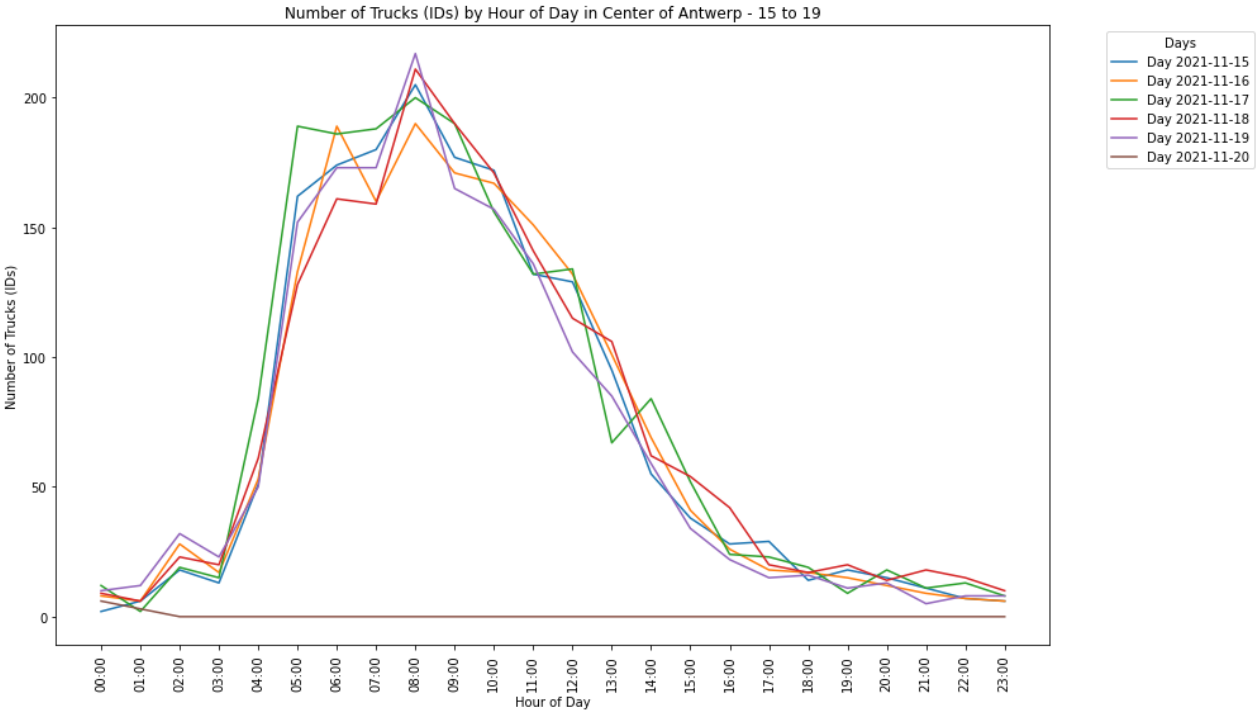


Figure 4-24: Number of Trucks by Hour of Day- Center of Antwerp



A similar pattern can be seen when comparing Figures 4-23 and 4-24 with the new Figures 4-19 and 4-20. This confirms that the stops are made by different trucks, supporting the hypothesis mentioned in section 4.1 that trucks enter a specific area simultaneously, within an hour interval, to carry out activities that require them to stop. For a more detailed analysis, Figures 4-25 and 4-26 present the numerical concentration of the number of trucks.

Figure 4-25: Number of Trucks by Hour of Day- Antwerp

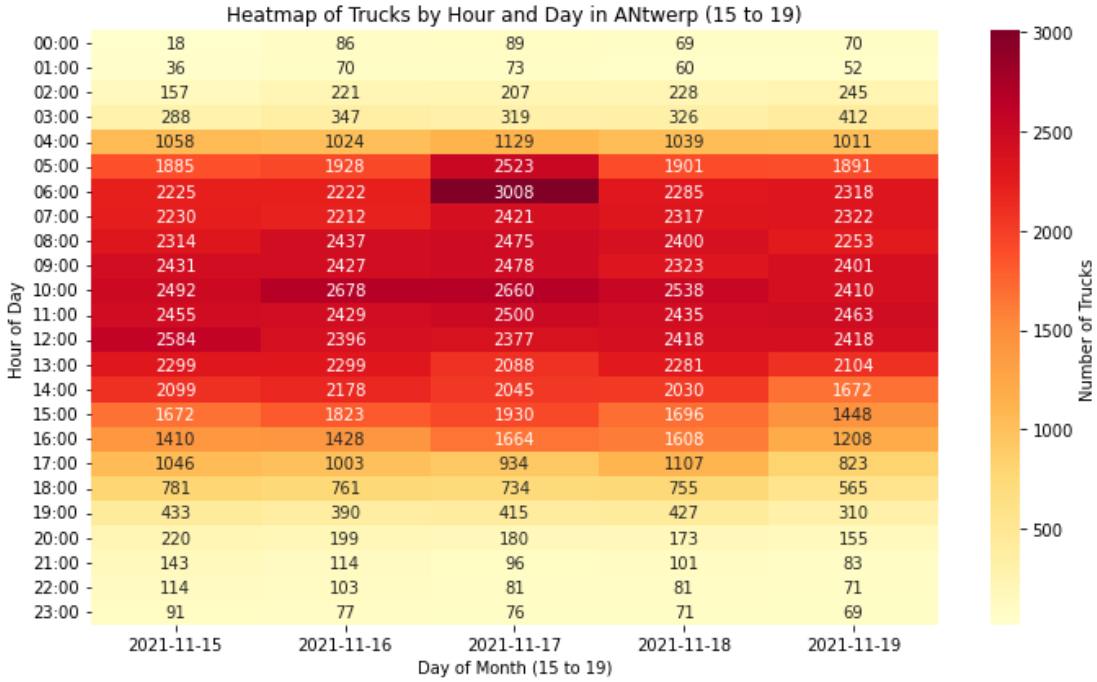


Figure 4-26: Number of Trucks by Hour of Day- Center of Antwerp

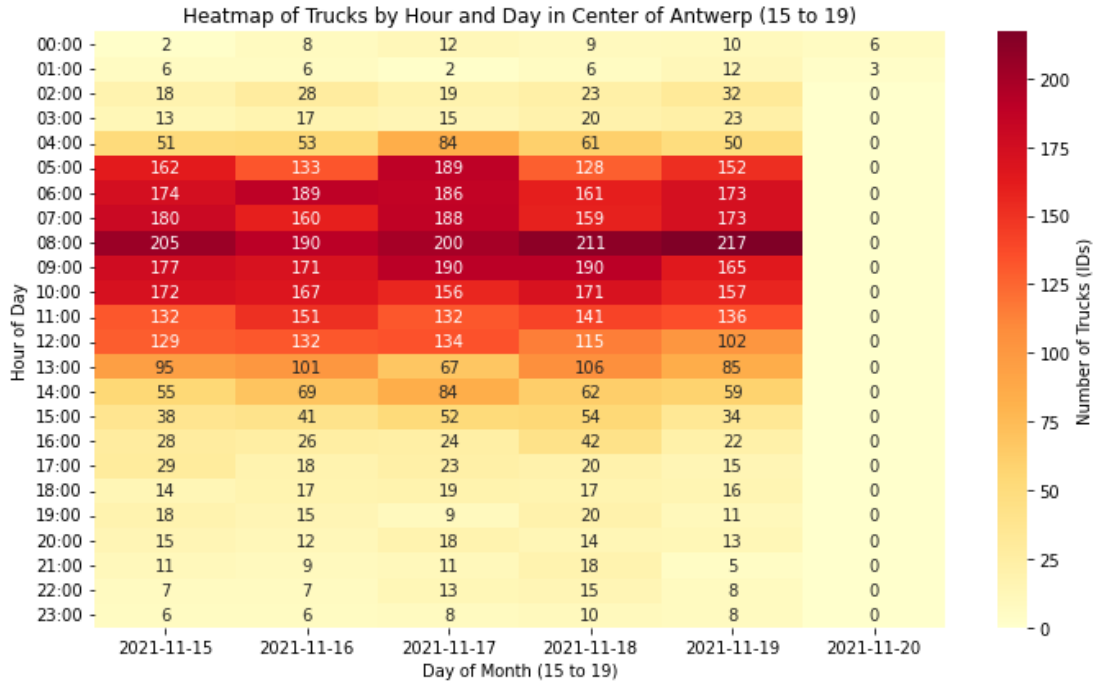


Figure 25 shows the number of trucks recorded at different hours for each day of the week in Antwerp, while Figure 26 provides the same information but focuses on the city center. Comparing this data with the stop figures, it is evident that in Antwerp, most trucks are concentrated between 6:00 and 12:00, with a particular case for Wednesday, when the highest concentration is at 6:00. In the city center, most trucks are concentrated between 7:00 and 10:00 and peak hour at 8:00. This leads to the same preliminary hypothesis in Ghent: most trucks make between one and two stops at different times throughout the day.

The number of trucks making a certain number of stops was calculated to verify the hypothesis. In Figure 4-27, a bar chart is presented, where the x-axis shows each day of the week, and the y-axis shows the number of stops per truck. This figure presents data for Antwerp, while Figure 4-28 shows the same information but focuses on the city center.

Figure 4-27: Number of Stops per Truck per Day- Antwerp

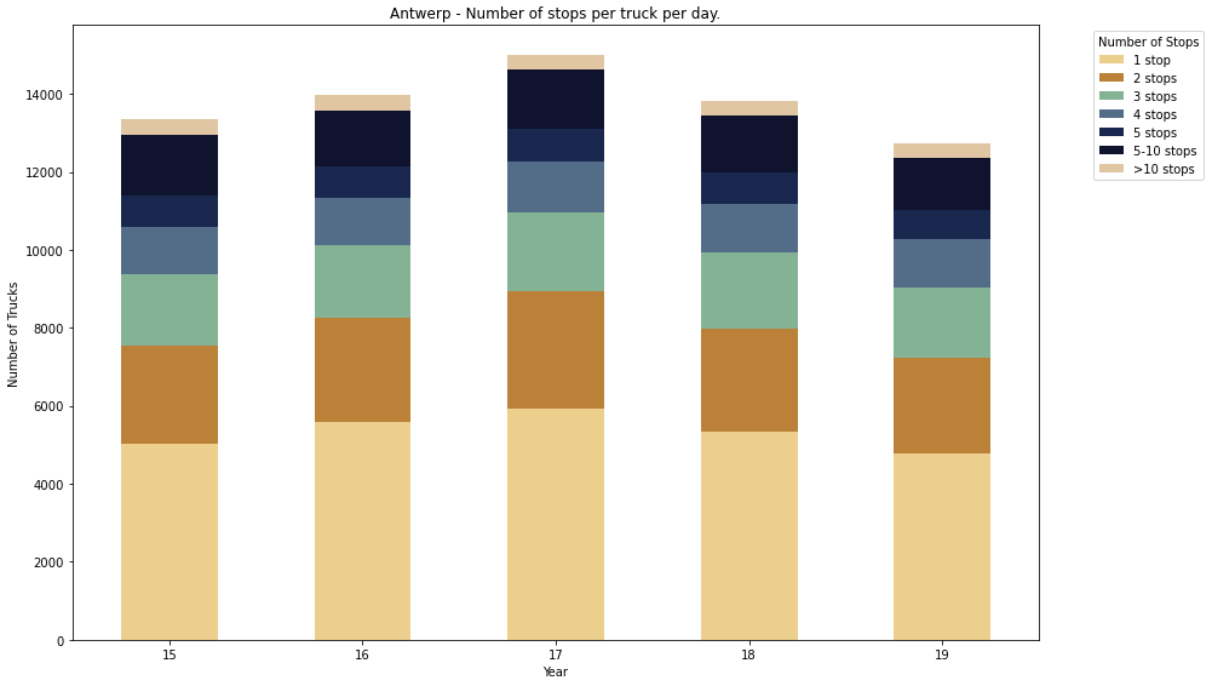
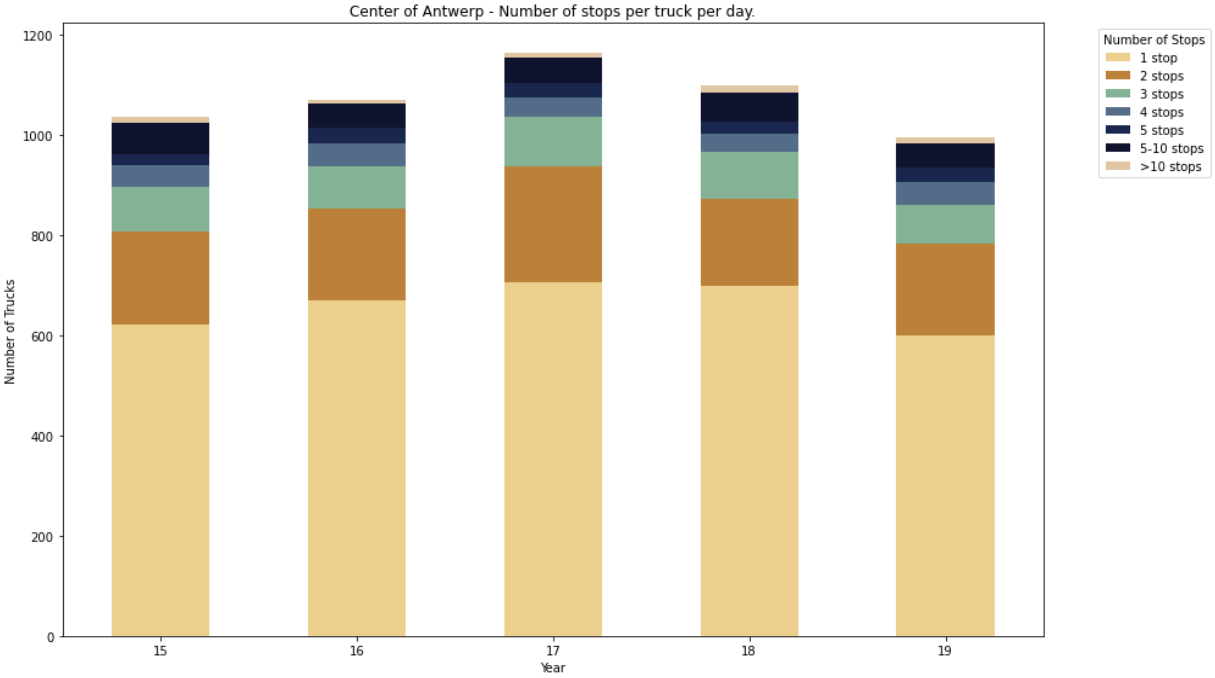


Figure 4-28: Number of Stops per Truck per Day- Center of Antwerp



As observed, most trucks make one (1) or two (2) stops, confirming what was suggested in the previous analysis. However, many trucks make between three (3) and four (4) stops in Antwerp. In the city center, the highest concentration of trucks is in those making only one (1) stop. To quantify this information, Table 4-7 y 4-8 displays the number of trucks falling into each category.

Table 4-7: Number of Stops per Truck per Day – Antwerp

	1 stop	**%**	**2 stops**	**%**	**3 stops**	**%**	**4 stops**	**%**	**5 stops**	**5-10 stops**	%	**>10 stops**
15	5030	38%	2500	19%	1847	14%	1226	9%	782	1556	12%	404
16	5578	40%	2694	19%	1857	13%	1214	9%	807	1414	10%	401
17	5915	39%	3026	20%	2007	13%	1318	9%	829	1524	10%	395
18	5326	38%	2658	19%	1944	14%	1244	9%	826	1451	10%	381
19	4790	38%	2441	19%	1800	14%	1248	10%	739	1352	11%	374

Table 4-8: Number of Stops per Truck per Day – Center of Antwerp

	1 stop	%	2 stops	%	3 stops	%	4 stops	%	5 stops	5-10 stops	>10 stops
15	622	60%	185	18%	89	9%	44	4%	22	63	11
16	670	63%	183	17%	84	8%	46	4%	32	47	8
17	707	61%	231	20%	97	8%	40	3%	28	52	10
18	699	64%	174	16%	94	9%	36	3%	24	57	14
19	599	60%	185	19%	76	8%	46	5%	29	48	13

Table 4-7 shows the data for Antwerp, while Table 4-3 presents the data for the city center. As observed, on average, 39% of trucks in the city and 61% in the city center make only one (1) stop. For two (2) stops, 19% of trucks in the city and 18% in the city center follow this pattern. About 14% of trucks in the city and 8% in the city center make three (3) stops, while the remaining percentage, corresponding to 28% in the city and 1% in the center, make more than three (3) stops. These percentages are reflected in the concentrations seen in the respective intervals and with a green underline in the tables. These results support the initial hypothesis, and it can also be noted that in the city center, there is a higher concentration of trucks making one or two stops compared to the rest of the city.

As mentioned in the previous analysis, analyzing how long these stops last is essential. For this reason, the number of stops is examined within different time intervals: less than 10 minutes, between 10 and 20 minutes, between 20 and 30 minutes, between 30 minutes and 2 hours, and more than 2 hours. Figure 4-29 shows the distribution of these time intervals on the x-axis and the number of stops on the y-axis. Each day of the week is represented by a different color in this figure.

Figure 4-29: Number of Stops Durations Per Week - Antwerp

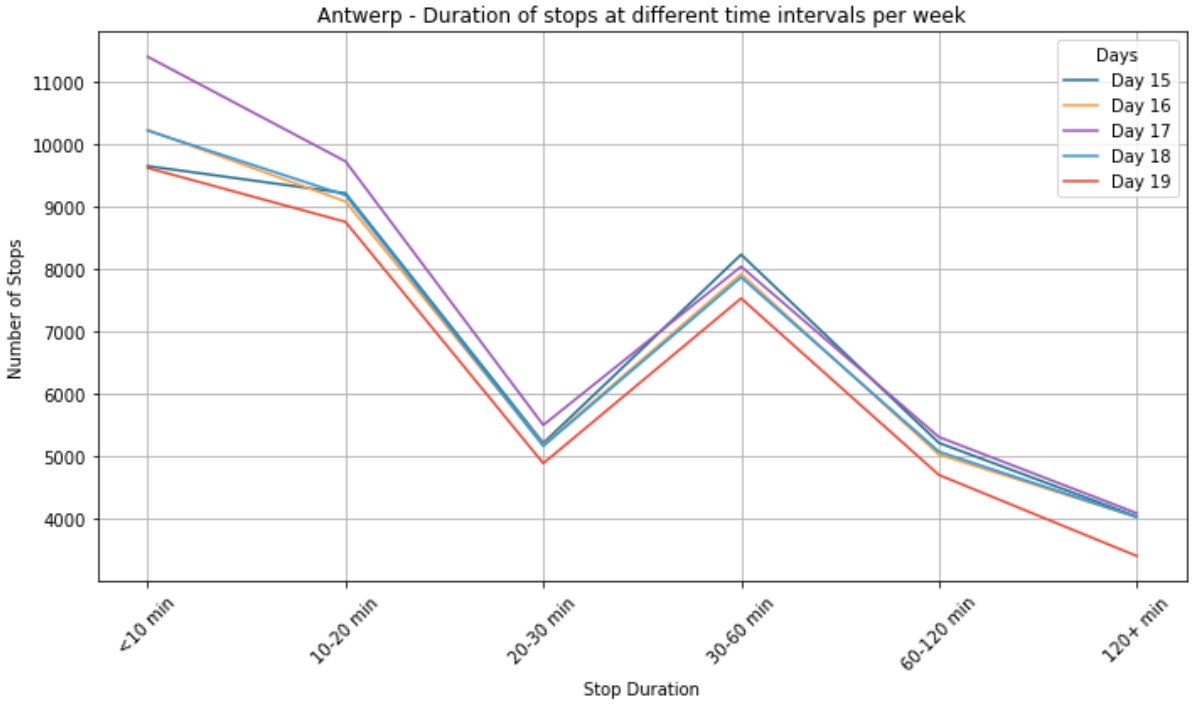


Table 4-9 summarizes the data from the graphs. It shows that approximately 66% of the stops are within three intervals: less than 10 minutes, between 10 and 20 minutes, and between 30 minutes and 1 hour. While the differences are insignificant, most stops last between 30 minutes and 1 hour. These percentages are reflected in the concentrations observed in the respective intervals and with a green underline in the tables.

Table 4-9: Number of Stops Durations Per Day - Ghent

Time stops	Day 15		Day 16		Day 17		Day 18		Day 19	
	Stops	**%**	**Stops**	**%**	**Stops**	**%**	**Stops**	**%**	**Stops**	**%**
<10 min	9652	23%	10231	25%	11405	26%	10221	25%	9622	25%
10-20 min	9217	22%	9083	22%	9728	22%	9185	22%	8757	23%
20-30 min	5211	13%	5180	12%	5500	12%	5164	12%	4886	13%
30-60 min	8233	20%	7921	19%	8041	18%	7869	19%	7531	19%
60-120 min	5214	13%	5028	12%	5308	12%	5074	12%	4700	12%
120+ min	4035	10%	4025	10%	4088	9%	4025	10%	3401	9%

Now, the same analysis has been done for the city center area. Figure 4-30 shows the time interval distribution, like the previous analysis. This figure shows each day of the week in a different color.

Figure 4-30: Number of Stops Durations Per Week - Center of Antwerp

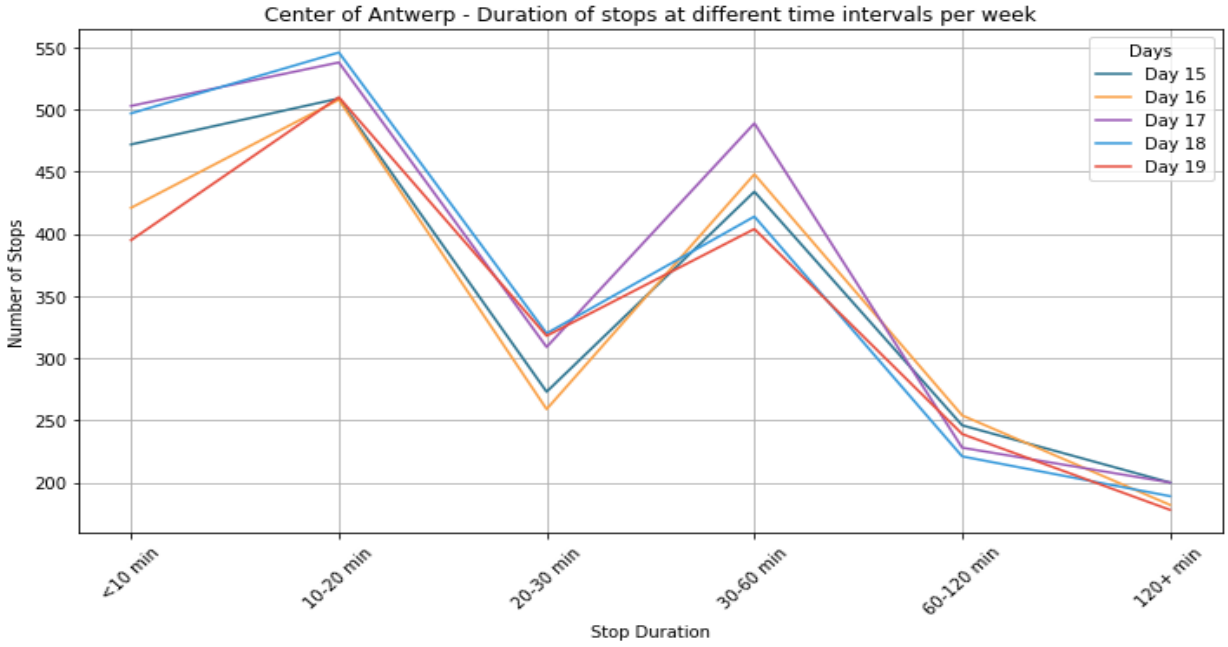


Table 4-10 summarizes the data from these graphs. Approximately 66% of the stops are at the same three-time intervals. Although the differences are not very large, on most days, the stops are concentrated between 10 and 20 minutes. These percentages are reflected in the concentrations observed in the respective intervals and with a green underline in the tables.

Table 4-10: Number of Stops Durations Per Day – Center Ghent

Time stops	Day 15		Day 16		Day 17		Day 18		Day 19	
	Stops	**%**	**Stops**	**%**	**Stops**	**%**	**Stops**	**%**	**Stops**	**%**
<10 min	472	22%	421	20%	503	22%	497	23%	395	19%
10-20 min	509	24%	508	25%	538	24%	546	25%	510	25%
20-30 min	273	13%	259	13%	309	14%	320	15%	318	16%
30-60 min	434	20%	448	22%	489	22%	414	19%	404	20%
60-120 min	246	12%	254	12%	228	10%	221	10%	239	12%
120+ min	200	9%	182	9%	200	9%	189	9%	178	9%

Finally, the origin and destination of tours stopping in Antwerp and those stopping only in the city center are analyzed.

Figure 4-31: Percentage of Internal and External Starting and Final Points – Antwerp

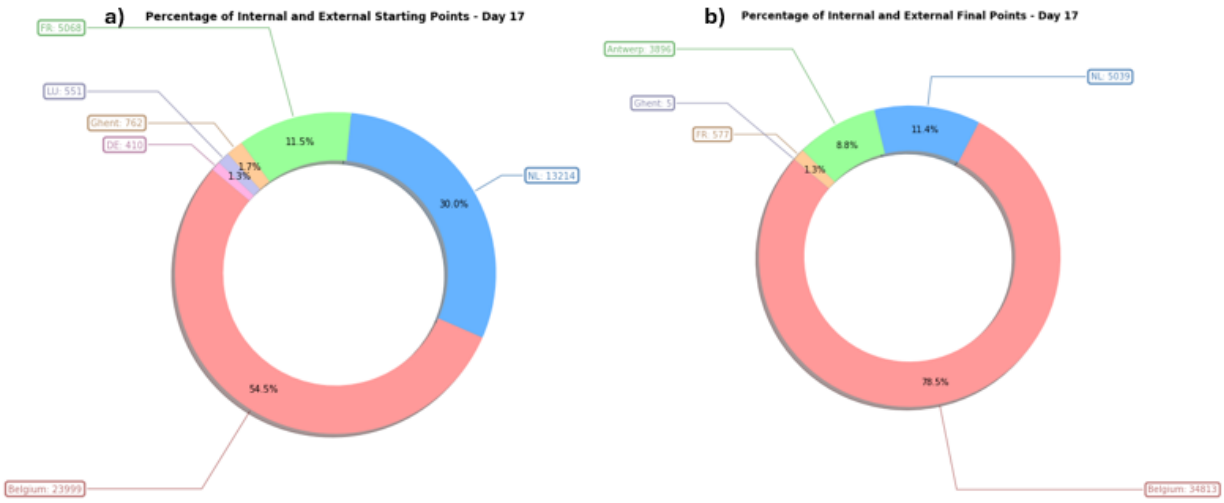


Figure 4-31 (a, b) shows the Starting Points (a) and Final Points (b) of the trips stopping in Antwerp on the 17th, which is selected because it is the day with the most tours. All other days show the same behavior. Figure 4-31(a) shows that approximately 55% of the trips start in Belgium, meaning they begin at different points, excluding Ghent and Antwerp. In the second place, 30% of the trips begin in the Netherlands, and 12% start in France. Figure 4-16(b) shows that approximately 79% of the trips end within Belgium. In second place, 12% of the trips end in the Netherlands, and 9% end within Antwerp.

Figure 4-32: Percentage of Internal and External Starting and Final Points – Center of Ghent

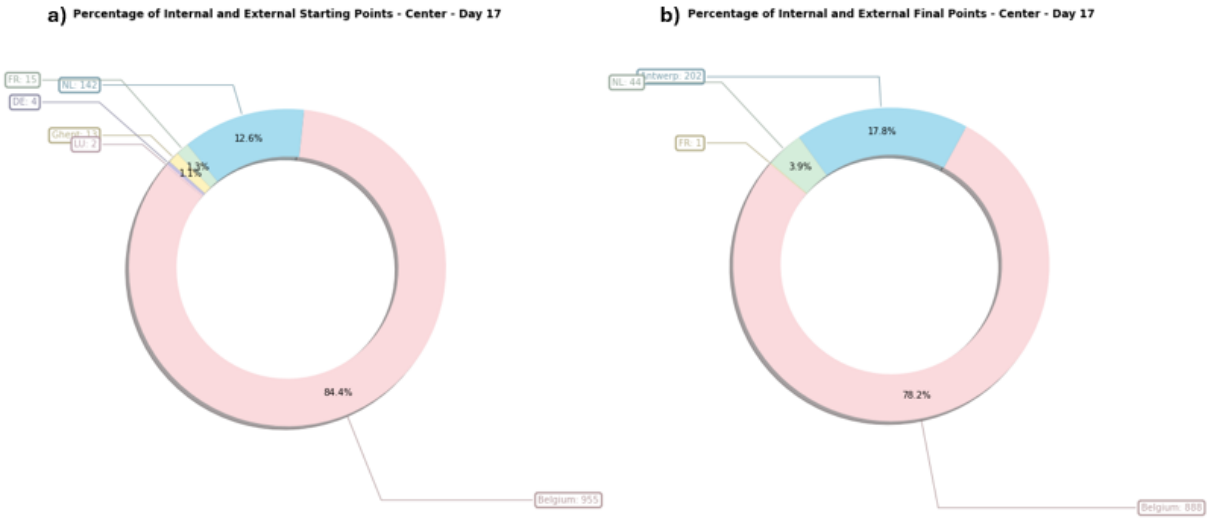


Figure 4-32 (a, b) shows the Starting Points (a) and Final Points (b) of the trips stopping in the center of Antwerp on the 17th, with all other days showing the same behavior. In Figure 4-32(a), it can be seen that around 85% of the trips start within Belgium, while 18% start in Antwerp itself, which is an important detail. Figure 4-32(b) shows that 78% of the trips end within Belgium, while 18% end in Antwerp.

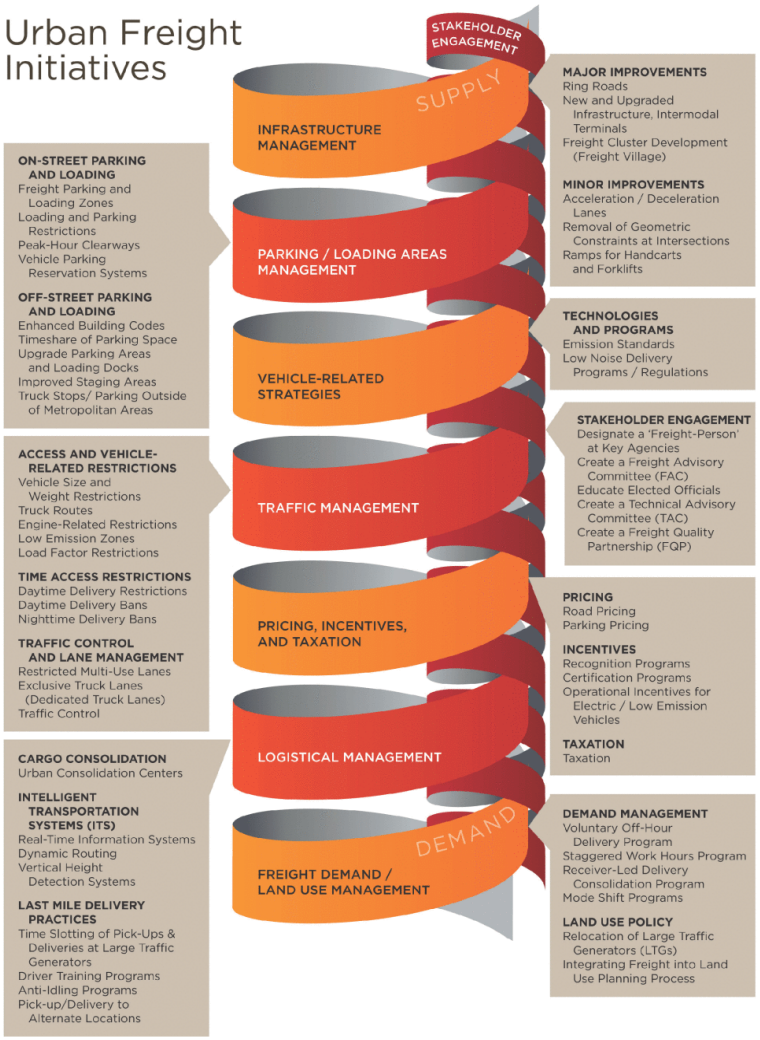
5. Critical Point Analysis

The main objective of this research is to propose public sector initiatives for urban freight transport planning based on GPS data from truck routes. The focus is analyzing residential area stops and identifying commercial zones to optimize logistics processes. The critical points of the two cities in the case study are examined to achieve this, along with the areas where stops are concentrated, as identified in the previous chapter.

For the proposal of these initiatives, the *NCFRP Report 33: Improving Freight System Performance in Metropolitan Areas: A Planning Guide* is used as a reference. This report provides a regional planning guide that identifies potential strategies and practices for both the public and private sectors to improve freight movement performance in various urban areas. It also includes a tool for selecting initiatives to help address different problems (Transportation Research Board & of Sciences Engineering, 2015). This report presents a wide range of initiatives, which are categorized into eight main groups, as shown in Figure 5-1:

- Infrastructure management
- Parking/loading areas management
- Vehicle-related strategies
- Traffic management
- Pricing, incentives, and taxation
- Logistical management
- Freight demand/land use management
- Stakeholder engagement

Figure 5-1: Districts of Ghent.



Source: (Transportation Research Board & of Sciences Engineering, 2015)

It is important to note that this guide does not replace the proper analysis of any specific initiative's potential to solve a particular urban problem. It is always crucial to analyze in-depth and consider the exact characteristics of the problem. This study will combine the guide with the findings from the specific cities analyzed.

5.1 Ghent.

Analyzing city center areas is very important, especially in Europe, where these zones are historically commercial and touristic. City centers often have narrow streets and older infrastructure, which makes planning more complicated. Also, many different actors, such as businesses, residents, tourists, and delivery vehicles, come together in these areas, increasing the chance of mobility and space use conflicts. This is why special attention is given to these areas to balance economic development, the flow of people and vehicles, and the preservation of cultural value. Proper planning here is essential to avoid congestion and ensure everyone can share the space harmoniously.

With all the results found in the analysis of Chapter 4, some key points deserve a deeper look, such as the times with the highest number of trucks and stops and the duration of the stops. Therefore, we first focus on the most frequent stop times: less than 10 minutes, between 10 and 30 minutes (these intervals are combined for a more complete analysis), and from 30 minutes to 1 hour. The remaining stops are grouped into an interval of more than one hour. These intervals are analyzed using geospatial tools to locate Hotspots in the city center. The purpose is to examine where most of these stops occur and suggest possible solutions, alternatives, or policies to help improve stop times.

The areas with the highest concentration of stops were analyzed, and the best way to do this was by comparing them with the districts that divide the center of Ghent. For this purpose, open data from the city's official website was used (see https://data.stad.gent/). In Figure 5-2, the 25 districts of Ghent are shown, but seven were analyzed in detail since the focus is on the city center (Figure 5-3). These images show how the districts are divided and assigned different shades of red, with the darkest red representing the most populated districts and lighter shades representing the least populated ones. The districts with the most stops were examined to determine if they were mainly commercial or residential areas to propose the most suitable initiatives for each zone.

Figure 5-2: Districts of Ghent.

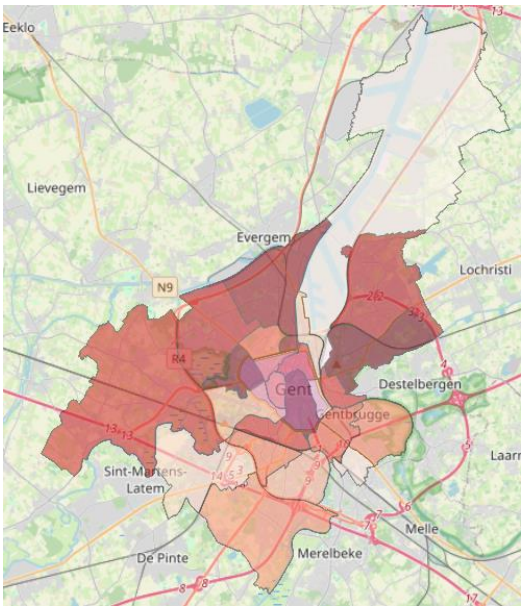


Figure 5-3: Districts Center of Ghent.

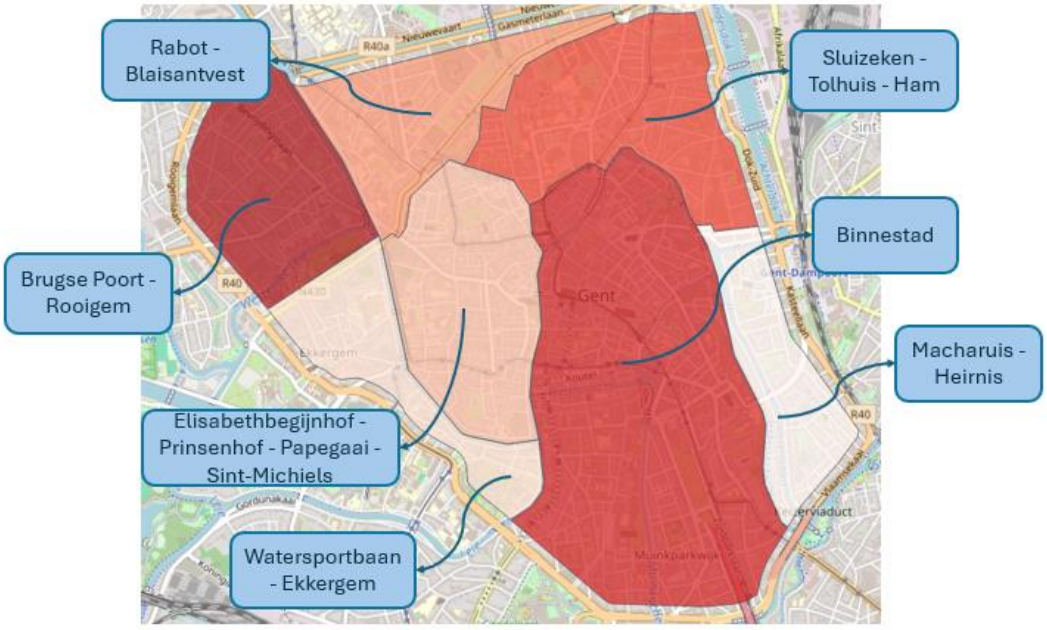
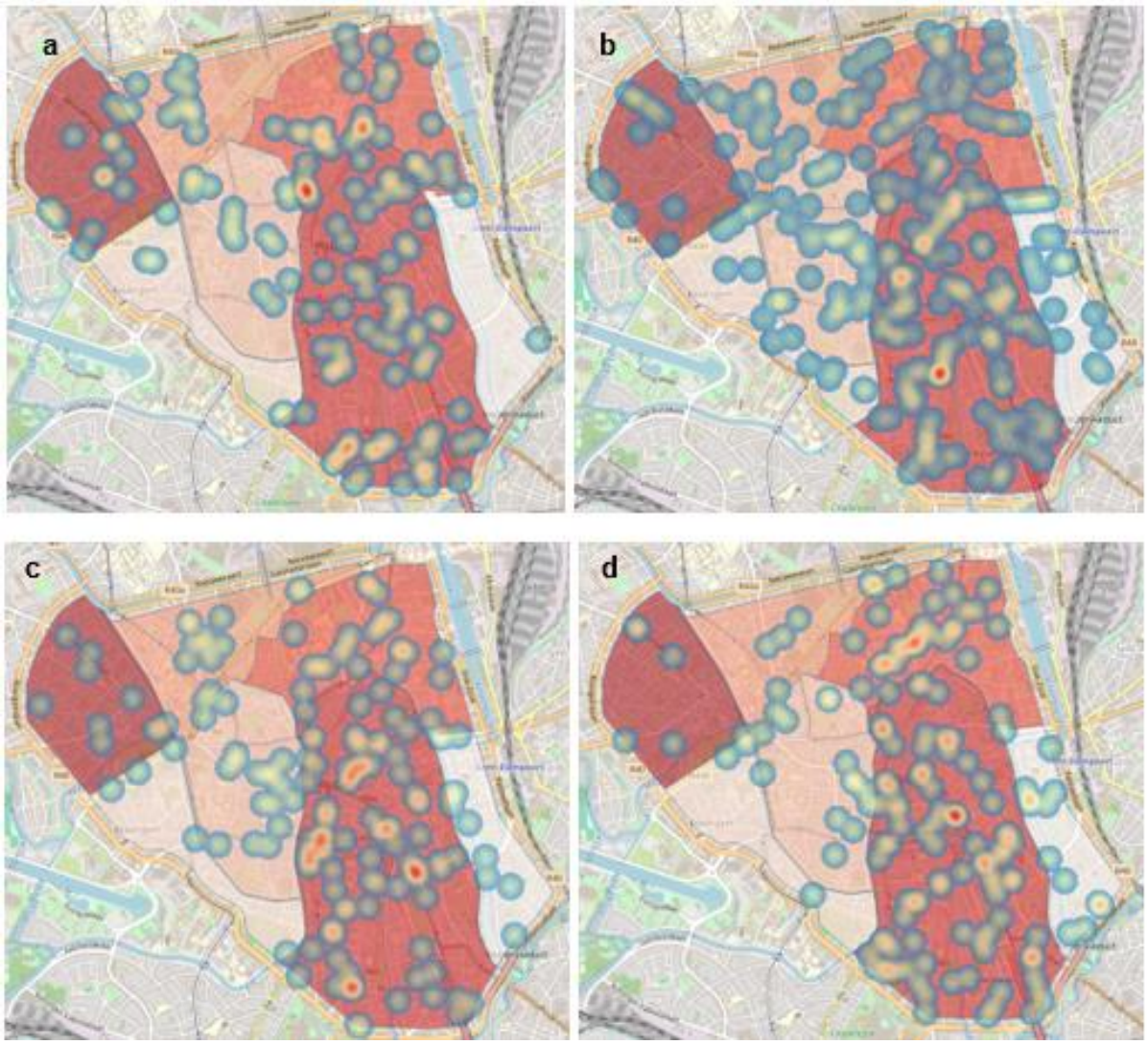


Figure 5-4 shows the different hotspots formed at each time interval. Figure 5-4(a) displays stops of less than 10 minutes, Figure 5-4(b) shows stops between 10 and 30 minutes,

Figure 5-4(c) covers stops between 30 minutes and 1 hour, and Figure 5-4(d) shows stops longer than one hour.

Figure 5-4: Hotspots at different time intervals - Ghent Center.



The hotspots are mainly concentrated in three districts: first, Binnestad; second, Sluizeken-Tolhuis-Ham; and third, Brugse Poort – Roogem.

Binnenstad, translated from Dutch as "city center," is Ghent's cultural, economic, and historical core. This district also hosts many of the city’s higher education institutions. It is a commercial area with branches of major retail chains and numerous smaller local businesses. Binnenstad is densely populated, with 7.2% of Ghent's population.

Sluizeken-Tolhuis-Ham is one of the city's most densely populated and urbanized neighborhoods. This diversity and population density put pressure on public space, creating a high need for more public areas. It is divided into four neighborhoods, one of which, Tolhuis, is known for its many Turkish restaurants, fruit and vegetable shops, and fabric stores. Another part of the area is changing, with new constructions increasing.

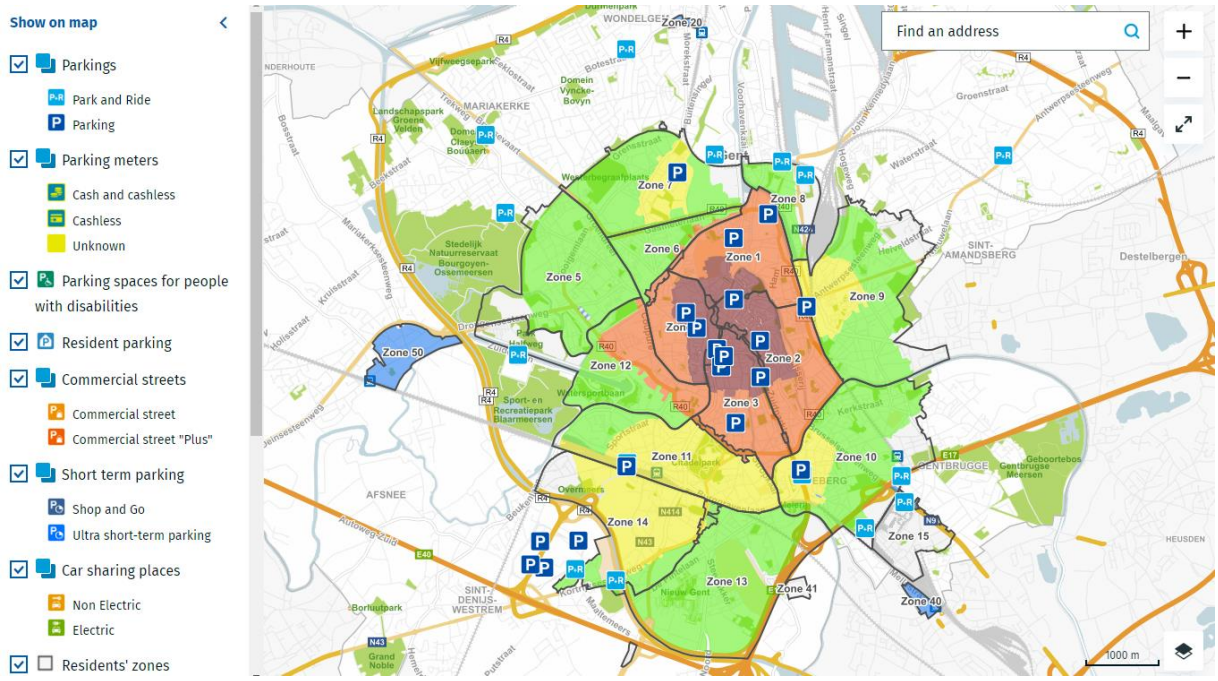
Brugse Poort – Roogem is a much larger district, divided by the ring road surrounding the city center. The image only shows the neighborhoods within the ring road. This district holds 7.3% of Ghent’s population and is primarily residential, one of the oldest neighborhoods. The division caused by the ring road leads to tensions due to traffic issues, and residents have reported security concerns. This district also shows significant economic differences among its residents. Some struggle with unemployment and poverty, while others enjoy financial stability. This makes it a "dual" district, marked by apparent inequalities.

The aim of describing each of the districts with identified hotspots is to support the proposed initiatives mentioned at the beginning of this chapter, based on the NFCRP 33 report. Figure 5-4(b) shows a high concentration of blue tones, which, although not hotspots, indicate the time interval with the highest number of stops, distributed across all sectors. Key characteristics such as land use are considered, with some areas being more commercial than others. Binnenstad is particularly interesting because, according to its description, it combines a high level of commercial activity with a densely populated area, suggesting a mixed land use. Additionally, as it is a historical area with limited space, policies here cannot focus on infrastructure management.

The initiatives focus mainly on parking/loading areas management for critical areas. A highlighted proposal is the implementation of vehicle parking reservation systems, where reserved spaces are assigned for trucks to load and unload. Although there is a risk that trucks may cause more congestion or interfere with others while searching for space to reserve, this measure can be combined with time sharing of parking space, which promotes shared use of parking spaces. Traffic management initiatives like daytime delivery restrictions are also suggested and are currently combined with pricing strategies. Figure 5-5 shows the designated parking areas, with the studied districts in the orange zone. This area has the following regulations: paid parking from 9 am to 11 pm, a maximum of 5 hours of parking between 9 am and 7 pm, free parking from 11 pm to 9 am on Sundays and public

holidays, as well as free parking with a ticket for 2 x 20 minutes per day (Stad Ghent, 2024b).

Figure 5-5: Web map of street parking rate zones.



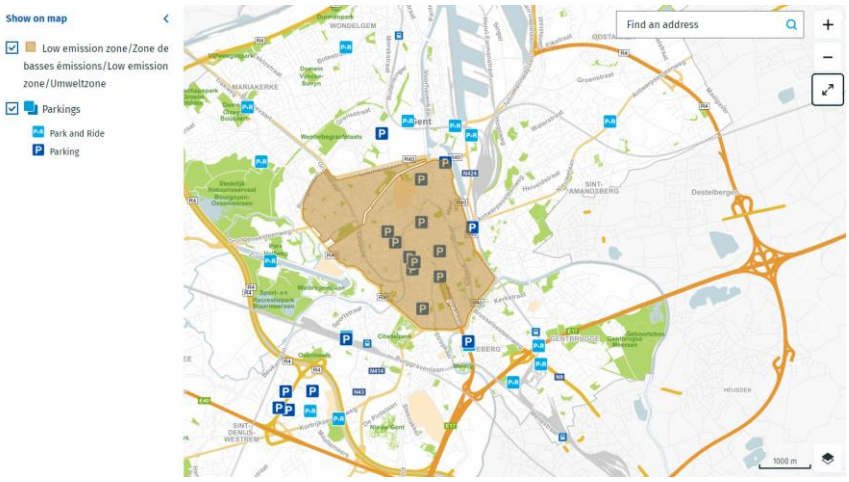
Source: (Stad Ghent, 2024b)

Although these measures are a good start, the results from the previous chapter show that peak stop times occur when parking is free. Additionally, the old streets do not have marked parking spaces in central areas with more shops and restaurants, so trucks park anywhere.

Logistically, several hotspots are located near the borders between the Binnenstad and Sluizeken-Tolhuis-Ham districts. Therefore, one proposal is to find a point between these two areas to build an urban consolidation center, especially since the second district is under development. In the southern part of Binnenstad, where there is a lack of space, receiver-led delivery consolidation programs that do not require additional infrastructure could be considered. In this model, one provider delivers their goods to another, who then makes the final delivery to the customer. The consolidation center and receiver-led delivery consolidation programs could be combined with mode shift programs, encouraging alternative transport methods like cargobikes.

It is highlighted that the city has designated low-emission zones, as shown in Figure 5-6. These zones specify the types of vehicles that can enter freely. Vehicles that do not meet the requirements can purchase a special pass, but there is a limit on the number of passes available (Stad Ghent, 2024a). The restrictions are mainly related to the type of fuel used by vehicles and their Euro value, a reference to the European pollution class. While these measures are necessary for reducing emissions, it is also essential to consider that even though some vehicles help reduce or eliminate emissions, they still occupy the same space in urban areas.

Figure 5-6: Low emissions zones.



Source: (Stad Ghent, 2024a)

5.2 Antwerp.

Antwerp was also analyzed because it is the second most populated city in Belgium after the capital, and its port is the second most important in Europe, making it a bustling city. Although Antwerp is very different from Ghent, the results from Chapter 4 show that the behavior of trucks in both towns has some similarities. Key points, such as the times with the highest number of trucks and stops and the duration of these stops, deserve a closer look. For this reason, we focused on the most frequent stop durations: less than 10 minutes, between 10 and 30 minutes (these intervals are combined for a more complete analysis), and from 30 minutes to 1 hour. The remaining stops are grouped into an interval of more than one hour. These time intervals were analyzed using geospatial tools to locate hotspots

in the city center. The goal was to understand where most of these stops occur and suggest possible solutions, alternatives, or policies to improve stop times.

We analyzed the areas with the highest concentration of stops by comparing them with the districts that divide the center of Antwerp. Open data from the official city website was used for this analysis (see https://www.antwerpen.be/data-en-onderzoek). Figure 5-7 shows the districts of Antwerp, and 22 districts were specifically analyzed, focusing on the city center. Some of the districts to which the results will be related are named. (Figure 5-8). In these images, the districts are divided into different shades of red, with the darkest representing the most populated areas and the lightest representing the least populated. The districts with the most stops were examined to determine whether they were mainly commercial or residential areas to propose the most appropriate initiatives for each zone.

Figure 5-7: Districts of Antwerp.

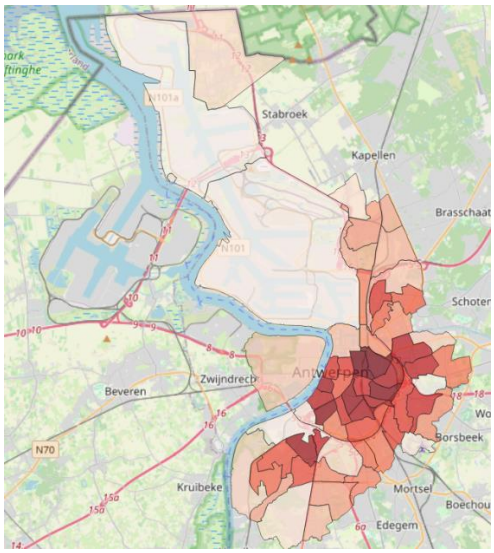


Figure 5-8: Districts Center of Antwerp.

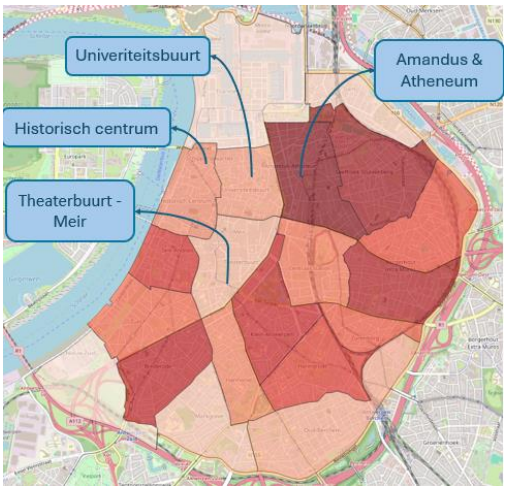
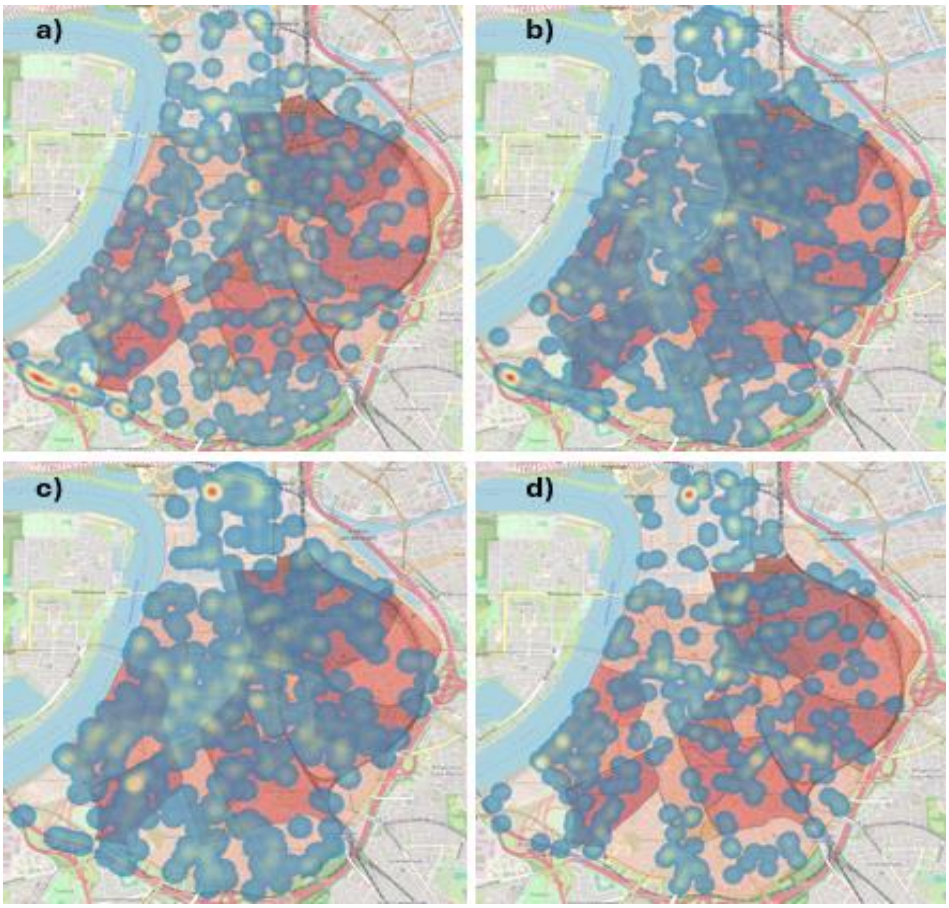


Figure 5-9 shows the different hotspots formed at each time interval. Figure 5-9(a) displays stops of less than 10 minutes, Figure 5-9(b) shows stops between 10 and 30 minutes, Figure 5-9(c) covers stops between 30 minutes and 1 hour, and Figure 5-9(d) shows stops longer than one hour.

Figure 5-9: Hotspots at different time intervals – Center of Antwerp.



In these heat maps, the concentration points are more dispersed because the affected area is more significant. However, in Figure 5-9(b-c-d), in the upper left corner, there is a recurring concentration point near one of the borders of the city center. In this specific location, there is a consolidation center for a crucial logistics company, which is significant because it confirms that the stops with longer durations tend to concentrate in this area.

On the other hand, we focus on the areas with more concentrated yellow tones. In Figure 5-9(a), there is a higher concentration of stops between Amandus & Atheneum and Universiteitsbuurt districts. This area is mainly residential and student-based, as it is near the University of Antwerp and is also close to several hotels due to its proximity to the city's central commercial zone. Although the concentration decreases in Figures 5-9(b-d) compared to the redder areas, it still stands out in the exact location, which justifies a closer look at this area of interest, shown in Figure 5-10.

Figure 5-10: Hotspots - Center of Antwerp.

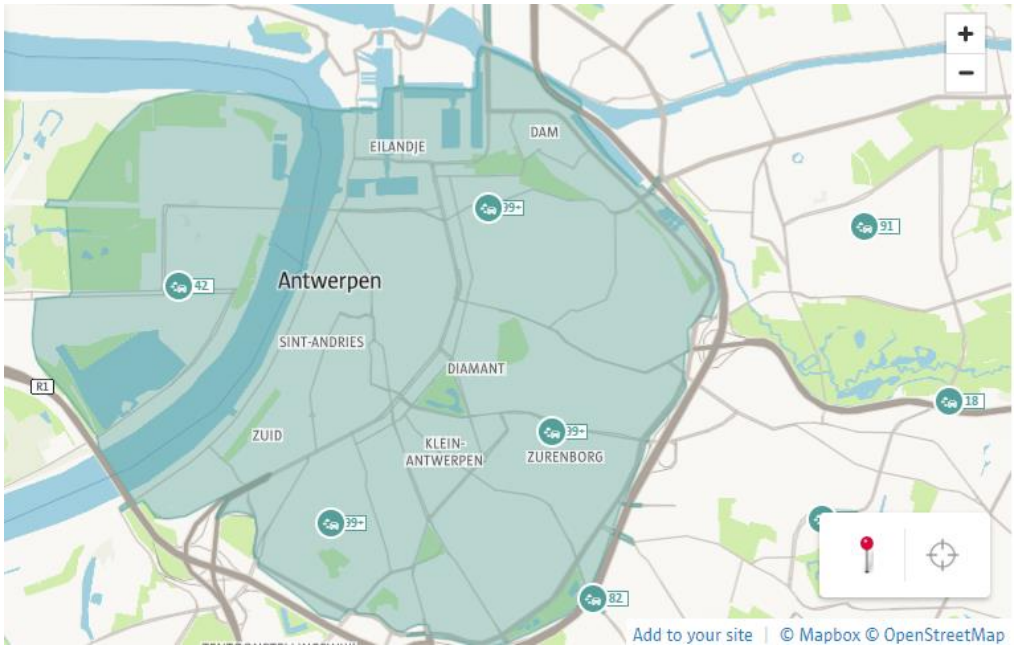
This concentration is mainly seen in the district of Theaterbuurt – Meir, where stops are grouped in three key spots. To the right, around the iconic opera building, there is a commercial area with supermarkets and restaurants. In the center, 'Meir' Street, the main commercial street in the city, has many clothing stores, personal items, and wholesale and retail chains. Finally, to the left, near Groenplaas Square and the intersection with Nationalestraat located in the district Historisch Centrum, there is another concentration point, where restaurants, cafés, and bars are dominant.

By analyzing the stop hotspots and the characteristics of each district, such as land use and population density, and using the NCFRP Report 33 as a guide, we propose initiatives and policies to improve urban planning and logistics processes. All the highlighted areas in the analysis have something in common: limited space. These areas have narrow streets, important tram stations, and bike lanes, which make any infrastructure changes difficult.

Parking spaces are very scarce in the Theaterbuurt – Meir district, especially on Meir Street. Unlike in Ghent, applying time sharing of parking spaces is not feasible in this part of the city since there is no space for any type of vehicle. However, it would be possible to implement a combination of freight parking and loading zones with restrictions. These restrictions should focus on delivery times, combining them with off-hour deliveries. This is important because the peak time for stops in the city center is 8:00 a.m., when pedestrians and cyclists interact with trucks, causing conflicts between these groups.

Additionally, Antwerp has already implemented a low-emission zone, as shown in Figure 5-11. The restrictions in this zone are similar to those in Ghent, focusing on the Euro value and the type of fuel used by vehicles. It is also possible to buy a pass to enter. While this is a significant step, it must be complemented with other measures, especially considering when these stops concentrate. Therefore, it is proposed that the restrictions of the low emission zone be rethought, with time restrictions added without exceptions and alternatives for deliveries.

Figure 5-11: Low Emissions Zones - Center of Antwerp.



Source: (Stad Antwerpen, 2024)

An alternative that could work in Antwerp, like in Ghent, is the implementation of receiver-led delivery consolidation programs, which do not require additional infrastructure like consolidation centers. In this model, one supplier delivers its goods to another, who then completes the final delivery to the customer. These programs could be combined with mode shift programs that promote alternative transportation, like cargo bikes. These strategies would be especially effective in Historisch Centrum and Universiteitsbuurt districts.

6. Conclusions and recommendations

6.1 Conclusions

This study highlights the essential role of truck stops in urban freight transportation planning, especially in cities facing severe congestion. Truck stops, identified through GPS data analysis, provide valuable information on the operational challenges of urban freight systems. A high percentage of truck routes show atypical stop data, emphasizing the complexity of urban logistics, where GPS data irregularities and congestion contribute to difficulties in accurately identifying stops.

This study used GPS data from truck routes in metropolitan areas of Belgium to develop a methodology for analyzing the duration, location, and type of stops. The research identifies elements that contribute to conflicts between trucks, vehicles, and pedestrians by investigating the relationships between these factors. Furthermore, it shows the variability of stop identification methods, highlighting the need for context-specific adjustments. Previous studies used different thresholds for detecting stops, reflecting the uniqueness of urban environments and GPS data accuracy. This study proposes reducing the stop duration threshold to 5 minutes, a key measure for accurately capturing the behavior of urban routes.

The methodological approach, which includes speed, distance, and time analysis, offers a more detailed understanding of stop characteristics and their causes. Moreover, it highlights that this methodology is adaptable and applicable in different urban contexts, using various types of GPS data and combining several factors analyzed in this research.

The second part of this study analyzes how the results of the methodology can be applied to better understand truck behavior in urban areas, especially regarding stops. Many cities' road networks face severe congestion, causing air pollution and noise for residents due to

transportation activities. Cities need solutions for inadequate loading and unloading areas, roadwork, and time restrictions.

For these reasons, analyses were conducted in two different cities, evaluating stop duration, stop concentration by time of day, the number of stops per truck, the number of trucks, and the origin-destination of trips stopping in these urban areas. These findings provide a general overview of how trucks occupy public space and how this affects other city actors. One of the main findings is that the highest stop concentrations in both cities are between 10 and 20 minutes and between 30 minutes and 1 hour, with peak hours from 8:00 to 9:00. Additionally, it was confirmed that approximately 61% to 63% of trucks entering the city make only one stop.

Based on these findings, a more detailed analysis was conducted using geospatial tools to identify the points with the highest stop concentration in different time intervals. The cities were divided into districts, providing relevant information for designing specific policies and initiatives for each area. This comparative approach also allowed a review of current policies, revealing significant points for improvement.

The analysis concludes that current measures should be adjusted, as not all areas have the same conditions. Policies must be adapted to the specific characteristics of each district since a single measure for the entire city may not be effective in all areas.

6.2 Recommendations

Several challenges were encountered throughout this study, and there are still opportunities to improve and expand this research.

First, regarding the methodology, while GPS data provided valuable results, validating the information with reference points that increase accuracy is always important. It is also necessary to compare and calculate the precision of this method with other approaches to ensure more reliable results.

As for the case study in Belgium, once the methodology is applied and truck stop information is obtained, it can be used in any city. However, a recommendation for future

research in Belgium is to consider that both towns have important ports that move goods within their area or to other cities. It would be interesting to study whether there is a relationship between these truck journeys from the ports to urban areas. This could help understand more accurate patterns and make better decisions from another perspective, addressing the issue before the trucks enter urban areas.

In terms of analyzing specific areas within cities, such as the districts studied here, developing more detailed models that include other socioeconomic variables is recommended. In this case, only population and land use were analyzed, but variables like income, number of businesses, and other factors could provide a more detailed understanding of each area.

It is also essential to understand that interconnected cities often share similar problems, but they can also have differences. It would be valuable to explore large-scale initiatives to optimize logistics processes not only at the city level but also at the national level. In Belgium, for example, a single truck may interact with more than one city in a single day and may face decisions that are not ideal for entering urban areas. A nationwide policy could help improve efficiency and reduce logistical conflicts.

Bibliography

Adam, A., Finance, O., & Thomas, I. (2021). Monitoring trucks to reveal Belgian geographical structures and dynamics: From GPS traces to spatial interactions. *Journal of Transport Geography*, *91*, 102977. https://doi.org/https://doi.org/10.1016/j.jtrangeo.2021.102977

Akter, T., Hernandez, S., Diaz Corro, K., & Ngo, C. (2018). *Leveraging open-source GIS tools to determine freight activity patterns from anonymous GPS data*.

Belgian Federal Government. (2024). *Geographical description of Belgium*. https://www.belgium.be/en/about_belgium/country/geography#:~:text=Belgium%20is%20situated%20in%20the,and%20the%20west%20by%20France.

Bjørgen, A., & Ryghaug, M. (2022). Integration of urban freight transport in city planning: Lesson learned. *Transportation Research Part D: Transport and Environment*, *107*, 103310. https://doi.org/https://doi.org/10.1016/j.trd.2022.103310

Bø, E., & Mjøsund, C. (2022). Use of GPS-data to improve transport solutions in a cost and environmental perspective. *Transportation Research Interdisciplinary Perspectives*, *13*, 100557. https://doi.org/https://doi.org/10.1016/j.trip.2022.100557

Brinkhoff, T. (2024). *City Population*. http://www.citypopulation.de

Camargo, P., Hong, S., & Livshits, V. (2017). Expanding the Uses of Truck GPS Data in Freight Modeling and Planning Activities. *Transportation Research Record*, *2646*(1), 68–76. https://doi.org/10.3141/2646-08

Cui, J., Dodson, J., & Hall, P. V. (2015). Planning for Urban Freight Transport: An Overview. *Transport Reviews*, *35*(5), 583–598. https://doi.org/10.1080/01441647.2015.1038666

Demissie, M. G., & Kattan, L. (2022). Estimation of truck origin-destination flows using GPS data. *Transportation Research Part E: Logistics and Transportation Review*, *159*, 102621. https://doi.org/https://doi.org/10.1016/j.tre.2022.102621

EUROCITIES. (2024a). *Antwerp*. https://eurocities.eu/cities/antwerp/

EUROCITIES. (2024b). *Ghent*. https://www.citypopulation.de/en/belgium/oostvlaanderen/gent/44021__gent/

Gingerich, K., Maoh, H., & Anderson, W. (2016). Classifying the purpose of stopped truck events: An application of entropy to GPS data. *Transportation Research Part C: Emerging Technologies*, *64*, 17–27. https://doi.org/https://doi.org/10.1016/j.trc.2016.01.002

Holguín-Veras, J., Encarnación, T., Pérez-Guzmán, S., & Yang, X. (Sarah). (2020). Mechanistic Identification of Freight Activity Stops from Global Positioning System Data. *Transportation Research Record*, *2674*(4), 235–246. https://doi.org/10.1177/0361198120911922

Holguín-Veras, J., González-Calderón, C., Sánchez-Díaz, I., Jaller, M., & Campbell, S. (2014). 7 - Vehicle-Trip Estimation Models. In L. Tavasszy & G. de Jong (Eds.), *Modelling Freight Transport* (pp. 143–162). Elsevier. https://doi.org/https://doi.org/10.1016/B978-0-12-410400-6.00007-0

International Transport Forum. (2023). *Key Transport Statistics 2022 Data*.

Jaller, M., Wang, X. (Cara), & Holguín-Veras, J. (2015). Opportunities for city logistics initiatives. *Journal of Transport and Land Use*, *8*(1), 51–67. http://www.jstor.org/stable/26202701

Kin, B., Buldeo Rai, H., Dablanc, L., & Quak, H. (2024). Integrating logistics into urban planning: best practices from Paris and Rotterdam. *European Planning Studies*, *32*(1), 24–44. https://doi.org/10.1080/09654313.2023.2242400

Lægran, J., Pitera, K., & Tørset, T. (2023). Carrier-provided freight data for improved sustainable urban mobility planning. *Research in Transportation Economics*, *102*, 101352. https://doi.org/https://doi.org/10.1016/j.retrec.2023.101352

Lindawati, van Schagen, J., Goh, M., & de Souza, R. (2014). Collaboration in urban logistics: motivations and barriers. *International Journal of Urban Sciences*, *18*(2), 278–290. https://doi.org/10.1080/12265934.2014.917983

Mjøsund, C. S., & Hovi, I. B. (2022). GPS data as a basis for mapping freight vehicle activities in urban areas – A case study for seven Norwegian cities. *Research in Transportation Business & Management*, *45*, 100908. https://doi.org/https://doi.org/10.1016/j.rtbm.2022.100908

Ortuzar, J. de D., & Willumsem, L. G. (2011). *Modeling Transport* (Fourth).

Sakai, T., Kawamura, K., & Hyodo, T. (2020). Logistics facilities for intra and inter-regional shipping: Spatial distributions, location choice factors, and externality. *Journal of Transport Geography*, *86*, 102783. https://doi.org/https://doi.org/10.1016/j.jtrangeo.2020.102783

Sharma, S. K., & Singh, A. P. (2023). Urban logistics stakeholder priority assessment to improve urban planning policy. *International Journal of Construction Management*, *23*(16), 2869–2878. https://doi.org/10.1080/15623599.2022.2106042

Stad Antwerpen. (2024). *Low Emission Zone*. https://www.slimnaarantwerpen.be/en/lez

Stad Ghent. (2024a). *Lage-emissiezone Gent*. https://stad.gent/nl/mobiliteit-openbare-werken/lage-emissiezone

Stad Ghent. (2024b). *Parkeertarieven op straat*.

Statbel. (2024). *Belgium in figures*. https://statbel.fgov.be/en

Statista Research Department. (2024). *The cities and municipalities with the highest population in Belgium in 2022*.

Statistical Office of the European Union - Eurostat. (2024, April 15). *Freight transport statistics - modal split*.

The Bussiness Research Company. (2024). *Road Freight Transport Global Market Report*.

Transportation Research Board, & of Sciences Engineering. (2015). *Improving Freight System Performance in Metropolitan Areas: A Planning Guide* (J. Holguín-Veras, J. Amaya-Leal, J. Wojtowicz, M. Jaller, C. González-Calderón, I. Sánchez-Díaz, X. Wang, D. G. Haake, S. S. Rhodes, R. J. Frazier, M. K. Nick, J. Dack, L. Casinelli, & M. Browne, Eds.). The National Academies Press. https://doi.org/10.17226/22159

Viapass. (2011). *ABOUT VIAPASS*. https://www.viapass.be/over-viapass/

Wang, S., Zhao, J., Shao, C., Dong, C., & Yin, C. (2020). Truck Traffic Flow Prediction Based on LSTM and GRU Methods With Sampled GPS Data. *IEEE Access*, *8*, 208158–208169. https://doi.org/10.1109/ACCESS.2020.3038788

Yang, X., Sun, Z., Ban, X. J., & Holguín-Veras, J. (2014). Urban Freight Delivery Stop Identification with GPS Data. *Transportation Research Record*, *2411*(1), 55–61. https://doi.org/10.3141/2411-07

Yang, Z., Chen, X., Deng, J., Li, T., & Yuan, Q. (2023). Footprints of goods movements: Spatial heterogeneity of heavy-duty truck activities and its influencing factors in the urban context. *Journal of Transport Geography*, *113*, 103737. https://doi.org/https://doi.org/10.1016/j.jtrangeo.2023.103737

You, S. I., & Ritchie, S. G. (2019). Tour-Based Truck Demand Modeling with Entropy Maximization Using GPS Data. *Journal of Advanced Transportation*, *2019*, 5021026. https://doi.org/10.1155/2019/5021026