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Ph.D. Thesis

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Urban Transportation Poverty: a Model for Assessing Transportation Poverty in Metropolitan Areas

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Dedication

To my family, I dedicate this dissertation with all my love and gratitude. Your unwavering support, encouragement, and sacrifices have made this achievement possible. Throughout the long journey of research and writing, you have been my anchor—reminding me of the importance of perseverance when challenges seemed too great and celebrating even the smallest milestones with me along the way. Your patience when my time and attention were consumed by study, your belief in my abilities even when I doubted myself, and your constant love have been the foundation upon which this work rests. This accomplishment is not mine alone—it belongs to you as well.

To my supervisor, I extend my deepest thanks and dedicate this work in recognition of your invaluable guidance. Your expertise, insight, and encouragement have shaped this dissertation in profound ways. From refining the first ideas into a workable framework to navigating the complexities of modelling and analysis, your mentorship has been both rigorous and supportive. You challenged me to think critically, to aim higher, and to remain committed to excellence. For your patience, dedication, and belief in my work, I will always remain grateful.

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To my family, my supervisor, and Mr. Almadhoun—this dissertation is dedicated to you, with heartfelt appreciation for your guidance, love, and inspiration. Without you, this journey would not have been possible.

Streszczenie

Tytuł pracy doktorskiej: *Zubożenie transportowe w miastach: model oceny zubożenia transportowego w obszarach metropolitalnych*

Zubożenie transportowe stało się poważnym problemem w rozwoju miast, wpływającym na sprawiedliwość społeczną, dostępność do usług transportowych i integrację ekonomiczną. Jest coraz poważniejszym problemem, ale często pomijanym w dyskursie, który wpływa na jakość życia w obszarach metropolitalnych, miejskich. Odnosi się ono do ograniczonego lub nieodpowiedniego dostępu do przystępnego cenowo, niezawodnego i wydajnego transportu, co w szczególności dotyczy społeczności o niskich dochodach i marginalizowanych. W miarę jak miasta się rozrastają i ulegają urbanizacji, zrozumienie i zajęcie się problemem zubożenia transportowego ma kluczowe znaczenie dla promowania sprawiedliwości społecznej, potęgowania możliwości gospodarczych i zrównoważonego rozwoju miast. Niniejsza praca analizuje zubożenie transportowe poprzez ustrukturyzowane ramy, które obejmują przegląd literatury, opracowanie modeli koncepcyjnego i formalnego oraz modelowanie i testowanie oparte na symulacjach. Rozdział 1 pracy rozpoczyna się od zdefiniowania pojęcia zubożenia transportowego w porównaniu z innymi podobnymi pojęciami, takimi jak zubożenie dostępności, narażenie na efekty zewnętrzne transportu, ograniczenie mobilności, przystępność cenowa transportu, identyfikacja wskaźników ryzyka oraz analiza metod oceny przystępności cenowej, mobilności, dostępności i narażenia na efekty zewnętrzne. Aby opracować metodę oceny zubożenia transportowego, należało również omówić istniejące miary tego zjawiska, w tym miary przystępności cenowej, mobilności, dostępności oraz narażenia na skutki zewnętrzne transportu.

W krótkim rozdziale 2 przedstawiono cel, zadania, zakres i tezę pracy doktorskiej, w tym cele cząstkowe podjęte wobec realizacji przedstawionej tezy. Rozdział 3 dotyczy planowania, budowania i łączenia miast z uwzględnieniem tematyki zubożenia transportowego. Zagłębiono się w nim w projektowanie infrastruktury transportu, podkreślając potrzebę analizy danych, udziału interesariuszy i oceniając zagrożenia zw. z nieodpowiednim planowaniem. Przeanalizowano dostępne rozwiązania wobec ulepszenia transportu publicznego.

Rozdział 4 skupia się na modelu koncepcyjnym, który został opracowany jako podstawa modelowania formalnego, tj. modelu matematycznego służącego do oceny zubożenia transportowego w obszarach metropolitalnych, szczegółowo sformułowanego w rozdziale 5, a ostatecznie przekształconego w model korzystający z metod symulacyjnych, opracowany

w celu symulacji dynamiki transportu, który obejmuje generowanie podróży, dystrybucję, wybór środka transportu i przypisanie do sieci, a także analizę dostępności i mechanizmy informacji zwrotnej. Sposób jego konstruowania, opracowywania i weryfikacji przedstawiono w rozdziale 6. W niniejszej pracy wykorzystano metodykę opartą na symulacji przy użyciu oprogramowania PTV VISUM. W badaniu oceniono potencjał oprogramowania w badaniach nad równością społeczną i niwelowaniem zubożenia transportowego.

W rozdziale 7 przedstawiono zastosowanie formalnego modelu oceny zubożenia transportowego w obszarach metropolitalnych w środowisku opartym na symulacjach, a w szczególności omówiono uzyskane wyniki. Wyniki zastosowania modelu omówiono ze szczególnym uwzględnieniem sytuacji zubożenia transportowego w Warszawie. Stanowi to istotną część rozprawy, a badania ukierunkowane są na trzy ważne pytania, na które można znaleźć odpowiedzi w niniejszej pracy. Pytania te są następujące:

(1) W jaki sposób można ocenić zubożenie transportowe w Warszawie za pomocą metody symulacji i ustalonych wskaźników?

(2) W jakim stopniu PTV VISUM jest przydatny do analizy transportu opartej na zasadach sprawiedliwości społecznej?

(3) Jakie sugestie można zaproponować w celu złagodzenia zubożenia transportowego w dzielnicach znajdujących się w trudnej sytuacji?

Aby odpowiedzieć na nie, opracowano matematyczny model formalny służący do oszacowania wielkości zubożenia transportowego. Wdrożenie modelu w przypadku Warszawy pozwoliło na opracowanie symulacji, która uwzględnia takie wskaźniki, jak czas podróży, czas oczekiwania, częstotliwość usług i odległość podróży.

Wyniki badań ilustrują zmiany czasowe między godzinami szczytu a godzinami poza szczytem, ujawniając powstałe nierówności. Wyniki podkreślają znaczenie PTV VISUM i podejść opartych na symulacjach dla identyfikacji słabych punktów i wprowadzania skutecznych, zorientowanych na równość zmian w transporcie. Zarówno model formalny, jak i jego wdrożenie mogą być stosowane jako narzędzie wspomagające podejmowanie decyzji w analizach związanych z rekonfiguracją transportu w systemach transportu miejskiego, mających na celu zmniejszenie problemu zubożenia transportowego.

Rozprawę kończą tematy takie jak: znaczenie poznawcze (aspekty teoretyczne) i utylitarne (aspekty praktyczne) pracy, wnioski, spostrzeżenia metodyczne, implikacje gospodarcze, kierunki przyszłych badań i wreszcie podsumowanie.

Słowa kluczowe: ubóstwo transportowe, symulacja, systemy transportowe, ubóstwo transportowe w miastach, ocena ubóstwa transportowego

Abstract

Dissertation title: *Urban Transportation Poverty: A Model for Assessing Transportation Poverty in Metropolitan Areas*

Transportation poverty has become a major issue in urban development, affecting social fairness, accessibility, and economic inclusion. Urban transportation poverty is a growing yet often overlooked issue that affects the quality of life in metropolitan areas. It refers to limited or inadequate access to affordable, reliable and efficient transport, which disproportionately affects low-income and marginalised communities. As cities continue to grow and become more urbanised, it is crucial to understand and address transportation poverty to promote social equity, economic opportunity and sustainable urban development. This thesis analyses transportation poverty using a structured framework that includes literature reviews, planning processes, conceptual and mathematical models, and simulation-based modelling and testing. Chapter 1 of the dissertation begins by defining terms of transportation poverty in comparison to other, similar terms as accessibility poverty, exposure to transport externalities, mobility poverty, transport affordability, identifying risk indicators, and analysing assessment methods for affordability, mobility, accessibility, and exposure to externalities. To develop a methodology of transportation poverty assessment also the existing transportation poverty measurements had to be discussed, including measures of affordability, measures of mobility, measures of accessibility, and measures of exposure to transport externalities.

A brief Chapter 2 present the aim, objectives, scope and thesis of the dissertation including sub-goals undertaken to fulfil the exposed thesis. While Chapter 3 focus on planning, building, and connecting the city to other ones, taking into account transportation poverty problem. The study then delves into transportation infrastructure design, emphasizing the need of data analysis, stakeholder participation, and effective execution while also evaluating the hazards of inadequate planning. Potential solutions are investigated, including enhancements to public transportation, novel technologies, infrastructure investment, and supportive policies.

Chapter 4 focuses on a conceptual model, which is developed as the fundament of formal modelling, i.e. mathematical model for assessing transportation poverty in metropolitan areas formulated in detail in Chapter 5, and finally transformed into a simulation-based model created to simulate transport dynamics, which includes trip production, distribution, mode selection, and network assignment, as well as accessibility analysis and feedback mechanisms. The way of its constructing, developing and verifying is given in Chapter 6. This thesis uses

a simulation-based methodology to analyse transportation poverty using the PTV VISUM software. The study assesses PTV VISUM's methodological potential in social equality research and investigates how its findings might help influence policy and structural recommendations.

Chapter 7 presents application of a formal model for assessing transportation poverty in metropolitan areas in simulation-based environment, and especially the obtained outcomes are discussed there. The results of using a model are discussed with special interest in transportation poverty situation in Warsaw city. It is significant part of the dissertation and consequently the research is directed by three important questions, the answers of which can be found there. These questions are as follows:

(1) How can transportation poverty in Warsaw be assessed by simulations and established indicator frameworks?

(2) To what extent is PTV VISUM useful for equity-based transportation analysis?

(3) What suggestions can be offered to alleviate transportation poverty in vulnerable districts?

To address these issues, a mathematical model (thus a formal model) is created to estimate transportation poverty. Implementation of a formal model for assessing transportation poverty in metropolitan areas in the case of Warsaw, allowed to develop a simulation which carry out with indications such as traveling times, waiting times, service frequency, and travel distance. The findings illustrate temporal changes between peak and off-peak hours, revealing spatial and social inequities. The findings highlight the importance of PTV VISUM and simulation-based approaches for identifying vulnerabilities and driving effective, equity-oriented transportation rearrangements. Both the formal model and its implementation can be applied as a decision support tool for decision-making analysis related to the reconfiguration of transportation in urban transport systems aiming to lower the problem of transportation poverty.

The dissertation is concluded highlighting topics such as the cognitive relevance (theoretical aspects) and utilitarian significance (practical aspects) concerned during the work, the following realizations, methodological insights, policy implications, broader implications, future research directions, and finally concluding statement.

Key-words: transportation poverty, simulation, transportation systems, urban transportation poverty, transportation poverty assessment

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List of Abbreviations and Definitions

Abbreviations

BRT	Bus Rapid Transit
EPA	Environmental Protection Agency
GIS	geographic information systems
IEA	International Energy Agency
IIJA	Infrastructure Investment and Jobs Act
JRD	Journey Distance
JRT	Journey Time
KPIs	Key Performance Indicators
M1	Metro Line 1
M2	Metro Line 2
M3	Metro Line 3
M4	Metro Line 4
MaaS	Mobility-as-a-Service
OD	Origin-Destination
OSM	OpenStreetMap
OWT	Origin Waiting Time
PPP	public-private partnership
PT	Public Transportation
RIT	Riding Time
SFQ	Service Frequency
TAZs	Traffic Analysis Zones
TPI	Transportation poverty Index
TWT	Transfer Waiting Time
US	United States
ZTM	Public Transport Authority of Warsaw (i.e. Zarząd Transportu Miejskiego)

Definitions of Parameters

$\alpha_1, \alpha_2, \alpha_3, \alpha_4$	Weight factors representing the relative importance of each component in the overall transportation poverty index
β_k	Externality weight factor, which can be determined through policy analysis, transport surveys, and environmental impact assessments
τ	threshold
ρ_m	Reliability - it measures the service's consistency and punctuality
A_i^m	Accessibility score for traveller i using mode m, based on proximity and network coverage. $A_i^m \in \mathbb{R}, \mathbb{R} = [0,1]$
A_o^m	Represents network coverage and proximity to transport services
A_z	number of trips attracted to zone z
C_i	User constraints
C_i^m	Cost of transportation
d	Destination
D	Set of destinations
e	Indicator representing exposure to externalities
E	Set of selected externalities
E_f	Primary externalities affecting transportation poverty (externality factor)
E_i^m	Externality exposure for traveller i, such as air pollution or noise from transport mode m. $E_i^m \in \mathbb{R}, \mathbb{R} = [0,1]$
F_m^*	Normalized frequency
F_i^m	Affordability for traveller i, expressed as the cost of transport C_i^m relative to their income I_i (affordability threshold). $F_i^m \in \mathbb{R}, \mathbb{R} = [0,1]$
F_m	Service frequency - the number of trips per hour or day along the route
F_{max}	Maximum frequency considered feasible
i	Index for traveller

I_i	Traveler's income
m	Transportation modes
M	Set of transportation modes
M_i^m	Mobility measure for traveller i using mode m, representing ease of movement (inverse of travel time). $M_i^m \in \mathbb{R}, \mathbb{R} = [0,1]$
N	Number of travellers or individuals
o	Origin
O	Set of origins
P_z	the total number of trips produced in zone z
$Q_{od}^m(i)$	Probability that traveller i can access a destination d from their origin o using mode m
$R_{od}^m(i)$	Route availability - this key determinant indicates whether a transport connection exists between the origin and destination using mode m
$S(o_i, d_i)$	Distance between origin o_i and destination d_i
T_i^m	Travel time [min] for traveller i (an individual) using mode m
t_o	on-time trips
t_{tot}	total trips

Introduction

Transportation poverty can be defined as a condition in which a transportation system's performance fails to provide adequate accessibility; as measured by indicators such as travel time, cost, connectivity, and reliability, so that individuals are unable to reach essential destinations within reasonable time-frames/thresholds (Lucas, et al., 2016; Martens & Bastiaanssen, 2019). Urban transportation poverty refers in the actual dissertation to the systematic investigation of inequalities in urban mobility using engineering methods, models, and indicators to measure and assess transportation poverty in metropolitan areas. *Urban transportation poverty* is defined as a situation in which individual or groups have limited access to passenger transportation system, prohibitive travel costs, limited mobility options, or disproportionate exposure to externalities such as traffic and pollution, and at the same time individual or groups is/are inhabitants of urban areas. Exploring this topic highlights the cross-connection of mobility, inequality, and urban planning, offering policymakers a framework to assess and reduce transportation-related disadvantages in metropolitan areas, so does the model for its assessment. Therefore, the core part of this dissertation is investigating, creating and applying *a model for assessing transportation poverty in metropolitan areas.* The *model for assessing* stresses the development of a systematic, engineering-based framework that combines mathematical model (formal), simulation platforms (such as PTV VISUM), and transport performance indicators to analyse the efficiency and equality of transportation systems. By locating the notion inside transportation engineering, the study not only detects and assesses discrepancies, but also applies findings to practical design, planning, and policy suggestions that improve network performance and assure equitable mobility access.

Background and Conceptual Foundations

Transportation systems are critical for ensuring fair participation in economic, social, and cultural life. Reliable and affordable access to employment, education, healthcare, and social networks are commonly acknowledged as a necessary condition for social inclusion (Litman, 2025). Individuals and households may experience transportation poverty, a type of deprivation that lowers life opportunities and fosters inequality (Commission, 2024; Verhorst, et al., 2023).

The concept of transportation poverty has emerged in tandem with broader discussions about social exclusion and mobility justice. Early research frequently associated transport disadvantage with limited road transport passenger vehicle access, but more recent scholarship has highlighted its multidimensional nature, including unsatisfactory public transportation availability, high travel costs relative to income, long travel times, and spatial mismatches between housing and opportunities (Lucas, 2012; Alonso-Epelde, et al., 2023). The European Commission (2024) now expressly identifies transportation poverty as a policy concern that necessitates careful measurement and targeted actions.

Measurement Challenges

Despite increased attention, identifying and operationalizing transportation poverty remains a contentious issue. Different studies utilize different metrics, with some focusing just on accessibility indicators (e.g., commute time to work), while others embrace broader frameworks that include affordability, geographical mismatch, and social vulnerability (Verhorst, et al., 2023). According to Alonso-Epelde et al. (2023), the metrics used can have a substantial impact on which groups or locations are classed as transport-disadvantaged. This makes it critical to use transparent, multidimensional, and context-sensitive measurements.

Modelling methods are increasingly being used in transportation poverty research to evaluate accessibility and simulate transportation scenarios. However, many transportation schemes are largely geared for operational efficiency rather than equity. There is an increasing need to investigate how such models might be tailored for social justice applications (Kostrzewski, et al., 2023).

Warsaw as a Case Study

Warsaw was chosen as the case study for this thesis as it is characterised by the largest and most complex metropolitan transportation system in Poland. As the capital, it combines various travel demands, multi-modal infrastructure, and large socioeconomic gaps between districts and suburbs, making it an excellent case study for measuring transportation poverty. Its metropolitan scale also allows for investigation of intra-urban (this term is understood as iniquities which are occurring or taking place within a city) and peri-urban inequities (this term is understood as inequities occurring or taking place on the edge of the city which is between the urban core and the surrounding areas), which are less evident in cities of smaller area.

It is worth mentioning here that there is solely few research conducted on such issues for local areas. It can be highlighted, for example research of Radzimski (2024) who considered analysis in four other Polish cities (Gdańsk, Kraków, Poznań and Wrocław), offering useful comparative insights. As a result, these cities were not included in the current study. Instead, the emphasis was on Warsaw to fill a gap in the literature and assess how simulation-based methodologies might reflect the unique issues of transportation poverty in a large capital city.

Warsaw, Poland's capital and largest urban region, provides a very relevant setting. Post-socialist urban development has altered the city's socio-spatial patterns, resulting in stark contrasts between dense, well-served centre sections and quickly expanding periphery neighbourhoods (Grzegorczyk & Jaczewska, 2018; Lisowski, 2004). Accessibility studies in Warsaw (Mościcka, et al., 2019) reveal significant discrepancies, especially in public transportation and journey times to central sites. Furthermore, socioeconomic disparities in income, housing, and car ownership indicate that certain demographic groups are more vulnerable to transportation poverty.

Despite this, few systematic assessments have used a complete transportation poverty paradigm in Warsaw. Much of the available research focuses on certain characteristics, such as trip time or modal accessibility, but does not consider affordability or service quality indices. This presents a gap in our understanding of how many factors interact to shape the city's transportation disadvantage.

Research Aim and Questions

A model for assessing transportation poverty in metropolitan areas consists of its formal part and in-software implementation in the simulation environment. This thesis uses a simulation-based approach with PTV VISUM to analyse transportation poverty in Warsaw. PTV VISUM was chosen as the software to be applied because it provides an integrated, multi-modal framework for trip production, distribution, mode selection, and assignment, making it thoroughgoing for studying transportation poverty. PTV VISUM, unlike open-source tools like MATSim or SUMO, which need extensive coding and calibration (Rakow, et al., 2025; Krajzewicz, et al., 2012), strikes a compromise between methodological rigor and usability and dependable results (this is an advantage for the model's users, who are going to be decision-makers in the transportation sector; however, not necessarily programmers). PTV VISUM outperforms Emme in schedule-based public transportation assignment, producing results comparable to agent-based simulations like MATSim while requiring less data and computation (Piątkowski & Maciejewski, 2013; Hildebrand & Hörtin, 2014). Recent improvements increase its ability to simulate emissions and assess service scenarios (PTV, 2025). PTV VISUM's qualities make it a reliable and policy-relevant instrument for analysing fairness in urban transportation.

The study uses a multidimensional collection of indicators to measure inequities among districts, evaluates PTV VISUM's applicability for equity-oriented analysis, and makes evidence-based policy suggestions.

The research is guided by three questions:

(1) How can transportation poverty in Warsaw be quantified using simulation and known indicator frameworks?

(2) To what extent may PTV VISUM be used as a methodological tool for equity-based transportation analysis?

(3) What policy and structural recommendations may be made to reduce transportation poverty in vulnerable districts?

Summing-up

This thesis makes contributions at three interrelated levels: empirical, methodological, and policy related. These contributions are contextualized within continuing discussions about mobility justice, socioeconomic equity, and the role of modelling tools in urban design.

The first contribution is empirical. Research on transportation poverty has primarily focused on Western European contexts, where significant policy frameworks and longitudinal research exist (Lucas, 2012; Verhorst, et al., 2023). Central and Eastern European cities, on the other hand, have gotten little attention, despite fast socioeconomic transition and major urban reconfiguration since the 1990s. Warsaw, Poland's capital, is an especially significant subject because of its uneven spatial development, high levels of suburbanisation, and increasing car dependence. Existing research have explored accessibility patterns inside the city (Mościcka, et al., 2019), but few have utilized a multidimensional framework of transportation poverty, including availability, affordability, and accessibility. This thesis fills this empirical gap by implementing such a framework and applying it to Warsaw's districts via simulation modelling. It achieves this by providing a systematic and spatially disaggregated assessment of transportation poverty, as well as a ranking of susceptible districts that can be used for academic and policy objectives.

The second contribution is methodological. PTV VISUM is commonly used for operational planning activities like traffic assignment, demand forecasting, and network optimization (Soares, et al., 2020). Its potential for assessing equity and social aspects of transportation has received less attention. This thesis shows how PTV VISUM can be used to assess transportation poverty by incorporating socioeconomic and demographic data into demand modelling, creating custom output indicators to reflect multidimensional disadvantage, and running scenario analyses to test the effects of policy interventions. These adjustments demonstrate PTV VISUM's ability to yield useful insights on accessibility and equity. In this approach, the thesis adds to the methodological discussion over how technological modelling techniques might be repurposed to address social justice issues in mobility planning.

The third contribution is policy related. Historically, Warsaw's transportation strategy has emphasized infrastructure investment and efficiency while paying less attention to the distributional effects of mobility. Limited affordability measures for low-income groups, insufficient public transport coverage in peripheral districts, poor integration between housing and transportation planning, and a lack of institutional monitoring of transportation poverty indicators are examples of structural and policy gaps (Commission, 2024). The thesis generates district-level profiles of transportation poverty, providing evidence to drive targeted actions. Policy recommendations based on this research include expanding service coverage in underprivileged districts, optimizing network design to reduce transfer hassles, and incorporating transportation poverty monitoring into the city's mobility policy. These methods address both structural gaps in service delivery and policy shortcomings in social equality planning.

Finally, the thesis places its contributions within larger ongoing discussions. Scholars in the subject of mobility justice, such as Martens (2017) and Sheller (2018), argue that fair access to mobility should be viewed as a right, with transport disadvantage as a kind of injustice. In talks about social equality, research shows that vulnerable populations, such as low-income households, the elderly, and those living in remote areas, are disproportionately impacted by inadequate or unaffordable transportation services (Lucas, 2012; Verhorst, et al., 2023). This thesis directly contributes to these discussions by presenting empirical evidence from Warsaw, methodological innovation in adapting PTV VISUM, and policy proposals that address both structural inequities and scholarly requests for more equitable mobility systems.

In summary, this thesis contributes to a better understanding of transportation poverty in Central and Eastern Europe by expanding the methodological limitations of PTV VISUM to address equitable concerns and providing policy approaches that address both service and structural inequalities. By doing so, it emphasizes the importance of viewing mobility not only as a matter of efficiency and sustainability, but also as a fundamental issue of equity and social justice.

1. Literature Review

Urban transportation poverty is often defined as inadequate access to basic opportunities as a result of a combination of limited mobility alternatives, poor accessibility, and high costs has resurfaced as a major equity issue in large urban regions. Recent policy work in Europe has consolidated definitions and indicator sets, emphasizing multidimensionality (affordability, accessibility, service availability, safety, and time costs) and advocating for measurement frameworks to guide targeted interventions (European Commission, 2024; European Parliament, 2025). In parallel, international organizations emphasize how transportation-related exclusion reduces well-being, limits labour-market access, and exacerbates inequality, advocating for measurements that link transport supply to distributive outcomes (ITF, 2023; Iimi, 2025).

Empirical research from 2023 has advanced operational indicators. Affordability metrics (e.g., 10% income, 2M, and LHIC thresholds) and composite indices now capture exposure to high transportation costs and insufficient access at fine spatial scales, while gendered and temporal analyses reveal disparities that system-average indicators overlook (Alonso-Epelde, et al., 2023; Balarezo, et al., 2025). New city-level and regional applications combine accessibility surfaces with socio-demographic vulnerability to identify "hot spots" of transportation poverty and assess policy levers such as shared mobility and transit-oriented development (European Parliament, 2025). Emerging research also links accessibility to climate vulnerability in rising cities, emphasizing the importance of models that are resilient to shocks and policy adjustments (Iimi, 2025).

Although most studies of transportation poverty focus on fairness and accessibility, complementing work in transport engineering emphasises the need of optimization and risk-aware allocation in system design. For example, Izdebski (2023) investigated how vehicle-task assignment might use failure probabilities to reduce operational risk. While not directly addressing transportation poverty, such methodological methods demonstrate how decision-support and optimisation techniques established in transport logistics might inform more robust models of transportation poverty in metropolitan contexts.

Transportation poverty is a problem that has never truly captivated the attention of the transportation engineering profession for a long time in either the ‘global north’ or the ‘global south,’ despite the fact that it impacts the everyday lives of millions of people all over the world. In this literature review, the definition of transportation poverty, transportation poverty risk indicators, and transportation poverty measures are going to be discussed.

This chapter focuses on defining terms of transportation poverty in comparison to other, similar terms as accessibility poverty, exposure to transport externalities, mobility poverty, transport affordability. Moreover, it identifies risk indicators in transportation poverty, and assessment equations for affordability, mobility, accessibility, and exposure to externalities. i.e. measures of affordability, measures of mobility, measures of accessibility, and measures of exposure to transport externalities.

1.1 Definition of Transportation Poverty

The definition of transportation poverty was not given adequately to the actual approach in academic, policy, or infrastructure design literature (Lucas, et al., 2016). Nowadays, hundreds, if not thousands, of young and old scholars are focusing on the essential social and distributional features of transportation, as well as their connection to greater economic and social inequities (Lucas, 2018). A variety of concepts are used to refer to the connection between (a lack of) transportation and people's life prospects in the expanding literature on transportation and equality. The words "transport disadvantage," "transportation poverty," "transport-related social exclusion," and "accessibility poverty" are frequently used (Jeekel & Martens, 2017).

A broad definition of transportation poverty can be explained as an individual is transport poor if, in order to satisfy their daily basic activity needs, at least one of the following conditions apply (Lucas, 2018):

- There is no mode of transportation that is appropriate for the individual's physical condition and ability.
- Existing transportation choices do not reach places where a person may meet his/her daily activity demands and maintain a fair quality of life.
- After paying for transportation on a weekly basis, the household's income falls below the official poverty threshold.
- An inordinate amount of time must be spent traveling, resulting in time poverty or social isolation.
- For the individual, the current travel conditions are dangerous, harmful, or unhealthy (Lucas, et al., 2016).

Moreover, it is critical to define the terms mentioned above (such as transportation poverty, transport disadvantage, etc.) and their interactions. Income poverty is defined in this corpus of literature as a lack of material resources, particularly money. In contrast, the concept of social exclusion emphasizes that a lack of material resources is only one of many possible reasons of deprivation. The absence or denial of resources, rights, products, and services, leading to the incapacity to engage in the usual interactions and activities, available to the majority of individuals in a society, whether in economic, social, cultural, or political arenas, is the definition of social exclusion (Jeekel & Martens, 2017).

Following this difference, the term "transportation poverty" would be proposed to refer to a lack of transportation-related resources. That is, a person is considered to be in transportation poverty if he or she does not have access to appropriate transportation, hence reducing a person's potential mobility in compared to that of the general population. The ability of a person to move through space is referred to as potential mobility (Martens, 2015; Sager, 2006). Financial constraints (e.g., preventing the purchase of a car or (multiple) public transportation tickets), legal constraints (e.g., lack of a driver's license), or mental or physical abilities (e.g., a person may be unable to use a bus service due to a travel-related impairment) can all contribute to transportation poverty (Jeekel & Martens, 2017).

In Table 1. the definitions of many terms that have been used to characterize transportation poverty interchangeably are being explained along with some of their indicators.

Table 1: A lexicon of definitions for transportation poverty (transportation poverty: a broad, overarching idea that identifies a research/policy topic and includes the sub-concepts listed below)

Notion (1)	**Definition (2)**	**Indicators (3)**
Accessibility poverty	The difficulty in getting to certain vital tasks (such as employment, education, healthcare services, shops, etc.) in an acceptable amount of time, with convenience and at a reasonable cost. (SEU, 2003)	The access to crucial social possibilities including job, education, trade, and recreational options, which connects a lack of mobility to social deprivation and marginalization (Guzman, et al., 2017).
Exposure to transport externalities	The consequences of disproportionate exposure to the transportation system's negative effects, such as traffic fatalities and	Pollution; energy consumption; crime rates; accidents rates; safety measures, etc.

Notion (1)	Definition (2)	Indicators (3)
	chronic illnesses, as well as deaths from pollutants caused by traffic. Environmental justice is frequently discussed in the literature in the United States. (Barter, 1999), (Booth, et al., 2000)	
Mobility poverty	A systemic shortage of (typically motorized) transportation that causes mobility issues, which is often (but not always) linked to a lack of services or infrastructure. (Moore, et al., 2013)	The official global core indicator on SDG 11.2 is: the % of the population that is 500m from a public transport stop (which equates to a walking distance of around 5 minutes). And other related measures ((UITP), 2019); Smart Mobility Indicator (Orlowski & Romanowska, 2019); delays can be defined as the average distance between the average actual travel time and the scheduled travel time (Eboli & Mazzulla, 2012) (Gillis, et al., 2016).
Transport affordability	Individual/household resources are insufficient to afford mobility alternatives, which commonly include the vehicle (in industrialized nations) and/or public transport. (Carruthers, et al., 2005), (Litman, 2015), (Serebrisky, et al., 2009)	The percentage of income spent on transport costs; the transport costs per week (Association, 2022); the estimation the proportion of household income or expenditure spent on public transport (Carruthers, et al., 2005), the housing plus transportation index (Guerra & Kirschen, 2016), the change in the affordability measures, were given in (Gómez-Lobo, 2011).

Source: (Eliwa & Kostrzewski, 2022) compiled based on (Lucas, et al., 2016)

In contrast to the concept of transportation poverty, accessibility poverty is based on a broader understanding of the concept of resources. When a person lacks access to critical options such as job, education, health care, or social support networks, they are said to be living in accessibility poverty (Lucas, 2012). Transportation poverty does not always imply accessibility poverty, as evidenced by a person's ability to reach crucial locations while having limited physical mobility (e.g., if she is living in a dense, mixed-use, environment). When a high amount of mobility is required to reach crucial destinations, however, transportation poverty becomes accessibility poverty (Levine, et al., 2012). This latter scenario is becoming more common in modern Western society, which are founded on the assumption of great mobility (Jeekel, 2013).

Furthermore, even if a person manages to access destinations without requiring a high level of mobility, it is highly likely that transportation poverty will translate into accessibility poverty at some point in a person's life, such as when a person's circumstances or plans change, and a high level of mobility is required to access key destinations. People who are disadvantaged in terms of transportation are also disadvantaged in terms of accessibility. Furthermore, accessibility poverty can exist without being associated with transportation poverty, such as when a person has a high level of potential mobility yet lives in a (very) distant location. Accessibility poverty is induced by current land use patterns rather than transportation poor in this scenario. It's worth noting that we only discuss accessibility poverty if it's caused by a lack of transportation (Jeekel & Martens, 2017).

Transport-related social exclusion, on the other hand, is about a person's degree of engagement in society, not about the resources accessible to them, whether in terms of transportation or accessibility options. If systematic issues with access to opportunities lead to major negative consequences in a person's life, such as unemployment, health degradation, or social isolation, accessibility poverty evolves into transportation-related social exclusion (Urry, 2004). As a result, accessibility poverty is less severe than transportation-related (or accessibility-related) social exclusion: the latter presumes long-term effects on a person's life, whereas the former may occur without these long-term effects and may not even affect a person's level of activity participation (Martens, 2019; Matrens, 2016). However, people who are inaccessible for a long time and for a variety of destinations are far more likely to be socially excluded from (parts of) society, especially when their circumstances change over time, and they may need to access a new set of destinations. In other words, people who are facing accessibility poverty are at danger of social exclusion due to transportation issues (Jeekel & Martens, 2017).

It is critical to distinguish between the ordinary concept of "transport problems" and accessibility poverty. Many people may have 'transport-related challenges,' such as traffic congestion or awkward transportation routes. This will have a significant impact on a person's degree of accessibility. However, as long as these issues do not prevent people from reaching a wide range of desired destinations at reasonable costs in terms of time, money, and effort, they do not suffer from accessibility poverty because they are not prevented from reaching a large number of destinations due to a transportation problem. While even relatively well-off households may face 'income problems' such as difficulty balancing income and spending on a monthly basis, such households often have enough money to meet much more than their basic requirements. Households in poverty, on the other hand, not only struggle to make ends meet, but also have a hard time purchasing even the most basic of necessities. People who have frequent, everyday 'transport problems' are similar to the first kind of families, whereas people who live in accessibility poverty are similar to the second type of households (Jeekel & Martens, 2017).

The above discussed definitions of transportation poverty are given in various contexts. Consequently, they can be aggregated as a definitions' summary within three following cohorts:

- Economic and social-related:
    - Transportation poverty is commonly referred to be a socioeconomic condition characterized by social exclusion and inequality.
    - It refers to situations in which individuals or groups cannot pay or obtain appropriate transportation to properly engage in society (Lucas, 2012; Lucas, 2018; Jeekel & Martens, 2017; SEU,2003).
    - It is also linked to greater exclusion from social, cultural, and economic life (Urry, 2004).
- Mobility alternatives-related:
    - Transportation poverty can also be defined as a lack of feasible transportation options other than private vehicle use.
    - Limited or unaffordable public transportation options increase dependency and limit opportunities, particularly for low-income people (Carruthers et al., 2005; Litman, 2015; Serebrisky et al., 2009).

- Engineering-related (service and infrastructure):
    - Defined as the absence of suitable transportation infrastructure and service provision, which limits accessibility.
    - Insufficient or poorly planned transportation infrastructure can prevent individuals from reaching jobs, education, healthcare, and other critical destinations (Moore, et al., 2013; Jeekel & Martens, 2017).

1.2 Transportation Poverty Risk Indicators

There is global quantification of rural road transport accessibility across 203 countries, however limited work has been done to estimate global household-level accessibility poverty risk, particularly in urban and developed-country contexts (Sun, et al., 2023). At the metropolitan level, some progress has been made: Lunke (2022) quantified transportation poverty in Oslo using modal accessibility disparities, and Martens and Bastiaanssen (2019) proposed the accessibility poverty risk index, which combines accessibility thresholds with distributional justice principles. These approaches demonstrate the breadth of available methodologies, however there is still no complete estimate of the global number of households exposed to accessibility poverty.

In order to address this issue, an estimation of the magnitude of accessibility poverty risk in developed countries will be needed. Two important indices of transportation poverty were utilized to arrive at this estimate: Car ownership and transport-related expenditures (Table 2). The first indicator, car ownership or, more accurately, the absence of car ownership, is a clear indicator of transportation poverty: in today's society, a car is a critical mode of transportation. Indeed, the significance of this indicator is predicated on the belief that, under normal conditions, a society's primary mode of transportation provides an adequate degree of accessibility for those who have access to that mode of transportation (Jeekel & Martens, 2017). Transport networks affect land use patterns, which tend to arrange around the speed given by the dominant mode of transportation, which is the mode utilized by the majority of the population (Hansen, 1959). In almost all industrialized cultures, the automobile is obviously the dominating means of transportation. People that have access to a car will find it easy to navigate these land use patterns. On the other hand, we know from the literature that households without a car are especially vulnerable to accessibility poverty due to the (typically) lower levels of potential mobility given by alternative forms of transportation (public transport, bicycle, walking, or a combination of these). At the same time, we know that many carless households do not face these issues, for example, because they are young and studying, are less pressed for time, or have limited needs to access a variety of destinations, or because they are car-free households by choice and have managed to organize their lives in such a way that high, car-based mobility is not required to reach key destinations. As a result, automobile ownership is a risk indication rather than a direct predictor of transportation poverty (Jeekel & Martens, 2017).

Table 2: Types of transportation poverty risks and related risks at accessibility poverty

	Car-owning households	Car-less households
Mobility expenditures above 20% of net household income	• Due to a lack of affordability, there is a danger of transportation poverty, and hence a risk of accessibility poverty.	• Risk of transportation poverty, and hence of accessibility poverty, due to a lack of affordable transportation choices, potentially in combination with inferior alternatives of transport.
Mobility expenditure lower than 20% net household income	• Accessibility poverty is not caused by a lack of transportation, but it might be caused by bad land use patterns.	• Due to a lack of alternatives to driving, there is a danger of transportation poverty and hence accessibility poverty. • No risk of accessibility poverty in case of or choice for car-free lifestyle

Source: (Jeekel & Martens, 2017)

A high percentage of mobility expense in the net household budget is the second indication for identifying those at risk of accessibility poverty. The percentage of spending isn't the most evident measure of the probability of falling into transportation poverty. However, it is possible that households that spend a significant portion of their income on transportation will be unable to continue doing so if conditions change, such as if oil prices rise or if household costs rise unexpectedly. Households may be obliged to adapt their mobility patterns, or perhaps restrict their real mobility, in such circumstances, or give up other vital items (Matas, et al., 2009) (Fan & Huang, 2011) (Lucas, et al., 2016). This shows that homes with high transportation costs are at danger of becoming transport disadvantaged, and therefore of being inaccessible.

The existing data on transportation-related costs may be used to establish an affordability criterion. In Europe, households spend between 10% and 20% of their net income on transportation on average (Litman, 2015). The statistics, however, varied significantly by income category. While low-income groups spend less on transportation than higher-income groups on average due to low car ownership, the situation is drastically different when only households with car-related transportation costs are considered. In this example, low-income households spend the vast majority of their money on automobile-related expenses. For example, one study in the United States found that households in the lowest income quintile spend 31% of their net income on car-related expenses, while the figure gradually decreases for each subsequent quintile (from 18% for the second-lowest quintile, via 16% and 14% to 12% for the highest income quintile) (Bureau of Labour Statistics (USA), 2007). According to another research conducted in the United States, households in the lowest income quintile spend up to 40% of their net income on automobile-related expenses (Surface Transportation Policy Project, 2003).

The problem of compulsory car ownership is clearly linked to the significant percentage of car-related costs in overall household spending. This idea refers to the fact that the poorest households are sometimes (forced to) reside in (low-cost) areas with little or no jobs or services, as well as no or poor-quality public transportation (Currie & Delbosc, 2011). Due to their restricted earnings, such households may be forced to purchase a (cheap) car in order to maintain an acceptable degree of mobility and accessibility, resulting in high transportation expenditures. Two Australian studies indicated that car-related expenses might occasionally reach 40% of a household’s income in the lowest income quintile (Currie, et al., 2009) (Johnson, 2007). Cain and Jones discovered comparable figures for Scotland (Cain & Jones, 2007).

1.3 Transportation Poverty Measurements

After determining what constitutes transportation poverty, it is possible to consider how to quantify its prevalence within any specific population group or geographical area. The following three sections will show that recording only certain parts of the transportation poverty problem (e.g., only affordability, mobility, accessibility, or externalities) is likely to be a crucial determinant in determining who is affected and the nature of policy responses proposed (Lucas, et al., 2016).

1.3.1 Measures of Affordability

In the literature, various measures of transportation affordability have been proposed. The first set of indicators looks at actual transportation spending as a percentage of total income. In the United Kingdom, the RAC Foundation suggested to label households that spend more than 10% of their income on transportation as ‘transport poor,’ emulating the official definition of fuel poverty prior to 2012. In developing-country studies, similar measures are frequently used to compare the (public) transportation expenditure of impoverished households to a baseline of average consumers (Serebrisky, et al., 2009). There are two major drawbacks to these methods. The first ignores issues of ‘suppressed travel demand’ by focusing on actual expenditure rather than normatively defined need (as is the case with fuel poverty). Households may need to spend a significant percentage of their income on transportation, but they avoid doing so, limiting their travel to meet competing requirements (Lucas, et al., 2016). The second constraint is transportation spending, which is non-regressive in most developed countries (unlike domestic energy), meaning that wealthier households spend a higher proportion of their income on transportation (this is often not the case in developing contexts, where, owing to massive income disparities, the proportion of income that low-income families may spend on transport is 20 percent , whereas wealthy families usually spend only around 5 percent) (Lucas, et al., 2016).

To avoid the problem of suppressed travel costs, Carruthers, et al. (2005) defined public transportation affordability as the percentage of monthly income required to make sixty 10-kilometer one-way trips. Measures generally relate to public transportation expenditure only in studies focusing on developing contexts (Carruthers, et al., 2005), reflecting the idea that car ownership and use are a luxury rather than a need. Private transportation costs are often included in industrialized countries, reflecting the premise that automobile ownership and use can be a necessity in car-dependent cultures. Indicators of household susceptibility to fuel price spikes, which can be interpreted as measures of ‘potential’ transportation affordability, are linked to this (Dodson & Sipe, 2007). Low-income regions with a significant reliance on cars are frequently targeted for these initiatives.

Another drawback of measurements based solely on transportation spending is that they do not account for housing expenditures. Higher transportation expenses may be countered by reduced housing costs (and vice versa), and households frequently trade off the two when deciding where to live. As a result, both rich and developing countries have used indices that take into account combined housing and transportation costs (Litman, 2015) (Isalou, et al., 2014).

What's vital here is to make sure that transportation affordability is viewed not as an absolute measure, but as a function of (a) other poverty indicators and (b) affordability in other critical sectors (such as housing). It's also crucial to compare transportation affordability to some sort of typical measure of spending for similar household types or geographic locations (Lucas, et al., 2016).

1.3.2 Measures of Mobility

The most common manner, in which transportation experts have traditionally investigated issues of transportation poverty is to measure the revealed mobility of different social groups. Moore and colleagues examined many ways for evaluating mobility among socially disadvantaged groups in their review of the literature in 2013 (Moore, et al., 2013). Typically, such studies use stratifications such as gender, age, wealth, employment position, and so on to point out disparities in trip-making patterns of different social groups. Typically, there are three variables which are being used to assess this (Lucas, et al., 2016):

1) Trip generation measures the number of trips taken by an individual or a household during a given period of time.
2) Trip distance can be used to assess mobility and as an implicit indicator of accessibility.
3) Trip duration has been studied using transport network techniques because journey time is typically dependent on network features, mode, and levels of use.

1.3.3 Measures of Accessibility

The economic and mobility components of transportation poverty are frequently considered in research to build accessibility strategies for transportation inclusion (Carruthers, et al., 2005). In the United Kingdom, for example, accessibility planning is cantered on determining whether or not people are physically and financially capable of using transportation (SEU, 2003). Halden and other researchers looked at various accessibility measurement methodologies in 2000 and came to the conclusion that accessibility analysis always considers a location (source or destination), the opportunities that people want to access, and the separation between people and those opportunities (Halden, et al., 2000).

Jaramillo and other researchers adapted a methodology developed by Curri in Australia to conduct community-based measurements of pedestrian access to the bus rapid transit (BRT) system in Santiago de Cali, Colombia, based on the community's geography, demographics, and income factors (Jaramillo, et al., 2012) (Currie, 2004). They came to the conclusion that the BRT did not increase access to many of the city's remote periphery neighbourhoods, which also had greater rates of illiteracy, unemployment, and households from poor socioeconomic strata (although at the time of the study only 9 percent of the system was operating). Other studies took a similar methodology but included activity-based metrics of access to important destinations including jobs, education, leisure, and health (Delmelle & Casas, 2012). To reflect an understanding of affordability as a significant feature of access to services, Bocarejo and Hernandez expand on this method by include measurements of travel time and expenses in their research (Bocarejo & Hernandez, 2012). Tiwari and Jain also calculated the number of destinations (by kind) that are within reach of various sorts of road users, as well as the number and categories of users for whom this statistic has grown, in order to assess accessibility to the Delhi BRT (compared to the pre-BRT situation) (Tiwari & Jain, 2012).

Engineers have played a key role in the creation of evaluation methods to quantify transportation poverty in the rural 'global south,' such as the rural development index, which assesses rural population access to the road network (Roberts, et al., 2006). These technologies have the potential to improve the spatial identification of transportation poverty. Recent studies, on the other hand, have highlighted the need for a more holistic approach to planning, in which the focus extends beyond infrastructure to ensure well-being and accessibility. There is also a rising realization of the need of actively involving local communities in the planning, design, and execution of local transportation projects at all phases (Freeman, 2009).

1.3.4 Measures of exposure to transport externalities

Several causes might lead to exposure to transportation externalities, but the majority of them fall into the categories of safety and the environment. Most studies measuring low-income people's disproportionate environmental exposure to various transportation externalities may be found in US literature under the category of environmental or transportation justice ((Bailey , et al., 2012) provide an insightful summary of this). The US Environmental Protection Agency (EPA) has developed 12 environmental indices based on recent demographic and environmental data. Most evaluation studies of new transportation projects in developing environments, according to (Venter, et al., 2013), fall short of explicitly illustrating the outcomes for various types of households and population sectors. It is strongly recommended to do large before and after studies to better understand the consequences of significant transportation infrastructure upgrades on the lowest segments of the population (Lucas, et al., 2016).

An efficient technique to gauge exposure to transportation externalities is to only measure or be aware of the necessary measurable parameters in the city or nation where the transportation is being utilized. One of the most crucial tasks in such measures is the identification of such components. For instance, under the environmental section, we should take into account dust emissions (road dust resuspension), carbon monoxide, lead, volatile organic compounds, nitrogen oxides and sulfur dioxide, and fluorocarbons as the main contributors to air pollution because they are all harmful to human health and the environment and have an adverse effect on infrastructure. The extensive use of natural resources, mostly metals, in the production, development, and usage of technologically advanced vehicles, apparatus, and infrastructure is another illustration of environmental problems.

On the other hand, measurements of general safety are also crucial, including crime, accident, and terrorist rates as well as rates of accidents due to other causes. Additionally, additional specific safety rates should be taken into account, such as risks connected to using technical modes of transportation, such as the potential for traffic accidents that might result in expenses that insurance only partially covers.

To sum-up the literature review chapter, it is significant to underline that the transportation poverty is lacking a comprehensive, integrated measure. Most indicators, as it was above stated, focus on only one aspect, such as: affordability, mobility or accessibility, which distorts the full picture of the phenomenon. Moreover, there is a lack of systematic tools that combine all these indicators, features and elements, and take into account local social and spatial conditions. Another aspect is that the various approaches related to transportation poverty discussion are often inconsistent between developed and developing countries, making it difficult to compare data and formulate global conclusions (for example the problem considered in developed countries takes into account the cost of private transportation, while is the case of developing countries, it takes into account mostly public transportation). Therefore, in order to meet this research gap, the dissertation has undertaken a consideration of the of integrated indicators in mathematical formal modelling and consequently in software to make the indicators more straightforward to apply by decision making personnel as well as general audience.

2. The Aim, Objectives, Scope and Dissertation's Thesis

The examination of scientific literature revealed a research gap in the field of assisting decision-making in the assessment and mitigation of transportation poverty in urban regions. While the issue of transport-related disadvantage has been acknowledged for some time, most of the debate remains fragmented, with different discussions on concerns such as affordability, accessibility, and exposure to negative externalities. What is required is an integrated methodological framework that enables the systematic assessment of transportation poverty using formal optimization approaches augmented by simulation techniques. Previous research (e.g., Lucas, 2012; Jeekel & Martens, 2017) has highlighted the importance of transportation poverty as a driver of social and cultural exclusion, but mechanisms for translating these concepts into operational models for metropolitan-scale decision-making remain underdeveloped.

The **goal of this dissertation** is to create a model for analysing transportation poverty in metropolitan regions, which will serve as a decision-support tool for the analysis and reconfiguration of urban transportation systems. The model was developed as an optimization one, with objective functions established to reflect the essential elements of transportation poverty: affordability, accessibility, mobility, and exposure to externalities. This work has been further realized in the form of software, which employs simulation approaches while building on the analytical foundation of mathematical programming.

The proposed model is designed to help planners and policymakers undertake practical decisions by providing an instrument for testing and assessing various options. Warsaw was selected as the empirical focus not solely for its status as Poland's largest metropolitan centre, but also for the disparities and inequities in its transportation system. While central districts are typically well connected, peripheral communities frequently experience lengthier travel times, less service coverage, and a greater reliance on expensive alternatives. These conditions match those seen by numerous European cities, towns, making Warsaw a relevant and adaptable case study.

The assessment of transportation poverty necessitates methodologies capable of dealing with multi-criteria problems, as aims can range from reducing prices and travel times to increasing accessibility and equity of service supply. Traditional descriptive techniques are insufficient to capture such complexity. The proposed approach, which combines mathematical programming and simulation, enables the investigation of various planning scenarios and their effects on various user groups. Simulation methods, in particular, provide "what-if" assessments, which allow for the examination of disruptions, infrastructure investments, and policy changes. In this way, the model takes into account not only objective measurements like journey times, costs, and service frequency, but also implicitly subjective variables like perceived accessibility and sensitivity to exclusion.

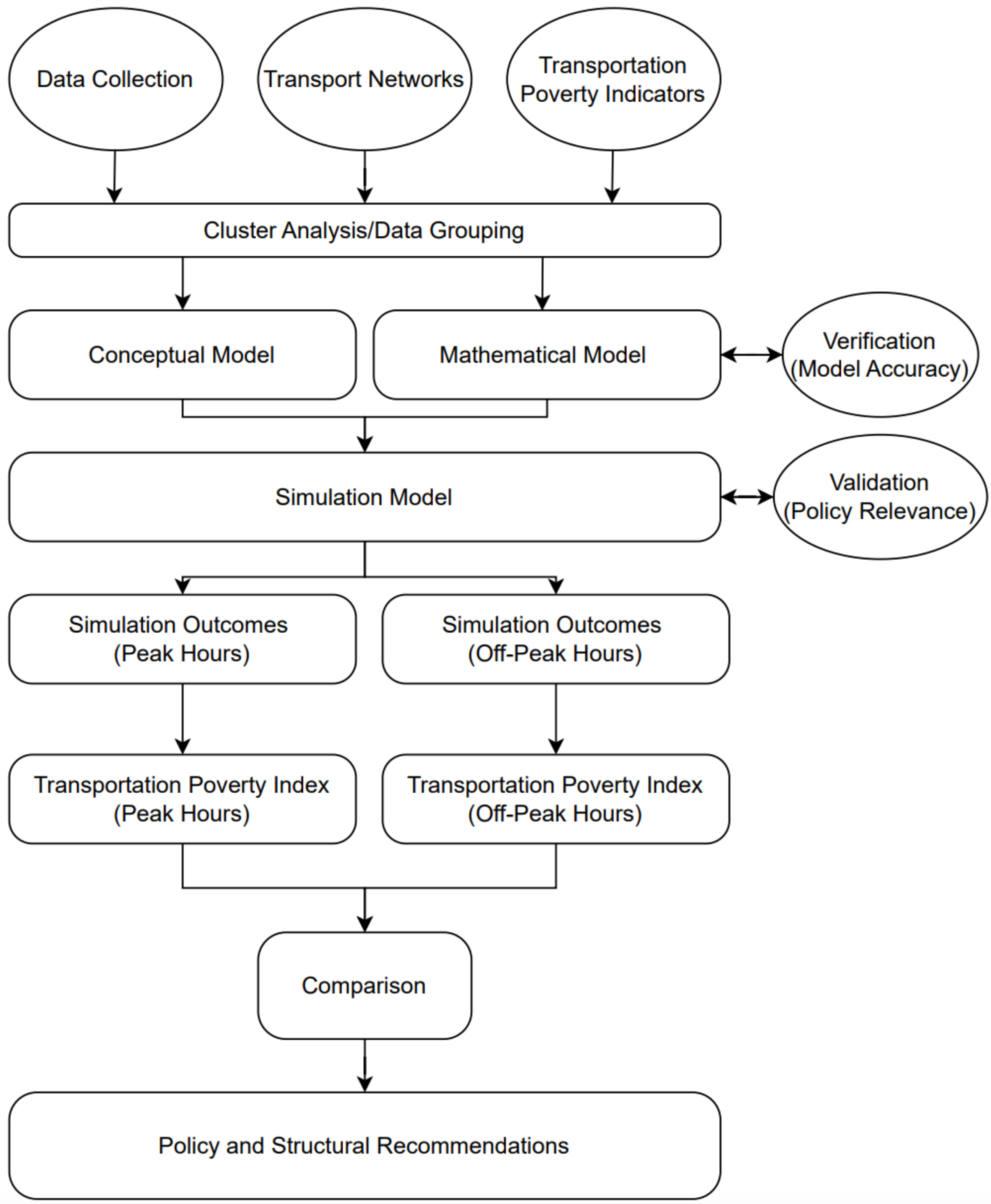

Figure 1: Graphical scheme of the applied methodology

Figure 1 shows a schematic representation of the dissertation's methodological technique. Its entire evolution is discussed in the following chapters, beginning with the conceptual model in Chapter 4 and progressing to the mathematical model in Chapter 5 until the last step in Chapter 7.

As a result of the assumptions outlined above, the **thesis of the dissertation** was developed as follows:

> ***The use of mathematical programming apparatus and the method of computer simulation, allows the development of an assessment model of transportation poverty in agglomeration due to predefined objective functions, as a decision support tool for decision-making analysis related to the reconfiguration of transportation in urban transport systems aiming to lower the problem of transport impoverishment.***

Moreover, the dissertation's goal is to create a decision-support model for analysing transportation poverty in metropolitan regions, which will be implemented in software and is based on simulation approaches and analytical methods of mathematical programming. Therefore, in order to fulfil the goal given within dissertation thesis defined above, the following sub-goals can be distinguished:

- Data preparation for the model of transportation poverty in metropolitan regions, including the development of variables, constraints, and objective functions relevant to the model's intended purpose.
- Creation of a conceptual (analytical) model of transportation poverty.
- Creation of a formal (analytical) model of transportation poverty.
- Implementation of a formal model into a simulation model for studying transportation poverty and testing various transportation system designs.

The dissertation consists of several major sections. In the first stage, the optimization problem of transportation poverty is defined, which leads to the development of the decision model. This is followed by a thorough analysis of the Warsaw transportation system, which serves as the foundation for empirical testing. Finally, the computer implementation of the model is shown, as well as the outcomes of its use in various circumstances. The dissertation finishes with a summary of the findings, highlighting theoretical contributions, practical applications, and potential future directions in the topic of transportation poverty evaluation and alleviation.

3. Infrastructural Urbanism: Integrating City Development with Regional Connectivity

Knowing how a city is planned, built, and connected to other cities is vital when identifying issues of transportation poverty because it provides essential context for understanding transportation disparities. This knowledge reveals historical decisions, infrastructure development disparities, connectivity limitations, and the role of policies and resource allocation in shaping transportation access. Understanding these factors helps in assessing the social and economic implications of transportation poverty, gathering relevant data for analysis, and designing targeted interventions to address transportation-related inequalities and improve the overall well-being of residents.

Cities have an important role as economic, social, and cultural centres in our quickly changing globe. As urban populations rise, the need for efficient and sustainable transport infrastructure becomes more pressing. Planning, building, and linking cities is an important part of urban development, influencing how people travel, interact, and prosper within their communities.

Transport networks are the lifeblood of cities, allowing for the free flow of people, products, and services. The first stage in creating an interconnected and effective urban transport network is effective planning. It entails a comprehensive examination of current infrastructure, population density, and growth predictions for the future. Building a strong transport system necessitates a diverse strategy that incorporates several means of mobility, such as highways, trains, public transport, bike lanes, and pedestrian walkways. Transportation infrastructure must be designed and built with safety, accessibility, and sustainability in mind. It entails the construction of road networks, bridges, tunnels, interchanges, stations, terminals, and other critical components that allow for efficient mobility and interconnection.

On the other hand, a city's transportation system does not exist in isolation. Connecting cities is a critical component of regional and national development. Cities may stimulate economic growth, boost trade and commerce, and improve cultural interchange by establishing intercity transit linkages. Highways, motorways, rail lines, and air links are critical conduits that allow people and products to travel across different areas, contributing to the general prosperity and growth of interconnected metropolitan centres.

Furthermore, technological developments and new transportation solutions have transformed how cities design, build, and link their transportation networks. Smart cities, self-driving cars, electric mobility, and intelligent transportation systems have changed urban transportation landscapes, presenting new opportunities and problems. Taking advantage of these improvements may assist cities in improving efficiency, reducing congestion, minimising environmental consequences, and improving the general quality of life for its citizens.

Understanding the transportation infrastructure planning process will be the primary focus of this chapter. This will aid in identifying possible issues that might contribute to transportation poverty. Some key questions will guide the path of this chapter, such as:

- What could inadequate city planning lead to? (the answer for this question can be found in Section 3.2)
- Is it possible to be fixed? (the answer for this question can be found in Section 3.3)
- How can it be avoided in the future? (the answer for this question can be found in Section 3.3)

3.1 Transport Infrastructure Planning Process

Transport infrastructure plays a crucial role in facilitating economic growth, improving accessibility, and enhancing the quality of life in urban and national contexts (Banister & Berechman, 2000). This section aims to discuss the transport infrastructure planning process in cities and countries. It mainly focuses on the key steps involved, including data collection and analysis, goal setting, evaluation of alternative options, stakeholder engagement, and implementation. The section also highlights the challenges and considerations associated with transport infrastructure planning.

3.1.1 Data Collection and Analysis

Accurate and reliable data form the foundation of effective transport infrastructure planning. (Wegener, 2004) utilized various methods and sources for collecting transportation-related data, such as traffic surveys, travel demand models, and geographic information systems (GIS). It also emphasizes the importance of data analysis techniques, including traffic forecasting, network modelling, and performance evaluation.

Various data sources help in transportation infrastructure planning. Traffic surveys, trip diaries, and origin-destination studies, for example, provide direct insights into transportation trends and user behaviour. Secondary data sources that give contextual information include census data, land use statistics, and socioeconomic indicators. Data integration from different sources is required for a complete knowledge of transportation networks (Golledge & Stimson, 1997) (Levinson & Krizek, 2018).

Data analysis tools make it easier to turn raw data into usable insights for transportation infrastructure design. Analytical tools that are often employed include descriptive statistics, regression analysis, network modelling, geographic information systems (GIS), and simulation models (Cascetta, 2009). Data visualization and geographic analysis help to analyse and communicate results even more effectively (Miller & Shaw, 2001).

3.1.2 Goal Setting

Establishing clear goals and objectives is a crucial step in the transport infrastructure planning process. Goal setting usually highlights common objectives, such as improving safety, reducing congestion, promoting sustainable modes of transport, and enhancing connectivity (Banister & Berechman, 2000). Essentially, goal setting guides the entire planning process, ensuring that transportation investments align with broader societal and environmental objectives and adapt to evolving needs. Additionally, setting goals that prioritize sustainability, and equity helps create transportation systems that are not only efficient but also environmentally responsible and inclusive, contributing to the overall well-being and development of communities and regions.

3.1.3 Evaluation of Alternative Options

Planning for transport infrastructure requires a thorough analysis of all available choices to identify the best ones. The evaluation of alternative options is a crucial and essential step at the core of this process. According to (Oliveira & Pinho, 2008), this evaluation is the cornerstone for making well-informed decisions because it ensures alignment with overarching goals, optimal resource allocation, risk management, incorporation of insightful opinions from key stakeholders, assurance of legal compliance, and support for economically sensible choices. Through this evaluation, planners and decision-makers systematically assess different project options, considering factors such as feasibility, effectiveness, cost, environmental impact, and community needs. Ultimately, this methodology for evaluation guides the selection of the projects that are best suited to address transportation issues while also promoting broader societal, environmental, and economic ambitions.

Furthermore, the evaluation includes crucial approaches including cost-benefit analysis, multi-criteria decision analysis, and sustainability assessments, as explained by Bannister and Berechman (2012). They also explored the complex world of trade-offs that arise when selecting between various transport options and technological advancements which can possibly change the direction of the evaluation.

3.1.4 Stakeholder Engagement

Stakeholder engagement is an integral part of the transport infrastructure planning process, fostering inclusivity, collaboration, and transparency. It involves actively involving diverse individuals, groups, and organizations with interests in or affected by transportation projects. Through engagement, planners gain valuable insights into the specific needs and concerns of various stakeholders, ensuring that transportation solutions are tailored to meet the community's unique requirements (Erkul, et al., 2016). This inclusivity also promotes trust and cooperation between planners and the community, helping to address conflicts, build consensus, and prevent misunderstandings.

Moreover, stakeholder engagement establishes an essential feedback loop, ensuring ongoing communication and adjustments based on stakeholder input. It plays a crucial role in legal and regulatory compliance, meeting requirements for certain infrastructure projects (Prebanic & Vukomanovic, 2023). Ultimately, effective engagement not only enhances decision-making quality but also secures project acceptance and support from the community, which is vital for securing funding and approvals and ensuring successful project implementation (Waris, et al., 2022). In essence, stakeholder engagement is a cornerstone of inclusive, well-informed, and community-supported transport infrastructure planning.

3.1.5 Implementation

Implementation is a pivotal phase in the transport infrastructure planning process, where plans and decisions made earlier are put into action through construction or development. It encompasses resource allocation, project management, environmental compliance, stakeholder engagement, quality control, and adaptation to changing circumstances. Effective implementation is crucial for realizing the goals of transportation infrastructure planning, improving mobility, and achieving broader societal and economic objectives.

Once the transport infrastructure plan is developed, its successful implementation is critical. Emmir & Juwono (2019) mentioned that infrastructure implementation must be monitored to ensure that project developments follow the project's manager vision and goal. Supervision begins with planning and continues throughout the construction process to guarantee that the quality of infrastructure meets citizen demand.

Challenges associated with the implementation phase of transportation infrastructure projects are often underrepresented in literature, despite their significant impact on project success. This is simply because of how common these challenges happen during the implementation phase which can be easily identified. Implementation hurdles encompass a wide array of issues, ranging from budget constraints and unexpected cost overruns to construction delays due to unforeseen circumstances. Ensuring compliance with environmental regulations and mitigating ecological impacts can be complex and time-consuming, while opposition from local communities or stakeholders can lead to legal disputes and project setbacks. Effective resource management, safety assurance, regulatory compliance, and quality control demand meticulous attention. Additionally, overcoming political and bureaucratic hurdles, land acquisition difficulties, and maintaining positive public relations are often overlooked but critical aspects of successful implementation. Recognizing the multidimensional nature of these challenges is crucial for enhancing the planning and execution of transportation infrastructure projects, ultimately benefiting communities and regions alike.

Planning, building, and connecting a city to other cities through an effective transport system presents a multitude of an overall challenges and considerations. These encompass challenges could be (and not limited to) limited financial resources, conflicting stakeholder interests, and uncertainties associated with future developments.

3.2 What Could Inadequate City Planning Lead to?

Inadequate initial city planning can exacerbate transportation poverty, which refers to the difficulties and disadvantages that low-income individuals and communities face in accessing affordable and reliable transportation options. There are multiple ways in which poor initial city planning can lead to transportation poverty such as Inadequate Public Transportation, Spatial Inequality, Environmental Injustice, Lack of Safe Walking and Cycling

Infrastructure, Gentrification and Displacement, etc. A brief discussion about each of these outcomes would be the goal of this section in order to give a clear understanding of the reason behind each outcome.

If a city's initial planning does not prioritize the building of a comprehensive and efficient public transportation infrastructure, low-income residents may have restricted access to economical and convenient transportation options. This can lead to longer commuting times, higher transportation expenditures, and decreased mobility. In 2021, a case study made by Sahed Hossen Sajib confirmed that poor and low traffic conditions due to **inadequate public transportation** have unpleasant effects on customers and commuters such as previously stated (Sajib, 2021).

In recent decades, urban design has shifted from ‘making good places’ to ‘making good places in the public interest’. In other words, modern urban planning practice is concerned not only with the location of buildings and the spaces between them, but also with serving the public interest by creating better areas. As a result, for urban designers and policymakers, analysing **spatial equity** is an essential concern for generating optimal urban design results (Liu, et al., 2023).

Poor city planning can lead to the spatial segregation of low-income communities, where they are located far from economic opportunities, jobs, and essential services. This spatial mismatch can make it challenging for residents to access employment and education opportunities, further perpetuating poverty. The Unbalanced allocation, distribution, and layout of urban public facilities would result in severe imbalance in the provision of resources and services to local citizens, marginalising vulnerable populations, and ultimately leading to overall injustice/inequity (Wu & Liu, 2022).

Spatial planning is critical for the distribution of **environmental hazards and benefits**. Rational spatial planning guarantees that all residents have equal access to a safe environment and may be used to promote environmental justice. Planning on degraded regions, which may be locations of hazardous material buildup, plays a critical role in providing health safety to existing and future residents of such sites. Brownfields are areas that require special attention because they have been “affected by the former uses of the site and surrounding land; are derelict and underutilized; may have real or perceived contamination problems; are primarily in developed urban areas; and require intervention to bring them back to beneficial use.” (Maciejewska & Ulanicka-Raczyńska, 2023; Oliver, et al., 2005)

Numerous studies have found that the residential environment is quite important in terms of health (Watters, 2020; Shortt, et al., 2010; Cummins, et al., 2005; Perdue, et al., 2003;

Braubach, 2007). People who live in areas with a high proportion of degraded land containing, or possibly harbouring, historical earth surface toxins are more likely to have health issues than people who live in areas with a low contribution of such places [(Bambra, et al., 2014), (Bambra, et al., 2015) , (Pirastu, et al., 2013), (Litt, et al., 2002), (Wang, 2011)]. In the worst-case scenario, degraded land poses a very high chance of carcinogenic chemicals being present in the surrounding area [(Colten, 1990), (Greenberg, et al., 1998), (Liu, 2010)].

Improving the quality of life and health of urban people (via physical activity promotion) is one of the most significant aims of urban planners in practice. A multilevel multidisciplinary strategy is necessary to accomplish long-term or population transformation (Koprowska, 2020). Sallis et al. (2006) recommended using ecological models and focusing on individuals, social settings, physical environments, and policy decisions (Sallis, et al., 2006). Boone and Modarres (2006) emphasized the interconnected processes occurring in cities, underlying the necessity for effective urban infrastructure design, including components of environmental justice and green planning (Boone & Modarres, 2006). Hence, poor city planning can lead to the concentration of pollution and hazardous facilities in low-income neighbourhoods. This environmental injustice can lead to health problems for residents, making transportation challenges even more burdensome.

Worldwide, cycling infrastructure has been put in place to encourage riding bicycles and reduce the danger of harm (Götschi, et al., 2018). Riding a bicycle can lower obesity, increase fitness, and lessen air pollution, noise pollution, and greenhouse gas emissions related to transportation. Nonetheless, compared to drivers of motor vehicles, cyclists are more likely to have injuries that need hospitalization (Reynolds, et al., 2009). Roundabouts were the primary focus of intersection research where they discovered that unless a dedicated cycling track is incorporated into the design, multi-lane roundabouts can considerably raise the risk to cyclists. Research on straightaways divided facilities into a small number of groups, possibly classifying facilities that posed varied dangers under one heading. According to the results thus far, main highways are riskier than smaller roads, walkways and multi-use trails are the most dangerous, and the availability of cycling facilities (such as off-road bike pathways, defined bike lanes and on-road bike routes) is linked to the lowest risk (Reynolds, et al., 2009). **Inadequate investment in sidewalks, crosswalks, bike lanes, and pedestrian-friendly infrastructure** can make it dangerous for people with low incomes to walk or cycle, forcing them to rely on more expensive and less efficient modes of transportation.

In an effort to encourage active living, lessen reliance on cars and greenhouse gas emissions, or improve neighbourhood social capital, several cities have increased their bicycle networks. Prioritizing the development of bicycle infrastructure in historically underprivileged neighbourhoods can aid in the reduction of socio-spatial disparities in health. Enhancements to the neighbourhood may also have unforeseen effects like **gentrification** (Kiani, et al., 2023). Gentrification is commonly defined as the in-migration of upwardly mobile, middle-class households into previously low-income, impoverished, and frequently racially segregated neighbourhoods. If left to its own devices, this process has the potential to completely reshape neighbourhoods, affecting not only the physical architecture but also the long-standing social networks and cultural identity of the place (Cheng, 2022). Thus, gentrification can result in the displacement of long-term residents who cannot afford to stay, which means they do not benefit from neighbourhood investment (Zuk, et al., 2017). As a summary, poor city planning can contribute to gentrification, where wealthier individuals and developers invest in and upgrade certain neighbourhoods. As property values rise, low-income residents may be displaced, forcing them to move to areas with limited transportation options and increased transportation costs.

To address transportation poverty, cities must prioritize equitable and sustainable urban planning that ensures all residents, especially those with low incomes, have access to safe, affordable, and reliable transportation options. This may involve investments in public transportation, improved pedestrian and cycling infrastructure, and policies to reduce spatial inequalities and displacement.

3.3 Transportation Poverty and Potential Solutions from the Government

Transportation poverty is a crucial issue with far-reaching consequences for communities. Governments must acknowledge the multidimensional impact of transportation poverty and adopt comprehensive solutions to guarantee that all citizens have equal access to economic, social, and cultural opportunities. Adequate transportation breaks the cycle of poverty and promotes economic growth by providing access to jobs, education, and healthcare. Furthermore, accessible and affordable transportation encourages social inclusion, resulting in healthier and more dynamic communities. Sustainable mobility solutions not only have a lower environmental effect, but they also help communities to be more resilient in the face of climate change. Additional benefits of reducing transportation poverty include equitable urban growth, increased access to education, and reduced traffic congestion. A healthy and reciprocal connection between residents and authority may be developed via community empowerment and open government policies, therefore increasing public confidence. In essence, comprehensive transportation solutions are required for the development of inclusive, resilient, and sustainable communities that promote the well-being and prosperity of everyone.

Governments should do extensive preparation before introducing measures to solve transportation poverty. This process starts with a requirements assessment and data collecting to better understand specific difficulties and demographics. Residents, organizations, and stakeholders must all be involved in decision-making through community involvement. Partnerships with multiple institutions, including the public and commercial sectors, should be formed, while a thorough examination of existing rules should guide the formulation of inclusive legislation. Financial planning and feasibility studies evaluate resource requirements and viability. Integrating technology and innovation can improve transportation alternatives, and legislative changes may be required to back up suggested solutions. Pilot projects allow for testing and feedback, while educational initiatives educate the public. Creating a strong monitoring and evaluation system guarantees long-term success and adaptation. This complete strategy optimizes the efficacy, inclusiveness, and sustainability of transportation poverty relief activities.

3.3.1 Improving Public Transportation

It is widely understood in the field of transportation economics that public transportation subsidies increase resource allocation in society under specific conditions. This is especially true when other modes of transportation, including private transportation, do not cover their full societal costs and second-best considerations necessitate subsidizing competing alternatives (Gómez-Lobo , 2011).

However, subsidies are frequently adopted for social or distributive purposes, particularly in developing nations. The social justification for transportation subsidies begins with recognizing the necessity of **accessible and affordable** transportation for inhabitants' well-being and welfare. Transportation is a necessary component for obtaining other social advantages such as education, health care, and job possibilities, among others. This is sometimes expressed in the broad concept of social inclusion, a tempting term that, unfortunately, is highly difficult to define in a way that is operationally relevant for policy choices (Gómez-Lobo, 2011).

A study was made in 2023 by Jean C. Mutiganda, Matti Skoog, and Eghosa Igudia with a research question 'how does a collective transport organization become effective in organizing accessible inter-municipal carriage of passengers by bus at an affordable cost for commuters?' (Mutiganda, et al., 2023). In this study, archetypal notions were utilized, with accessibility and affordability serving as pillars of the interpretive framework in the transition process. According to research findings, FÖLI (a not-for-profit organization tasked with collective transport of passengers by bus in Southwest Finland) executed a bold revolutionary shift by adopting a new framework for regional bus passenger carriage with a zone-free and flat ticket policy, which has been in place since mid-2014. By abandoning zone-based bus ticket methods and structures (including pricing) and institutionalizing a zone-free system with a flat-price approach for all passengers in the region, the transition was rapidly successful (Mutiganda, et al., 2023).

It is important for governments to take into consideration affordability and accessibility whenever a new potential solution plan might be in order. If the government can subsidize public transportation services or offer reduced fares for low-income individuals, then this can make public transit more accessible. Moreover, government should consider expanding public transportation networks to cover underserved areas ensures that people in remote locations have reliable access to transportation.

3.3.2 Innovative Transportation Solutions

Embracing innovation is critical for solving transportation poverty in a sustainable and forward-thinking manner. On-demand mobility platforms, electric and shared vehicles, and intelligent transportation systems are all emerging technologies that have the potential to increase access while minimizing environmental impact. Digital solutions, such as mobility-as-a-service (MaaS) software, combine numerous modes of transportation into a single, easy-to-use platform, increasing mobility efficiency and affordability. In rural and underserved areas, demand-responsive transit and community-based ride-sharing programs provide flexible alternatives to traditional mass transit. Investment in active transportation infrastructure, such as safe bicycle paths and pedestrian-friendly networks, encourages more equitable and cost-effective modes of transportation. Innovative solutions that combine technology and inclusivity ensure that vulnerable populations do not fall behind in the transition to contemporary transportation systems.

Many of these approaches have been supported by recent research. For example, the review of sustainable transportation solutions by (Etukudoh, et al., 2024) examines advancements in public transportation systems, electric vehicles, alternative fuels, and shared mobility, highlighting potential and difficulties of making them available to all social groups.

Similarly, a study on shared mobility suggests that boosting public/shared transportation options reduces reliance on private vehicles and increases spatial equity (Tönnies, et al., 2025).

3.3.3 Infrastructure Investments

Long-term effectiveness in combating transportation poverty necessitates ongoing and fair infrastructure improvements. Upgrades and expansions to public transportation networks guarantee that communities of all sizes have consistent access to jobs, healthcare, and education. Prioritizing underprivileged areas for infrastructure development can help to transcend geographical and socioeconomic disparities. Investments in multimodal hubs enable seamless linkages between buses, trains, bicycle routes, and pedestrian paths, increasing accessibility and efficiency. Governments must also consider resilient design principles to ensure that infrastructure can survive climate change-related consequences such as flooding and excessive heat. Beyond physical construction, expenditures in maintenance and safety upgrades are crucial to the long-term viability of transportation systems. An equitable distribution of funds, coordinated by social impact evaluations, ensures that infrastructure development benefits underprivileged populations while promoting economic growth and environmental sustainability.

Evidence suggests that investing in transportation infrastructure provides measurable benefits in terms of cost savings and economic growth. Malhotra et al. (2021) found that rural road upgrades in Bangladesh reduced poverty by cutting transportation and input costs, resulting in increased agricultural productivity.

Furthermore, The Innovation Effects of Transportation Infrastructure (Mao, et al., 2024) investigates how enhanced infrastructure might boost business innovation output, resulting in indirect socioeconomic benefits.

The US Infrastructure Investment and Jobs Act (IIJA) and the Inflation Reduction Act are examples of large-scale public investment targeted at enhancing accessibility, transit modernization, and environmental mitigation.

3.3.4 Policy and Regulations

Effective legislative and regulatory frameworks are critical to combating transportation poverty. Governments must enact legislation that explicitly stresses equity, accessibility, and sustainability in transportation design. Clear regulations can help direct resource allocation, create minimum service standards, and enforce affordability measures to safeguard vulnerable populations. Fare caps, subsidies, and universal design criteria are examples of regulatory tools that keep transportation systems inclusive and accessible to all citizens. Furthermore, incorporating environmental standards and emission reduction targets into transportation laws encourages the shift to greener mobility. Strong governance tools, such as accountability frameworks and frequent audits, contribute to transparency and public trust. Policy coordination at the local, regional, and national levels promotes consistency, whereas engagement with private and civil society players improves regulatory efficacy. Finally, well-designed rules and regulations are the foundation of fair and sustainable transportation systems that serve present and future generations.

Several empirical policy recommendations have been proposed and evaluated. For example, in Policy Prescriptions to Address Energy and Transportation poverty in the United Kingdom (Sovacool, et al., 2023), policies that received widespread public and expert support included lowering or eliminating bus and train fares, restarting and expanding bus services, and increasing financial assistance to households.

WHO/WB-style approaches to assessing transportation poverty prioritize measurement and targeted policy interventions. Transport and Poverty: A Review of the Evidence (Hernandez, 2014) categorizes vulnerable populations and proposes actions to minimize transportation poverty, such as regulatory tools and service provider improvements.

Best practices also include implementing public-private partnership (PPP) models within a solid legislative and policy framework to assure investment and service quality. The UNECE guidance on public-private partnerships in transportation infrastructure addresses legislative and legal conditions, transparent procurement, business cases, and risk allocation.

To sum up, Section 3.3 views transportation poverty as both a social difficulty and a policy design issue. It serves as the conceptual foundation for the dissertation's development of a model that combines mathematical programming and simulation: to provide governments and planners with an evidence-based way to evaluate and compare solutions in terms of transportation poverty indicators, ensuring that transportation systems contribute to inclusive and sustainable urban growth.

4. Conceptual Model

A conceptual model is a high-level representation of how a system or process works. It focuses on essential entities, relationships and rules, rather than implementation details. It is used to organise and communicate ideas about a system and often serves as a foundation for system design, database development or theoretical frameworks (Kostrzewski, 2018; Rumbaugh, et al., 2004; Wand & Weber, 1990).

The conceptual model created in this thesis offers the analytical foundation for development of formal model and further evaluating Warsaw's transportation poverty using a network-based, demand-oriented methodology applied in PTV VISUM. By using the city's 18 administrative districts as the primary traffic analysis zones, the model is intended to capture both the spatial and socioeconomic aspects of accessibility/mobility. This district-based zoning scheme makes it possible to clearly connect accessibility results, transportation infrastructure, and population characteristics.

The model is based on two main data sources: OpenStreetMap (OSM), which gives a thorough depiction of the road, walking, and cycling networks as well as the locations of important destinations; and Public Transport Authority of Warsaw (i.e. Zarząd Transportu Miejskiego ZTM), which offers comprehensive information on the supply of public transport services (lines, stops, timetables, fares, and capacities). When combined, these datasets allow for a multi-modal simulation of travel behaviour that incorporates road-based and non-motorized travel options with scheduled public transportation services.

In order to emphasize the difficulties related to transportation poverty, the model modifies each step of the well-known transport demand modelling sequence, which includes trip generation, trip distribution, mode selection, network assignment, and accessibility assessment. While the mode choice model takes into consideration variations in affordability and vehicle availability across income levels, trip creation and distribution reflect disparities in mobility demands and opportunities among districts. Realistic representation of the effects of traffic, waiting times, transfers, and capacity limitations on public transportation is ensured via network assignment.

A collection of key performance indicators is used to quantify transportation poverty in the model's final step, which focuses on accessibility/mobility and result assessment: Average Origin Waiting Time (OWT), Average Transfer Waiting Time (TWT), Average Journey Time (JRT), Average Riding Time (RIT), Average Service Frequency (SFQ), and Average Journey Distance (JRD) are some of these measures, when taken as a whole, they give a thorough picture of how locals use the transportation system, showing differences in time, cost, service quality, and opportunity access across districts and income levels. These measures are briefly presented here; their definitions and empirical outcomes are described in detail in Chapter 6.

The above called performance indicators are defined as follows:

- Average Origin Waiting Time (OWT): The average time passengers spend waiting at the starting point or station before beginning their journey.
- Average Transfer Waiting Time (TWT): The average time passengers wait when switching from one means of transportation to another during a trip.
- Average Journey Time (JRT): The average time it takes to travel from point A to point B, including time spent riding and waiting.
- Average Riding Time (RIT): The average amount of time passengers spend in the vehicle while traveling between stops or stations.
- Average Service Frequency (SFQ): The average time between consecutive departures of a transportation service, indicating its availability and convenience.
- Average Journey Distance (JRD): The average distance travelled (e.g. in kilometres) from origin to destination.

This conceptual model creates the methodological foundation for assessing the degree of transportation poverty in Warsaw and testing possible policy interventions meant to increase accessibility for underprivileged groups by fusing socioeconomic data with high-resolution transport supply and network information.

4.1 Model Components

The conceptual model is made up of the following major components, which interact to depict the problem of transportation poverty:

1. *Population and Socio-Economic Data*

   Among this component of data, one should include the following aspects:

   - All 18 districts serve as Traffic Analysis Zones (TAZs).
   - Districts allocate socioeconomic characteristics, such as employment, household income, automobile ownership, and population.
   - Income stratification is the division of each district into low-, middle-, and high-income groups to account for variations in accessibility and affordability.

2. *Trip Generation*

This component is related to the following features and data that ought to be collected from external sources:

Each district's trip productions (the number of trips created in a district, typically from residential populations as sources of travel demand) and attractions (from commerce, healthcare, schools, and job areas) are calculated. It involves computing number of trips are produced and attracted in each zone within the study area.

- Sources of data:
    i. Employment and population figures based on official Warsaw data (Statistical Office in Warszawa, 2024).
    ii. Points of Interests (schools, hospitals, etc.) from OSM (OSM, 2025).
- Illustrates how demand differs in districts with various socioeconomic traits (e.g. Educational and healthcare facilities, Employment density, Income levels, etc.).

3. *Trip Distribution*

This component benefits from the following data and features:

- The 18 districts split up the generated trips.
- A gravity model (estimates travel flows between zones using trip productions/attractions and inverse travel cost) calibrated with generic trip (a combined measure of travel time and financial cost) expenses (including time and fares) is used in the simulation model (created within PTV VISUM) to accomplish this.
- Captures disparities in space, such as remote areas with lengthy commutes to major services.

4. *Mode Choice*

The following data and features are available for this component:

- Public transportation (PT), cars, walking, and bicycling were all taken into consideration.
- A logit model (a statistical model commonly used for prediction, which assigns the probability of default based on relevant data; Glantz & Kissell 2014) was used to

estimate the mode split (this model can is an available function in PTV VISUM software; Ziedén 2017 discussed the same ones), which was sensitive to:

  i. Time spent traveling (traffic jams, PT schedules).
  ii. Cost (car operating expenses, fares).
  iii. Availability (restrictions on car ownership).

- Low-income groups have less access to private vehicles and are more sensitive to financial costs (implemented in PTV VISUM by adding an approximate percentage of the people who owns cars in Warsaw).

5. *Network Assignment*

In order to develop the network assignment, the data of the following sources are required, and the component has the following characteristics:

- The transport networks are assigned to trips based on:
  i. Network of roads, paths, and bicycles from OSM (OSM, 2025).
  ii. ZTM provides public transportation (lines, stops, schedules, prices, and capacity; ZTM, 2025).
- Captures heavy PT traffic, wait times, transfers, and rejected boarding.

6. *Accessibility and KPIs*

The following information and capabilities are associated with this component:

- Indexes of accessibility:
  i. Percentage of inhabitants in each district who are able to access healthcare, education, or employment within specified time/cost constraints (identified by the simulation model).
  ii. Fare burden (the portion of income used for transportation).
- Key Performance Indicators (KPIs – quantitative indicators applied to evaluate the effectiveness of a system, here: the discussed transportation system of Warsaw, and its equity impacts):
  i. Average travel time by district and mode.
  ii. Modal division by income bracket.
  iii. Average cost as a percentage of revenue.

4.2 Key Considerations

When developing a comprehensive transport model, it is crucial to consider several key factors that affect the quality, equity and sustainability of the transport system. The following key considerations have been identified as critical to ensuring a well-rounded and inclusive approach:

- **Transport Mobility:** include factors affecting the speed and efficiency of travels.
- **Transport Accessibility:** account for the ease of reaching transport facilities and final destinations.
- **Transport Affordability:** Costs associated with each mode of transport are included in the model.
- **Exposure to Externalities:** consider environmental and safety impacts of each mode of transport.

4.3 Model Diagram

The diagram (Figure 2) presents depicts a conceptual flow of the travel decision-making and journey process, organized in five consecutive steps with a feedback loop.

a) Trip Planning and Need Identification

Individuals initially specify the goal of their journey, such as work, healthcare, shopping, or education, as well as the schedule and frequency needs. Agent-specific factors such as income level, budget limits, travel preferences, and trip urgency may all have an impact on planning and determining alternative options to explore in the simulation model.

b) Mode Selection Decision-Making

In the second step, tourists assess their transportation options, which include public transportation, private vehicles, and walking or biking. Factors that influence decisions include cost, projected trip time, accessibility, service availability, public transportation capacity, and route proximity. Based on these factors, the traveler chooses a method of transportation or makes changes in accordance with financial and time constraints.

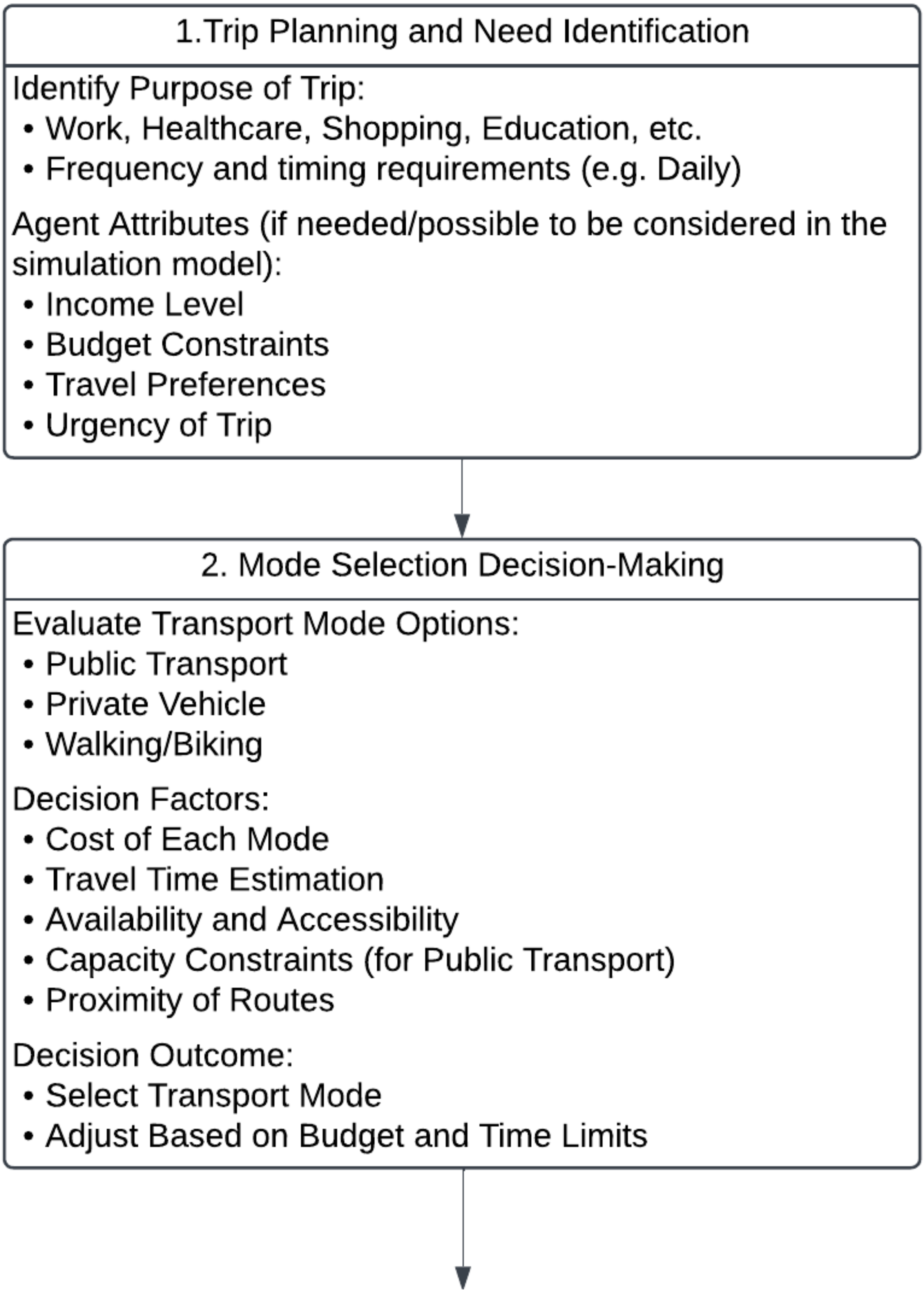

Figure 2: Conceptual Model Diagram, part (a)

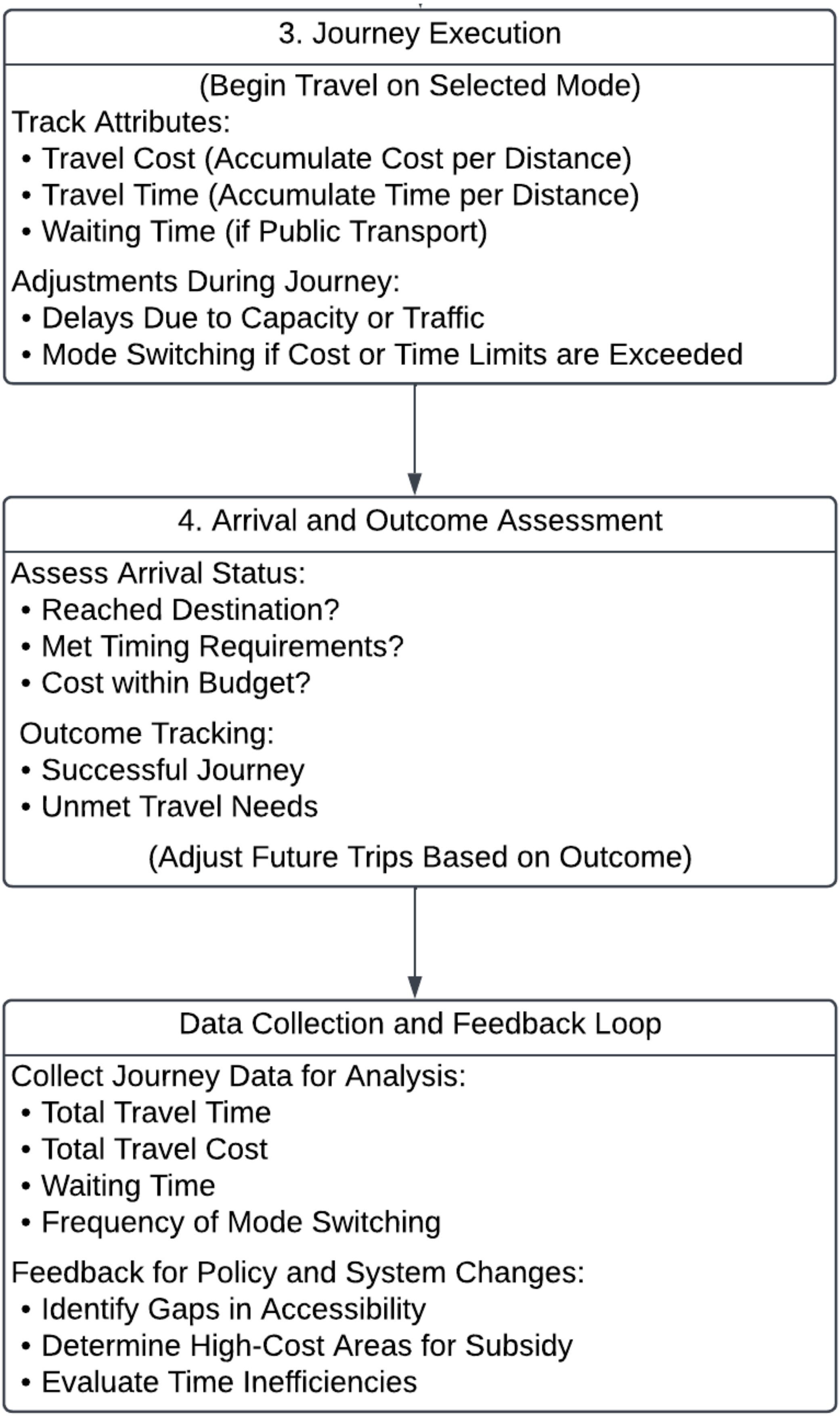

Figure 2: Conceptual Model Diagram, part (b)

c) Journey Execution

After selecting a means of transportation, the adventure begins. Several attributes are recorded during execution, such as cumulative travel cost, cumulative travel time, and waiting time (for public transportation). If there are any disturbances, such as delays caused by capacity constraints or road congestion, adjustments may be required. If the traveller's budget or time constraints are surpassed, he or she may change modes of transportation in the middle of the voyage.

d) Arrival and Outcome Assessment

At this point, the arrival status is assessed. The review considers whether the traveller arrived at the planned location, if timing requirements were met, and if the trip remained within budget. The outcomes are classified as either successful journeys or unmet travel needs. These findings help to inform future travel plans.

e) Data Collection and Feedback Loop

Finally, the model includes a feedback mechanism that collects and analyses journey data such as total travel duration, total cost, waiting time, and frequency of mode switching. This information reveals accessibility gaps, shows places with disproportionately high travel expenses that may require subsidies, and highlights inefficiencies in trip time. The feedback loop guides system modifications and policy initiatives aimed at improving equity and efficiency in transport provision.

4.4 Model Breakdown

To efficiently simulate transportation poverty with PTV VISUM software, we must first understand how the model works, including the flow of entities (travellers), decision-making processes, data inputs, and performance indicators. The model is generated from data collected through Zarząd Transportu Miejskiego (ZTM) and OpenStreetMap (OSM). The following sections will demonstrate a detailed explanation of how this model will work.

4.4.1 Trip Generation in District Zones

The model begins by predicting how many trips are generated in each of Warsaw's 18 districts. Trip production is related to residential populations, whereas attractions are determined by employment density, educational facilities, healthcare centres, and retail activities in each neighbourhood. To differentiate demand characteristics between districts, socioeconomic factors (e.g., income distribution, car ownership rates) are used whenever possible. This stage demonstrates how different districts have varying levels of transportation needs and resources.

4.4.2 Trip Distribution Between Districts

Generated trips are divided across the 18 districts to create an Origin-Destination (OD) matrix. An OD matrix is a table that shows the number of trips between each origin and destination zone over a certain time period. This is accomplished with the use of population and their common daily destinations such as work, school, etc. The distribution shows how distance, travel time, and monetary costs limit actual destination alternatives. In practice, inhabitants of outer districts face greater transport expenditures and travel longer distances to access centre services (including facilities as e.g. offices and workplaces, schools and universities, shopping centres, etc.), which the model identifies as a form of transportation poverty.

4.4.3 Mode Choice Across Population Segments

After distribution, the model uses a mode selection technique. In PTV VISUM software, a logit model is used to divide demand between private vehicles, public transportation, walking, and cycling. A logit model is a statistical choice model used in transportation planning to assess how travellers distribute their demand among alternative modes of transportation. It is based on the random utility maximization principle, which states that each means of transportation (e.g., road vehicle, bus, bicycle or simply walking) has a utility defined by characteristics such as journey time, cost, and convenience. The chance of selecting a certain mode is stated using a logistic function (Ren & Wang, 2023), with higher utility options attracting a bigger percentage of demand. Generalized cost functions include travel time, waiting time, transfers, and fares, which are weighted by the income-based value of time. Low-income residents are assumed to be more cost-conscious and less likely to buy private vehicles, hence increasing their reliance on public transportation, cycling or walking. This stage is critical for discovering disparities in modal accessibility among Warsaw's districts.

4.4.4 Network Assignment and Journey Simulation

Trips are subsequently assigned to their appropriate networks. Road traffic is routed through the OSM-derived road network, capturing congestion and delays. Demand for public transportation is assigned to the ZTM timetable-based supply network, allowing for accurate calculation of wait times, transfer fines, and capacity-related difficulties such as rejected boarding. Walking and bicycle excursions are assigned to the appropriate OSM networks based on distance and pace. This process generates realistic district-to-district travel times, charges, and modal conditions, which match residents' actual travel experiences.

4.4.5 Accessibility Analysis and Outcome Assessment

Once the trips are completed, accessibility measures are determined for each district and socioeconomic group. Metrics include the percentage of residents who can go to work, school, or the hospital in reasonable time or expenses. These results show a spatial depiction of transportation poverty, emphasizing differences between central and peripheral areas.

4.4.6 Data Collection, Indicators, and Feedback

The model aggregates results into district-level KPIs, such as average door-to-door travel time, modal split by income segment, average fare burden, and waiting and transfer times. These indicators allow for scenario testing of potential interventions, such as increasing bus frequencies, introducing fare subsidies, or extending ZTM services into underserved districts. The feedback loop ensures that the model can be iteratively refined to reflect observed travel behaviour and to support policy recommendations aimed at reducing inequalities across Warsaw’s districts.

The conceptual model created in this chapter is converted into a formal mathematical framework in Chapter 5, according to the methodology developed by Kostrzewski (2018, pp. 93–94). Each qualitative component (mobility, accessibility, affordability, and externalities) is expressed using quantifiable variables, functions, and indicators. These indicators not only capture different aspects of transportation disadvantage but also enable systematic comparison between districts and time periods. By organizing the interactions between indicators within a mathematical framework, the model translates the abstract concept of transportation poverty into a measurable event that can be consistently evaluated.

The indicators are then aggregated into a composite Transportation Poverty Index (TPI), which is the dissertation's main methodological innovation. The TPI offers a unifying measure that reflects the multifaceted character of transportation poverty while staying clear and reproducible. This allows for the identification of the city's most disadvantaged districts, the ranking of districts based on their vulnerability, and the long-term monitoring of prospective actions. The TPI was developed with the goal of bridging the gap between theoretical definitions of transportation poverty and their practical application in policy planning and evaluation.

The integration of the mathematical framework into a simulation environment (PTV VISUM) improves its analytical capabilities. While PTV VISUM is a computational tool for demand modelling, network assignment, and indicator calculation, the author's model determines what is measured and how results are interpreted, making it unique. This guarantees that the research extends beyond traditional traffic or infrastructure planning to include an explicit equity dimension.

In sum, the transition from the conceptual to the mathematical model is an important methodological step. The conceptual framework outlines the rationale behind how transportation poverty occurs, whereas the mathematical model formalizes this logic into variables, indicators, and functions that allow for systematic examination. The Transportation Poverty Index, devised and developed expressly for this research, embodies this connection and serves as the foundation for the formal model for assessing transportation poverty in metropolitan areas, which is described in depth in Chapter 5.

5. Mathematical Model

This chapter describes the formal mathematical model used to quantify transportation poverty in metropolitan areas. The model is directly based on the conceptual framework described in Chapter 4, but it goes beyond qualitative representation to include measurable variables, indicators, and composite measures. It is important to emphasize that the model presented in this work constitutes the original contribution of the author. Based on a thorough review of the available academic and professional literature, no prior studies have been identified that propose or implement this specific modelling approach. As such, the model fills an evident gap in the existing body of knowledge and offers a novel perspective on the analysed problem (this was also signalised at the end of literature review chapter, when a research gap was mentioned). This originality lies both in the conceptual framework and in the methodological integration of key transport-related dimensions, which, to the best of the author's knowledge, have not been addressed collectively in previous research. As such, it is a fresh and inventive solution designed particularly for the purpose of this dissertation.

Let's define the key data as follows:

- $d \in D$: d is the destination, while D is a set of destinations, $d \in \mathbb{N}$;

$$D = \{d : d \in \mathbb{N}\} \tag{1}$$

- $o \in O$: o is the origin of where the traveler is currently at, while O is a set of origins, $o \in \mathbb{N}$;

$$O = \{o : o \in \mathbb{N}\} \tag{2}$$

- $m \in M$: m is a transportation mode, while M is a set of transportation modes, $m \in \mathbb{N}$;

$$M = \{m : m \in \mathbb{N}\} \tag{3}$$

- $e \in E$: e is an indicator representing exposure to externalities in E a set of selected externalities, $e \in \mathbb{N}$;

$$E = \{e : e \in \mathbb{N}\} \tag{4}$$

- $S(o_i, d_i)$: Distance between origin o_i and destination d_i.

Let's define the key variables as follows:

- N: Number of travellers or individuals;
- i: Index for traveler i, where i =1,2, … , N, $i \in \mathbb{N}$;
- M_i^m: Mobility measure for traveller i using mode m, representing ease of movement (inverse of travel time). $M_i^m \in \mathbb{R}, \mathbb{R} = [0,1]$;
- A_i^m: Accessibility score for traveller i using mode m, based on proximity and network coverage. $A_i^m \in \mathbb{R}, \mathbb{R} = [0,1]$;
- F_i^m: Affordability for traveller i, expressed as the cost of transport C_i^m relative to their income I_i (affordability threshold). $F_i^m \in \mathbb{R}, \mathbb{R} = [0,1]$;
- E_i^m: Externality exposure for traveller i, such as air pollution or noise from transport mode m. $E_i^m \in \mathbb{R}, \mathbb{R} = [0,1]$;

Based on the above defined data and parameters the following indicators are given. Among them one can find:

- Mobility measures,
- Accessibility measures,
- Affordability measures,
- Exposure to externalities measures.

5.1 Quantifying the Components of Transportation poverty

5.1.1 Mobility

Mobility measurements represent individuals' abilities to move efficiently within the urban transportation system. Their objective is to demonstrate how well the network facilitates travel in terms of time, convenience, and dependability. These measurements, which quantify variables like as journey times, and ride times, provide insight into the performance of transportation services from the perspective of users. In the context of transportation poverty, mobility metrics highlight disparities between districts and demographic categories in terms of access to timely and reliable transportation.

Transport mobility M_i^m for traveller i using mode m is inversely related to travel time (in mins) is given according to Equation (5).

$$M_i^m = \frac{1}{T_i^m} \tag{5}$$

where T_i^m is the travel time [min] for traveller i (an individual) using mode m; $T_i^m \in \Re^+$. Lower values of travel times lead to higher values of mobility. For those travellers whose journeys are characterized with very long travel times or no available transport, M_i^m will result is lower values, consequently indicating low mobility.

5.1.2 Accessibility

Accessibility measures describe how easily people can get to important places including work, school, healthcare, and shopping. Their goal is to emphasize the spatial and temporal disparities in possibilities between metropolitan neighbourhoods. These measurements go beyond simple mobility and examine the interaction between land use and transportation connectivity. In the context of this dissertation, accessibility indicators are critical for determining how the location of services and infrastructure contributes to unequal opportunities and possible social exclusion.

Transport accessibility A_i^m is based on how easily an individual can access essential services using a transport mode m. It is calculated as given in Equation (6).

$$A_i^m = \sum_{d \in D} Q_{od}^m(i) \cdot A_o^m \tag{6}$$

Where $Q_{od}^m(i)$ is the probability that traveller i can access a destination d from their origin o using mode m, ($Q_{od}^m(i) \in \mathbb{R}, \mathbb{R} = [0,1]$) and A_o^m represents network coverage and proximity to transport services.

Hence $Q_{od}^m(i)$ is the probability of a successful trip from o to d using mode m for individual i which can be determined by route availability $R_{od}^m(i)$, Service frequency F_m, Reliability ρ_m, and user constraints C_i. The combined formula can be presented as the Equation (7).

$$Q_{od}^m(i) = R_{od}^m(i) \cdot F_m^* \cdot \rho_m \cdot C_i \tag{7}$$

Where such key determinants are:

- Route Availability $R_{od}^{m}(i)$: this key determinant indicates whether a transport connection exists between the origin and destination using mode m ($R_{od}^{m}(i) \in \boldsymbol{B}, \boldsymbol{B} = \{0,1\}$):
    - $R_{od}^{m}(i) = 1$ if a route exists, and 0 if not
    - $\forall\, S(o_i, d_i) > 0 \;\Rightarrow\; R_{od}^{m}(i) = 1;$
    - $\forall\, S(o_i, d_i) = 0 \;\Rightarrow\; R_{od}^{m}(i) = 0.$

- Service Frequency F_m ($F_m \in \mathbb{N}$): The number of trips per hour or day along the route (e.g. the scheduled transportation in the public sector throughout the route). Higher frequencies enhance the chances of access. It is given according to Equation (8).

$$F_m^* = \frac{F_m}{F_{max}} \tag{8}$$

    - Where F_{max} is the maximum frequency considered feasible and F_m^* is the normalized frequency.

- Reliability ρ_m ($\rho_m \in \mathbb{R}, \mathbb{R} = [0,1]$): It measures the service's consistency and punctuality (e.g. how accurate do the public transportation arrive on schedule? Or how any trips can the private car user go through the route without any delays? etc.). Reliability may be expressed as Equation (9).

$$\rho_m = \frac{t_o}{t_{tot}} \tag{9}$$

    - Where is the t_o on-time trips and t_{tot} is the total trips.

- User constraints C_i: Affordability and physical accessibility may limit a person's capacity to use the mode (C_i is 1 if the mode is usable by the individual, and 0 otherwise; $C_i \in \boldsymbol{B}, \boldsymbol{B} = \{0,1\}$)

5.1.3 Affordability

Affordability measurements examine the relationship between the cost of travel and the income or resources of the travellers. Their goal is to establish if households can reasonably maintain mobility without financial burden. These criteria are especially important for identifying disadvantaged groups that may be priced out of effective transportation options, resulting in limited access to opportunities. Within the model, affordability indicators establish a direct link between transportation poverty and broader socioeconomic disparities.

Transport affordability F_i^m (in currency. e.g. PLN) is the parameter determined by the cost of transportation C_i^m (i.e. total amount of money needed to pay for the use of any mode of transportation throughout a month or a year which can be simply described as how much percent of the user's salary does/do he/she/they pay for transportation? For example, total cost of using public transportation per month or year, total cost of using a private car per month or year) relative to the traveller's income I_i. The parameter is calculated according to Equation (10).

$$F_i^m = \frac{C_i^m}{I_i} \tag{10}$$

If F_i^m exceeds a certain threshold τ, the traveller is considered to be in transportation poverty with respect to affordability. The threshold τ is typically set as a percentage of income that should not be exceeded for transport costs (e.g., 10-15%). These percentages are influenced by multiple factors such as car payments, fuel, maintenance, public transport, insurance, etc.

5.1.4 Exposure to Externalities

Exposure metrics capture the negative effects of transportation systems, such as air pollution, noise, congestion, and safety hazards, which disproportionately affect specific communities. Their goal is to account for not only accessibility and affordability, but also the environmental and social costs of transportation. By quantifying exposure, the model understands that transportation poverty is caused by both limited possibilities and unevenly distributed harms. These parameters broaden the assessment, ensuring that transportation poverty is viewed as both a lack of advantages and an unequal distribution of expenditures.

Exposure to externalities E_i^m represents the negative environmental and social impacts experienced by a traveller using a transport mode m. This can include air pollution, noise, and traffic congestion and other externalities and is treated as the sum of the individual components as given in Equation (11).

$$E_i^m = \sum_{e \in E} \beta_k \cdot E_f \tag{11}$$

Where:

- β_k = the externality weight factor, which can be determined through policy analysis, transport surveys, and environmental impact assessments
- E_f = primary externalities affecting transportation poverty (externality factor), which includes the following:
  - **Congestion:** Congestion increases travel time, limits accessibility, reduces transport reliability, and raises travel costs. In urban areas, high congestion disproportionately affects low-income travellers reliant on public transport, reducing their mobility and economic opportunities (Litman, 2007). Studies show that congestion costs major cities billions annually in lost productivity (Schrank et al., 2021).
  - **High Energy Consumption & Fuel Costs:** High fuel consumption leads to increased transport costs, disproportionately impacting lower-income populations who rely on fuel-dependent transport (Banister, 2018). According to the International Energy Agency (IEA), fuel price volatility exacerbates transportation poverty in regions with inadequate public transport infrastructure (IEA, 2022).
  - **Accidents & Partial Insurance Coverage:** Road accidents disproportionately affect vulnerable communities due to limited access to comprehensive insurance and healthcare (World Bank, 2020). Studies indicate that uninsured or underinsured travellers face significant financial burdens after transport-related accidents (Peden et al., 2004).
  - **Air Pollution:** Low-income communities, often living near highways or industrial zones, experience higher exposure to transport-related air pollution (WHO, 2021). Research has linked long-term exposure to air pollution with

respiratory diseases, reducing quality of life and increasing healthcare costs (Brunekreef & Holgate, 2002).

- **Noise Pollution:** Noise pollution from road traffic and rail systems disproportionately affects lower-income neighbourhoods, leading to increased stress, sleep disorders, and reduced cognitive function (Münzel et al., 2021). Studies have found correlations between prolonged exposure to noise pollution and cardiovascular diseases (Babisch, 2014).
- **Climate Change Impact:** Transport emissions contribute to climate change, which, in turn, exacerbates infrastructure vulnerability, food security, and displacement risks (IPCC, 2022). Climate-induced disruptions (e.g., flooding affecting transport infrastructure) further isolate low-income populations, deepening transportation poverty (Ji et al., 2022).
- **Transformation of Natural Landscapes:** Urban transport expansion often displaces marginalized communities, reducing their access to affordable housing and essential services (Sheller, 2018).
- **Risks Associated with Hazardous Cargo:** Although not a widespread contributor to transportation poverty, hazardous cargo risks affect communities near transport hubs and industrial areas. Accidents involving hazardous materials can lead to long-term environmental and health consequences for exposed populations.
- **Pollution from Vehicle Operation and Disposal:** Transportation poverty is also affected by long-term vehicle disposal practices. Poorly regulated vehicle scrapping disproportionately affects low-income regions, leading to environmental degradation (UNEP, 2020).

5.2 Overall Transportation poverty Index

We now combine the individual components of transportation poverty into a composite index. Transportation poverty for each traveller i is defined as Transportation poverty Index (TPI) given in Equation (12).

$$TPI = \alpha_1 \cdot \left(\frac{1}{M_i^m}\right) + \alpha_2 \cdot \left(\frac{1}{A_i^m}\right) + \alpha_3 \cdot \max(0, +F_i^m - \tau\ ) + \alpha_4 \cdot E_i^m,\ TPI \in \langle 0; 1 \rangle \quad (12)$$

Where:

- $\alpha_1, \alpha_2, \alpha_3, \alpha_4$ are weight factors representing the relative importance of each component in the overall transportation poverty index. Weight factors thresholds are $\{\alpha_1, \alpha_2, \alpha_3, \alpha_4\} \in \langle 0; 1 \rangle$.
- $\frac{1}{M_i^m}$: Inverse of mobility – low values of mobility increase a range of transportation poverty.
- $\frac{1}{A_i^m}$: Inverse of accessibility – low values of accessibility increase a range of transportation poverty.
- $\max(0, +F_i^m - \tau)$: Excessive transport costs beyond the affordability threshold τ contribute to poverty.
- E_i^m: Exposure to negative externalities adds to the level of transportation poverty.

The Overall Transportation Poverty Index (TPI) is a comprehensive tool for assessing and quantifying the multidimensional concept of transportation poverty. Transportation poverty is more than just a lack of transportation; it has numerous interconnected characteristics, including mobility, accessibility, price, and exposure to externalities such as pollution or noise. The TPI combines these variables into a single index, providing a comprehensive picture of transportation deprivation in a population. It is important to compute this indicator for the following reasons:

1. **Comprehensive Assessment**: The TPI integrates multiple factors such as mobility, accessibility, affordability, and externalities to measure transport deprivation. A study in Madrid demonstrated the use of big data techniques to assess transportation poverty by analysing commuting patterns and economic burdens (Gutiérrez et al., 2021).
2. **Policy Decision-Making**: TPI helps governments identify transport-deprived areas. A study in Milan used Public Transport Accessibility Levels (PTAL) to highlight social vulnerabilities and recommend policy actions (Transform Transport, 2023).
3. **Equity & Social Justice**: The European Parliament (2022) emphasized transportation poverty as a key social vulnerability issue, linking poor access to mobility with economic and social exclusion.
4. **Sustainability & Environmental Impact**: The World Bank highlighted that transportation poverty contributes to economic disparity, and sustainable transport policies are necessary for balanced economic growth (World Bank, 1997).

5. **Performance Monitoring**: In England, the government introduced integrated transport apps to monitor accessibility improvements in deprived regions, promoting better transport connectivity (Haigh, 2024).

5.3 Mean Transportation poverty Index

The total transportation poverty for the city can be calculated by the mean value of the TPIs of the zones (districts) as given in Equation (13).

$$TPI_C = \frac{\sum_{z=1}^{N} TPI_z}{N} \tag{13}$$

This gives the overall transportation poverty in the system of the city, considering all travellers i and their respective levels of mobility, accessibility, affordability, and externality exposure. The higher the aggregated *TPI* the higher the transportation poverty in that system and vice versa. The *TPI* is considered to be between zero and one ($TPI \in \mathbb{R}, \mathbb{R} = [0,1]$):

- **0.75 ≤ *TPI* ≤ 1**: High transportation poverty, indicating severe deprivation, high transport costs relative to income, and significant barriers to employment, education, and essential services
- **0.25 ≤ *TPI* < 0.75:** Moderate Transportation poverty, showing limited transport accessibility in certain areas, moderate affordability concerns, and some socio-economic groups experience difficulties in mobility
- **0 ≤ *TPI* < 0.25**: Low transportation poverty, reflecting equitable and efficient transport access.

This mathematical model integrates mobility, accessibility, affordability, and exposure to externalities into a single framework. By adjusting the weights $\alpha_1, \alpha_2, \alpha_3, \alpha_4$, policymakers can prioritize which aspects of transportation poverty to address more urgently, such as improving accessibility, reducing costs, or mitigating externalities like pollution. The goal is to identify and implement policies that will reduce the overall transportation poverty in a given population.

6. Building a Simulation Model: Simulations and Testing

Addressing transportation poverty requires comprehensive solutions that consider the diverse needs of individuals and communities. This chapter presents the development of a simulation model in PTV VISUM to explore the complex dynamics of transportation poverty and its impact on urban systems in Warsaw.

The complexity of urban transportation networks and their interplay with land use patterns necessitates a holistic approach to simulation modelling (Assaad, et al., 2020). Previous studies have demonstrated the potential of system dynamics modelling in capturing the interdependencies between land use and transportation systems (Haghani, et al., 2003). Additionally, the use of dynamic gravity models has been explored in the context of urban passenger transportation, highlighting the importance of accounting for various external and internal factors (Sergiy, 2023).

This model serves as a foundational analytical tool for evaluating transportation poverty across different socio-spatial segments of the city. In this specific scenario, the phrase "transportation poverty" illustrates the various forms of exclusion and difficulties that individuals experience as a direct consequence of their limited access to transportation that is both affordable and characterized by efficiency and reliability. In order to assess the affordability and accessibility of transportation services, the model takes into account the interplay among land use, population distribution, and the multimodal transportation network.

The model simulates origin-destination flows under present network topologies, takes into consideration sociodemographic heterogeneity over 18 aggregated zones, and integrates both public and private transportation systems. The model provides insights into how fare policies, service frequency adjustments, and infrastructure affect travel behaviour and equality in transportation accessibility by utilizing PTV VISUM's assignment algorithms.

6.1 Study Area and Zoning Structure

The capital and largest city of Poland, Warsaw, has a complicated urban layout with wide-ranging differences in land use, population density, and socioeconomic circumstances. A unique zoning scheme consisting of 18 aggregated zones was created in order to strike a compromise between manageability and model detail. Administrative borders, important transportation routes, and noted socio-spatial trends (such as working places, universities, city centre, etc.) were taken into consideration while designing these zones.

Each zone represents a different district of Warsaw and was carefully generated in Visum manually (Figure 3).

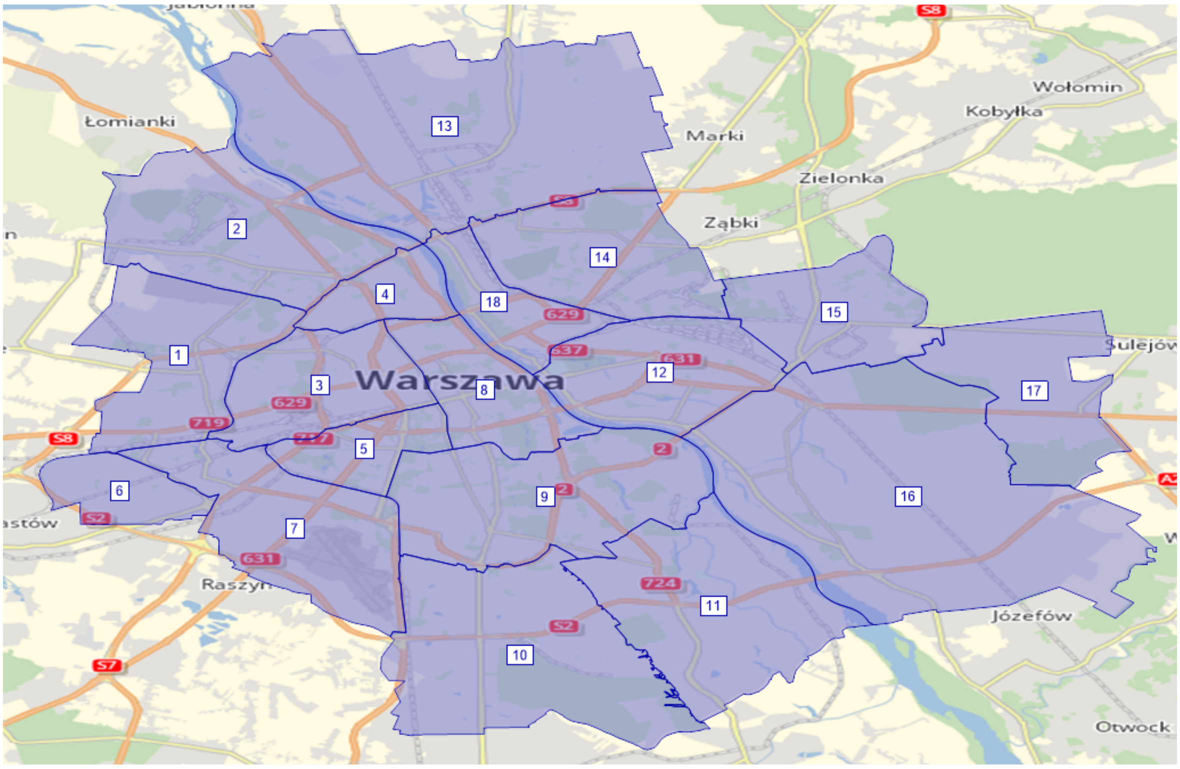

Figure 3: Zones in the simulation model using PTV VISUM

The zones are linked to the transport network via centroid connectors. These are artificial links that allow trips to start and terminate at the zone's centroid and connect to the adjacent nodes in the public transportation or road network. The connectors were designed to connect passengers to public transportation stops to have realistic walking distances and maintain spatial logic in trip generation and assignment which will then connect them to their destinations by using the public transport network (Figure 4 below). A total of 960 connectors were created across all 18 zones to provide a more accurate and realistic options for the passengers in the simulation model as in real life.

In Table 3 below, each district and its representative zone including the population in each zone are presented.

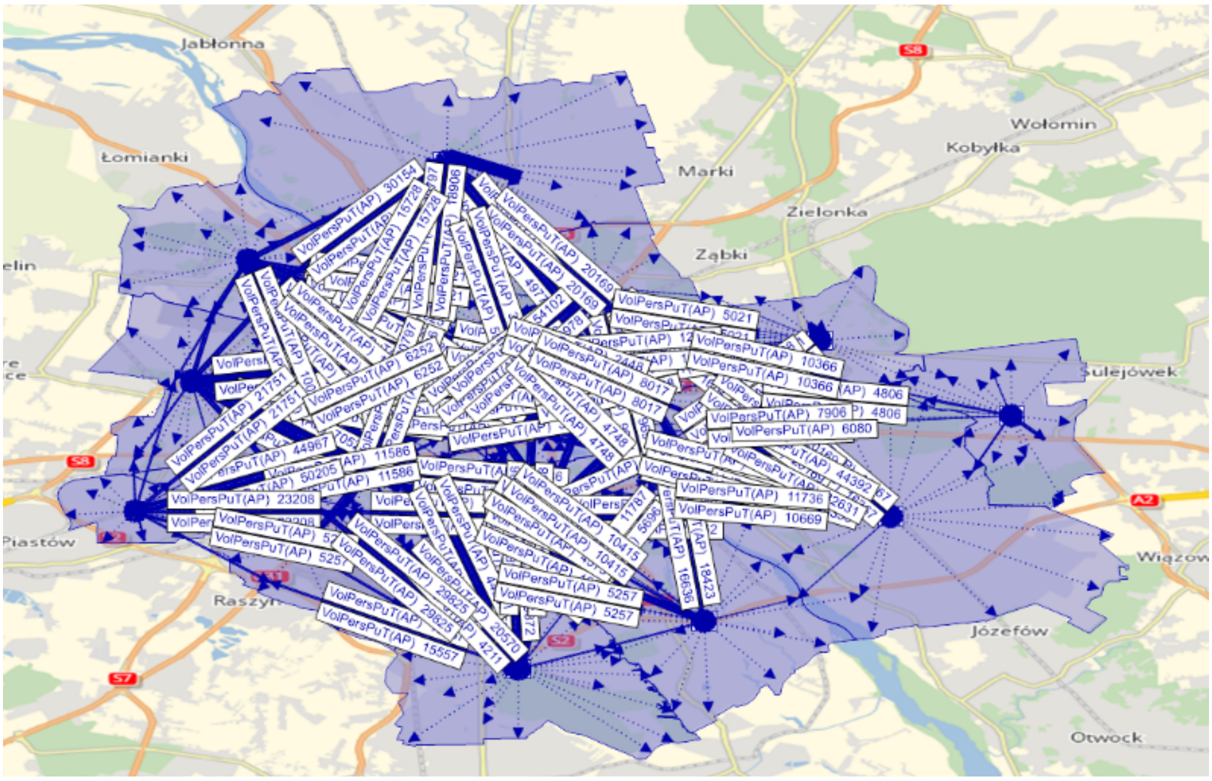

Figure 4: All connectors applied to the zones using PTV VISUM

Table 3: Warsaw Districts and their respective PTV VISUM zones

Zones (1)	**Warsaw District (2)**	**District's Population (by 2024) (3)**	**per 1 km^2 (4)**
1	Bemowo	129169	5177
2	Bielany	133478	4127
3	Wola	151158	7848
4	Żoliborz	58633	6922
5	Ochota	80988	8332
6	Ursus	67373	7198
7	Włochy	49280	1721
8	Śródmieście	101979	6550
9	Mokotów	225916	6378
10	Ursynów	151432	3458
11	Wilanów	51172	1393
12	Praga-Południe	186834	8348
13	Białołęka	153100	2096

Zones (1)	Warsaw District (2)	District's Population (by 2024) (3)	per 1 km^2 (4)
14	Targówek	124240	5106
15	Rembertów	24670	1278
16	Wawer	86399	1084
17	Wesoła	26380	1150
18	Praga-Północ	60855	5381
	Total Population of Warsaw city	1863056	

6.2 Network Development

6.2.1 Base Network

The model's foundation transportation network was created through OpenStreetMap (OSM), which provides precise and up-to-date information about road hierarchies, intersections, and limitations. The OSM import established a solid foundation for Warsaw's both road and rail network, which included main arterials, secondary highways, and local streets, etc. After import, the network was cleaned and updated to guarantee logical connectivity and alignment with PTV VISUM's assignment requirements as shown in Figure 5 below.

The directional connections between nodes that represent road segments, railroad tracks, or other infrastructure where movement takes place are called *links* in PTV VISUM. They carry important characteristics like length, speed, capacity, and travel time, which are used in assignment to determine routes and model congestion. They also define network connectivity. Links are essentially the fundamental components of the network that transform the isolated nodes (shown in Figure 5) into a functional transport system (shown in Figure 6). The following 2 Figures (6,7) will present how the transport network will look like after including the links. Figure 6 will show the overall look of Warsaw city's network while Figure 7 will show a zoomed in small segment to present the accuracy of the network.

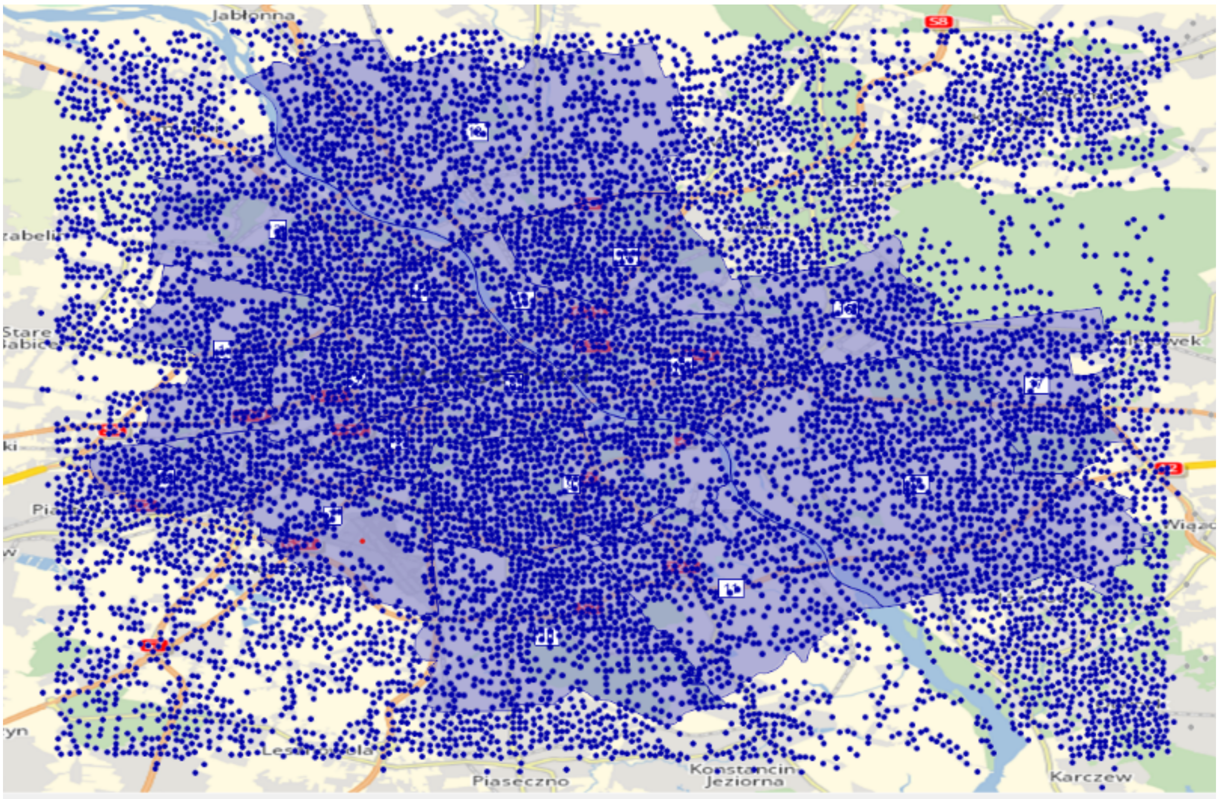

Figure 5: Updated nodes in the simulation model

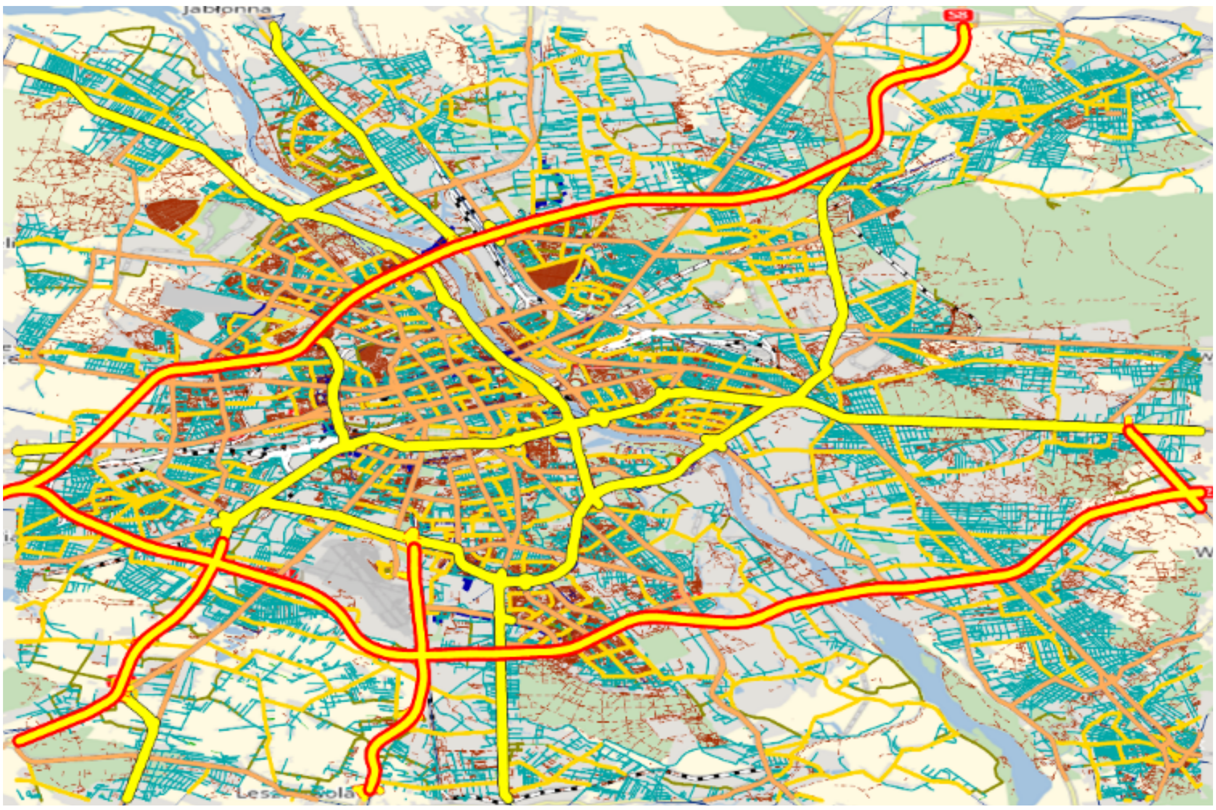

Figure 6: Overall transport network links

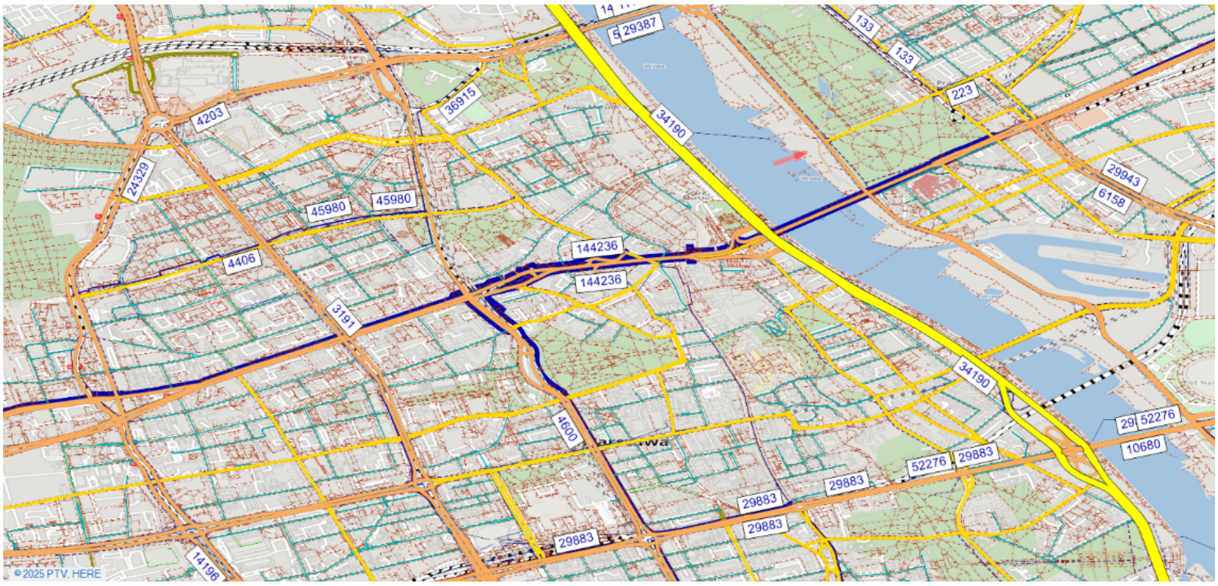

Figure 7: Zoomed in segment of transport network links

Attributes including speed limits, road capacities, and lane configurations were assigned default values based on road classifications. Signal timings, turn limitations, and one-way systems were also implemented where data was available (by OSM).

6.2.2 Public Transport Network

The public transportation (PT) network included bus, tram, metro, and train services. Rather of using GTFS feeds, which can result in misaligned imports, all public transportation lines were created by the public transport system feature offered by Warsaw's public transportation authority (ZTM Warszawa). This method guaranteed correctness in line geometry, stop sequences, and operating characteristics. All of this data was imported from the official website of Warsaw's public transportation authority (ZTM Warszawa).

Each PT line was assigned the following:

- A unique line ID and mode type (bus, tram, metro, or train),
- Stop locations and stop intervals,
- Headway and frequency patterns for peak periods,
- Operating hours (depending on each line's real-life operation),
- Average travel speed and dwell times per stop.

Transfer points were manually verified to ensure consistency, and lines were structured to allow seamless intermodal connections. Transfer penalties and waiting times were specified to reflect realistic travel behaviour according to the ZTM data file.

The resulting model contains a total of 326 lines after manual adjustments to include the lines operating within the 18 zones (also including the lines extending outside of the zones range), covering the full range of bus, tram, train, and metro services operated under ZTM. This dataset provides a comprehensive representation of the public transportation system and enables further analysis of service accessibility, passenger assignment, and scenario testing. The Figure below shows how these lines are spread throughout the simulation model to insure a real-world replication.

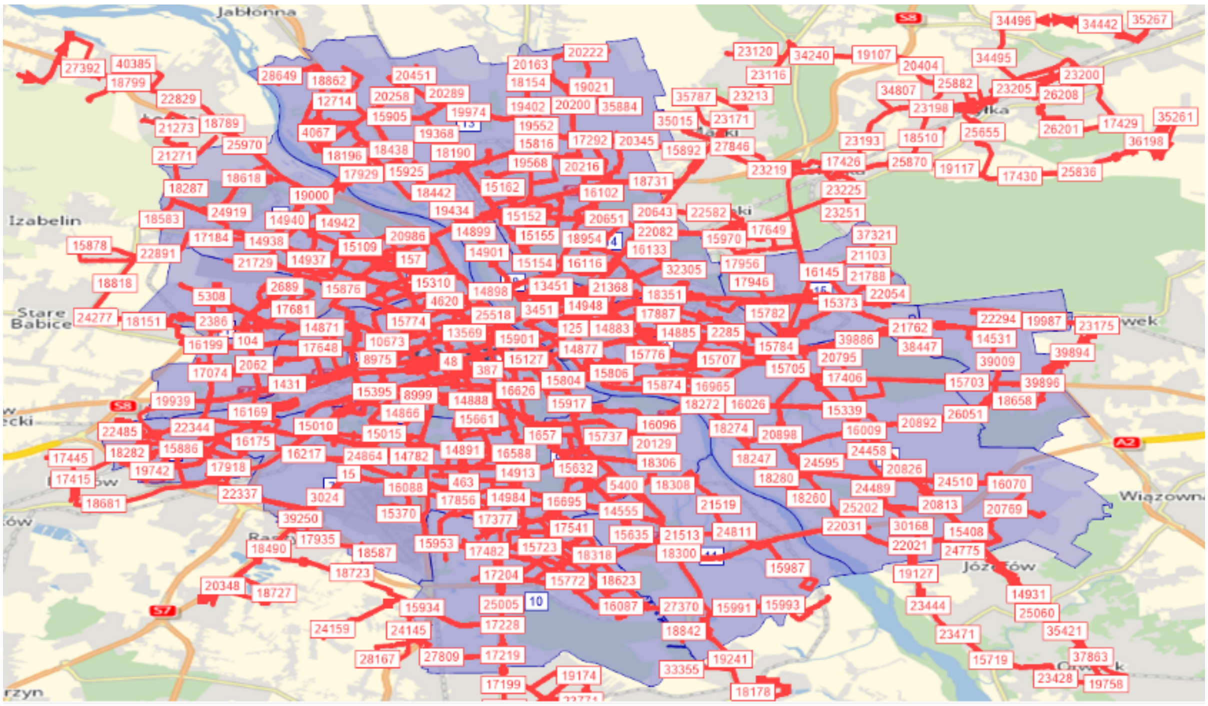

Figure 8: Public transportation lines in PTV VISUM

Alongside the public transport lines, the imported ZTM dataset included the full set of passenger stops. The geographic coordinates of each stop, along with its name, service type (bus, tram, metro, train), and related timetable details, define it. In order to integrate these stops directly into the transport network, they were transformed into PTV VISUM nodes during the import process.

PTV VISUM organizes the system into stop areas, which cluster adjacent stops serving various directions or modes, in addition to individual stops. For instance, a single interchange might have a metro entrance, several bus bays, and a tram stop. By combining these facilities into a single stop area, it is possible to accurately model passenger transfers between lines and reflect their actual role as transfer points. Figure 9 demonstrates the stop areas which are connected to all the lines described above.

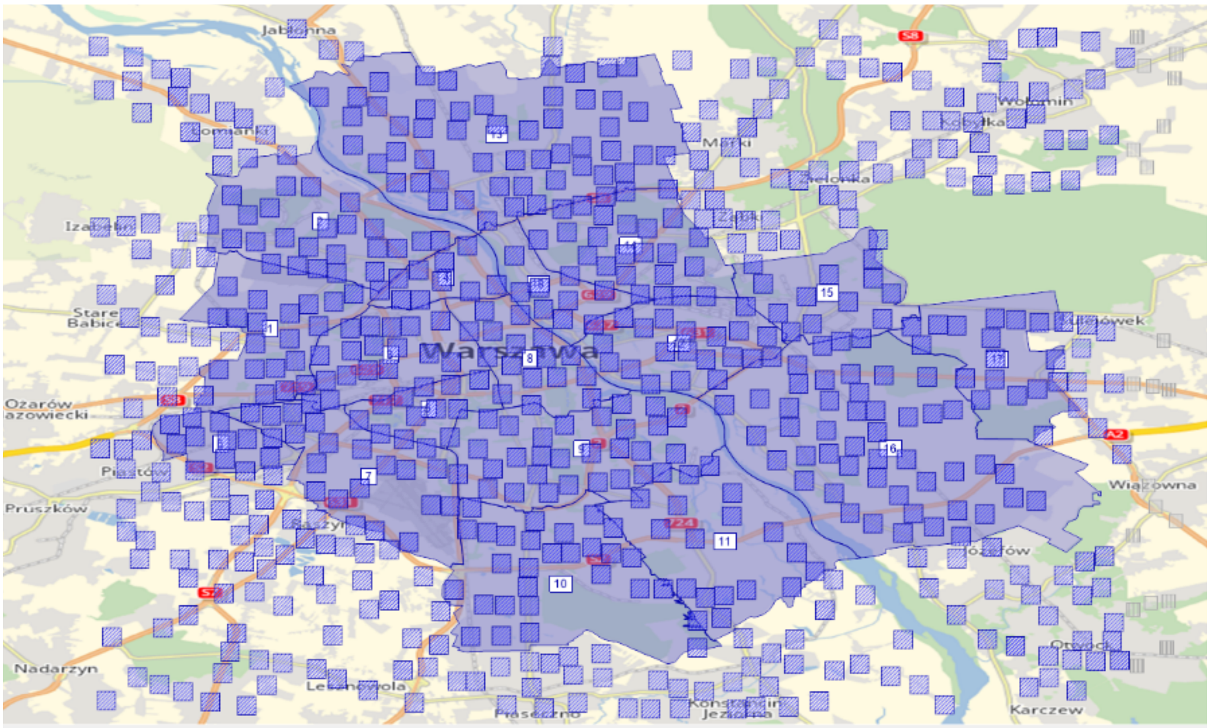

Figure 9: Stop areas for the public transportation system

The required framework for line operations was established in the imported ZTM network by integrating 12,487 stops into 11,637 stop areas. Stop areas guarantee accurate representation of multimodal interchanges and passenger transfer options, while stops serve as boarding and alighting locations. When combined (Figure 10 below), they allow the imported lines to work as a single unit and render the network appropriate for scenario analysis, passenger assignment, and accessibility studies.

6.3 Demand Modelling

The population distribution across the 18 traffic analysis zones (TAZs) established in Table 3 (shown above in section 6.1) served as the basis for the demand component of the model. The main basis for estimating daily trip productions and attractions was the residential population, which was used to characterize each zone.

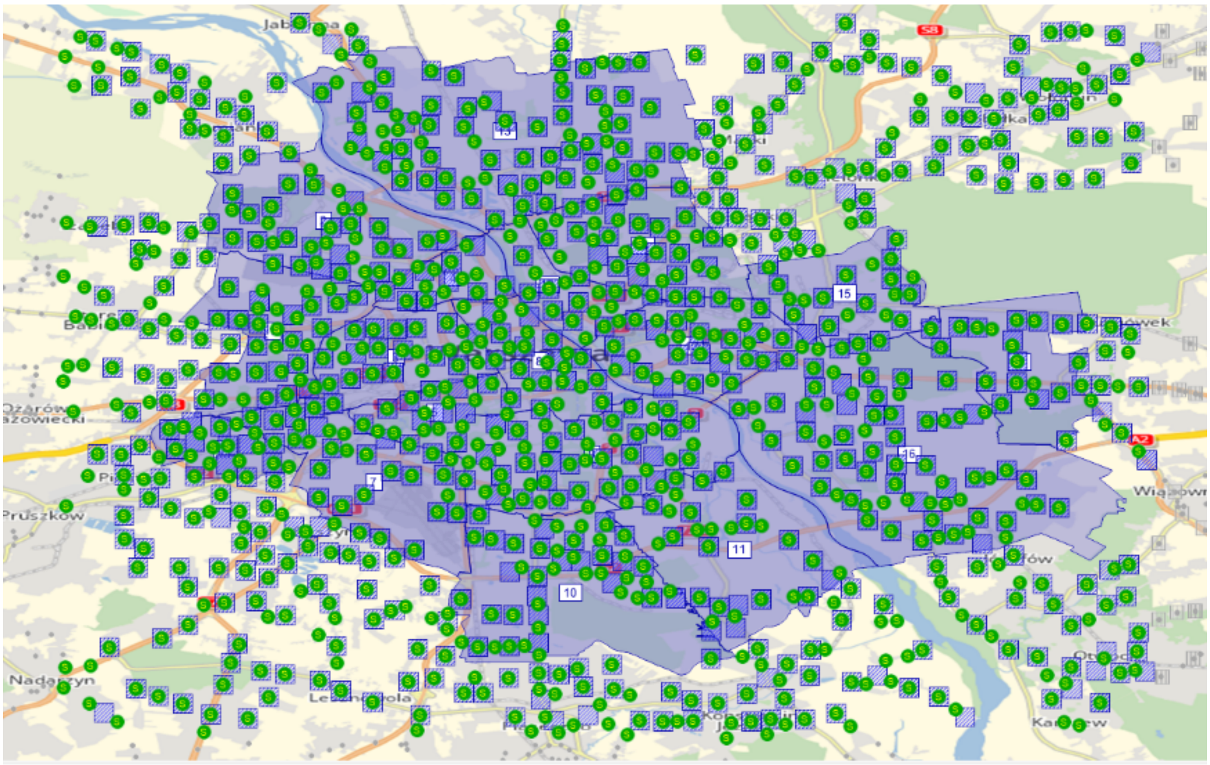

Figure 10: Combined stop areas and stops

6.3.1 Trip Productions

Estimates of trip productions were made in relation to population. The average urban trip generation rate usually falls between 2.8 and 3.2 trips per person per day, according to international travel surveys (such as German Mobility Panel, 2024; FHWA, 2024; City of Warsaw, 2023 studies). 3.0 trips per person per day was chosen as the standard value for this model. Each zone's total number of trips was determined using the following formula:

$$P_z = Population_z \times 3 \tag{14}$$

Where:

- P_z = the total number of trips produced in zone z.

For example, Zone 1 (Bemowo), with a population of 129,169, produces approximately 387,507 trips per day.

6.3.2 Trip Attraction

Trip attractions were assumed to equal trip productions for each zone in the absence of comprehensive land-use data, such as employment or service distribution. This strategy ensures that the demand matrix stays balanced, meaning that total productions and total attractions are equal. The definition of the relationship was given as the one in Equation (15).

$$A_z = P_z \tag{15}$$

Where:

- A_z = trips attracted to zone z,
- P_z = trips produced in zone z.

This simplification is frequently used in early-stage strategic modelling, despite the fact that it does not accurately represent real-world dynamics (such as employment centres drawing disproportionately higher trips). This limitation is addressed in the next section (Section 5.3.3) by applying weighting factors to central zones, thereby reflecting their increased significance as attractors in Warsaw's transportation system.

6.3.3 City Centre Weighting

Since the city centre draws more trips than it generates because of its concentration of employment, services, and cultural facilities, the notion that trip attractions (term refers to destination places) equal productions (term refers to the **origins** of trips) do not accurately represent the realities of travel in Warsaw. To address this imbalance, three key zones were allocated weighting factors that differentiated the major district, secondary comparator, and periphery reference region. These parameters were motivated by empirical trip attraction patterns from Warsaw's 2015 Travel Survey and other European research, which reveal that city-center zones often draw 30-60% more visits than they create (Wegener & Fuerst, 2004; Ortúzar & Willumsen, 2011; EMTA, 2020). The values are illustrative baselines that can be modified in future applications to reflect population, demand, or policy priorities.

- **Śródmieście district (Zone number 8, +50%, 1.5 multiplier to the number of trips)**: selected as the main city centre and employment hub, thus given the strongest weighting (to make the information clear, zone number refers to a specific traffic analysis zone in the PTV VISUM model – it is a spatial unit applied for modelling and aggregating data related to defined trips; a zone typically represents a neighbourhood, district – as in this case, or other geographical area; a value of percentage indicates that the certain number of trips in a particular zone is being increased by this value in percentage, while multiplier means that all base trip values for a particular zone are multiplied by a value of multiplier).

- **Wola district (Zone number 3, +30%, 1.3 multiplier to the number of trips)**: designated as a rapidly developing business and commercial district adjacent to the core, warranting a moderate weighting.
- **Ochota district (Zone number 5, +10%, 1.1 multiplier to the number of trips)**: included as an outer central district with significant residential and service activity, receiving a lighter weighting.

With Śródmieście district having the strongest pull, Wola district playing a secondary role, and Ochota district a tertiary role, these percentage increases were implemented to represent the relative strength of each district in luring tourists. To ensure consistency between total productions and attractions, the attractions were normalized after the weights were applied. This was accomplished by scaling the modified attractions until their sum matched the total productions once more. Consequently, the model's overall trip volume stayed the same, but the demand distribution moved more realistically in the direction of central districts.

6.3.4 Trip Distribution

Allocating trips between origins and destinations was the next stage after trip productions and attractions were decided. The productions of each zone were dispersed among all destination zones based on their relative attractiveness using a proportional distribution technique. This made sure that every trip generated by a zone was distributed equally, with more trips going to more appealing locations.

At the system level, the approach preserved equilibrium between attractions and productions. The proportional method offered a consistent framework for producing an entire Origin–Destination (OD) matrix, despite the fact that no travel time or distance data were included at this point, which restricted the model's capacity to capture impedance effects. The basic demand input for later assignment processes in PTV VISUM is this OD matrix, which shows the spatial distribution of travel demand across the 18 zones.

6.3.5 Intra-Zonal Trips

Some daily trips, like short-distance shopping, school, or leisure trips that do not cross administrative boundaries, take place completely within the same zone in addition to inter-zonal travel. Intra-zonal trips were specifically included in the model to take these internal movements into consideration. Intra-zonal demand was defined as a set percentage of each zone's total production, 10%.

This modification made sure that both local and inter-zonal travel behaviour was represented in the OD matrix. Including intra-zonal demand is particularly important in larger zones, where significant proportions of trips may be contained within the district itself. The model maintains the overall trip balance throughout the system while more accurately representing realistic patterns of urban mobility by assigning a portion of productions to the diagonal of the OD matrix.

6.3.6 Origin-Destination Matrix Calculations

Starting with trip productions based on population and a standard generation rate of three trips per person per day, the demand model was developed in stages. To keep the model balanced in the absence of comprehensive employment and service data, trip attractions were first assumed to have equal productions. By applying weighting factors to central zones, demand was more realistically redirected toward the city centre and central zones' relative attractiveness was increased, better reflecting the functional role of Warsaw's urban core.

A proportional allocation method was used to distribute the trips, assigning productions to destinations based on their adjusted attractiveness. Despite not taking travel impedance into consideration, this method offered a reliable way to produce a balanced Origin–Destination matrix. Ten percent of productions were allocated to internal demand within each zone in order to further improve realism and incorporate intra-zonal trips.

The outcome of this procedure is a balanced 18 × 18 OD matrix that reflects the central districts of Warsaw's dominating influence while capturing both intra- and inter-zonal travel patterns. This matrix serves as the basis for VISUM's later private and public transportation assignment processes.

Demand modelling was based on synthetic OD matrices designed for the 18-zone scheme. These matrices were created to depict typical peak-period flows and account for the city's predominant travel patterns. Each OD pair was assigned a number of trips based on population distribution, employment areas, and established commuting patterns. Table 4 (split into 2 for better visibility) shows the OD matrix which was used in the simulation model.

Table 4: OD Matrix

Matrix editor (Matrix '6 New matrix')

18 x 18			1	2	3	4	5	6	7	8
	Name		Bemowo	Bielany	Wola	Żoliborz	Ochota	Ursus	Włochy	Śródmieście
		Sum	380248.13	392055.98	558280.49	178910.11	266369.20	204681.13	151073.60	441354.24
1	Bemowo	400817.25	38750.70	26289.14	38702.69	11548.05	17546.08	13269.44	9705.93	30127.89
2	Bielany	413311.27	26289.14	40043.40	39993.79	11933.29	18131.40	13712.10	10029.72	31132.93
3	Wola	453530.19	29771.30	30764.45	45347.40	13513.93	20533.02	15528.35	11358.22	35256.69
4	Żoliborz	188246.95	11548.05	11933.29	17568.11	17589.90	7964.60	6023.33	4405.76	13675.79
5	Ochota	256259.15	15950.98	16483.09	24266.30	7240.54	24296.40	8319.84	6085.55	18889.96
6	Ursus	215409.73	13269.44	13712.10	20186.86	6023.33	9151.82	20211.90	5062.50	15714.34
7	Włochy	158921.03	9705.93	10029.72	14765.68	4405.76	6694.10	5062.50	14784.00	11494.26
8	Śródmieście	312744.71	20085.26	20755.29	30555.79	9117.19	13852.64	10476.23	7662.84	30593.70
9	Mokotów	667700.81	44495.25	45979.58	67690.83	20197.49	30688.01	23208.19	16975.64	52693.54
10	Ursynów	464759.78	29825.26	30820.22	45373.31	13538.42	20570.24	15556.50	11378.81	35320.60
11	Wilanów	164874.84	10078.57	10414.79	15332.58	4574.91	6951.11	5256.86	3845.13	11935.56
12	Praga-Południe	563326.65	36797.86	38025.41	55980.75	16703.46	25379.18	19193.32	14038.96	43577.90
13	Białołęka	469489.65	30153.78	31159.70	45873.09	13687.55	20796.82	15727.85	11504.14	35709.65
14	Targówek	386456.09	24469.67	25285.96	37225.82	11107.39	16876.53	12763.09	9335.56	28978.23
15	Rembertów	80483.00	4858.88	5020.96	7391.83	2205.56	3351.13	2534.33	1853.74	5754.13
16	Wawer	273734.53	17016.70	17584.37	25887.59	7724.30	11736.28	8875.71	6492.14	20152.04
17	Wesoła	85992.88	5195.67	5368.99	7904.19	2358.44	3583.41	2710.00	1982.23	6152.97
18	Praga-Północ	195174.73	11985.69	12385.52	18233.88	5440.60	8266.43	6251.59	4572.73	14194.06

9	10	11	12	13	14	15	16	17	18
Mokotów	Ursynów	Wilanów	aga-Południ	Białołęka	Targówek	Rembertów	Wawer	Wesoła	raga-Półno
631725.51	440645.46	156726.11	533574.85	445109.71	366671.88	76554.50	259976.18	81792.09	185484.07
44495.25	29825.26	10078.57	36797.86	30153.78	24469.67	4858.88	17016.70	5195.67	11985.69
45979.58	30820.22	10414.79	38025.41	31159.70	25285.96	5020.96	17584.37	5368.99	12385.52
52069.87	34902.55	11794.29	43062.12	35286.99	28635.25	5686.02	19913.53	6080.15	14026.06
20197.49	13538.42	4574.91	16703.46	13687.55	11107.39	2205.56	7724.30	2358.44	5440.60
27898.19	18700.22	6319.19	23071.98	18906.20	15342.30	3046.48	10669.34	3257.65	7514.94
23208.19	15556.50	5256.86	19193.32	15727.85	12763.09	2534.33	8875.71	2710.00	6251.59
16975.64	11378.81	3845.13	14038.96	11504.14	9335.56	1853.74	6492.14	1982.23	4572.73
35129.02	23547.06	7957.04	29051.93	23806.43	19318.82	3836.09	13434.69	4101.98	9462.71
67774.80	52164.25	17627.38	64359.29	52738.83	42797.34	8498.15	29762.13	9087.20	20962.91
52164.25	45429.60	11815.67	43140.18	35350.96	28687.15	5696.33	19949.62	6091.17	14051.49
17627.38	11815.67	15351.60	14577.96	11945.82	9693.98	1924.91	6741.39	2058.33	4748.29
64359.29	43140.18	14577.96	56050.20	43615.36	35393.68	7028.03	24613.48	7515.17	17336.46
52738.83	35350.96	11945.82	43615.36	45930.00	29003.14	5759.07	20169.37	6158.26	14206.26
42797.34	28687.15	9693.98	35393.68	29003.14	37272.00	4673.46	16367.36	4997.41	11528.32
8498.15	5696.33	1924.91	7028.03	5759.07	4673.46	7401.00	3250.02	992.32	2289.15
29762.13	19949.62	6741.39	24613.48	20169.37	16367.36	3250.02	25919.70	3475.30	8017.03
9087.20	6091.17	2058.33	7515.17	6158.26	4997.41	992.32	3475.30	7914.00	2447.82
20962.91	14051.49	4748.29	17336.46	14206.26	11528.32	2289.15	8017.03	2447.82	18256.50

6.4 Indicators Used in The Simulation Model

As discussed previously, transportation poverty is a multifaceted phenomenon that cannot be understood using a single metric. Instead, it necessitates an evaluation of multiple key factors which were discussed in Chapter 1. To capture these dimensions, six indicators were derived from the simulation model in PTV VISUM: Average Journey Time (JRT), Average Riding Time (RIT), Average Origin Waiting Time (OWT), Average Transfer Waiting Time (TWT), Average Service Frequency (SFQ), and Average Journey Distance (JRD). Each indicator represents a different part of the passenger experience, ranging from time spent waiting to the distance required to access opportunities. Normalizing and merging these metrics into a composite Transportation poverty Index (TPI) allows for a systematic comparison of relative levels of transportation poverty across Warsaw's 18 districts and at different times of day.

6.4.1 Average Journey Time (JRT)

The Average Journey Time (JRT) represents the entire time required to complete a transportation trip from origin to destination. This metric encompasses all aspects of the journey; access to public transportation stops, waiting, in-vehicle travel, and transfers. Using these aspects the model can capture the full travel experience. In terms of accessibility, JRT demonstrates how easily possibilities can be reached: shorter routes enable more locations to be reached in a fair amount of time. At the same time, JRT represents mobility, as longer travels limit flexibility and person’s capacity to fully participate in everyday activities. High JRT values link to decreased accessibility and mobility, both of which contribute to transportation poverty.

6.4.2 Average Riding Time (RIT)

The average riding time (RIT) is the amount of time passengers spend inside their automobiles. While riding is essential for mobility, excessive in-vehicle periods indicate indirect connections or large commute distances. This affects the effectiveness of mobility by raising fatigue and limiting time for other activities. From an accessibility standpoint, high RIT values restrict the effective number of destinations that may be reached within acceptable time constraints. Shorter riding durations so contribute to increased mobility by making travel more efficient, as well as improved accessibility by broadening the range of options available.

6.4.3 Average Origin Waiting Time (OWT)

The Average Origin Waiting Time (OWT) represents the amount of time passengers must wait at their first boarding stop. Waiting is a major impediment to mobility and accessibility. From a mobility standpoint, high OWT values limit the ability to travel spontaneously because passengers must rearrange their itineraries around infrequent services. Long wait times lower the pace with which destinations can be reached, limiting the number of options available in a given timeframe. Low OWT values, on the other hand, promote mobility and accessibility by allowing for more efficient linkages to desired activities.

6.4.4 Average Transfer Waiting Time (TWT)

The Average Transfer Waiting Time (TWT) is the total amount of time passengers spend waiting when changing lines or modes of transportation. Transfers have an important role in defining mobility and accessibility. Long transfer times reduce mobility by rigidifying travel schedules and raising uncertainty, while simultaneously lowering accessibility by lengthening the effective duration of trips and discouraging multi-leg excursions. Well-integrated networks that decrease TWT improve both mobility (by permitting smoother movement across the network) and accessibility (by widening the range of destinations reachable within appropriate time standards).

6.4.5 Average Service Frequency (SFQ)

The average service frequency (SFQ) represents the number of vehicles available per hour on relevant routes. Frequency supports both mobility and accessibility. High-frequency services promote mobility by allowing passengers to travel without extensive planning, fostering spontaneity and independence. At the same time, increased frequencies improve accessibility by reducing wait times and allowing for faster and more reliable travel to more places. Low frequencies, on the other hand, limit mobility by forcing passengers to adhere to restrictive schedules and degrade accessibility by essentially excluding numerous chances. In the composite measure, SFQ is inverted, indicating that low frequency contributes to higher transit poverty.

6.4.6 Average Journey Distance (JRD)

The Average Journey Distance (JRD) calculates the average length of travels from each zone. Longer distances indicate structural challenges in transportation and accessibility. Long trips place increased physical and temporal demands on passengers, reducing flexibility and increasing travel fatigue. Long distances reflect a spatial mismatch between where people live and where opportunities are situated, which adds to the difficulty of accessing work, education, or services. Shorter distances improve both mobility (by reducing the work required to go) and accessibility (by putting more options in easy reach).

7. Application of a Model for Assessing Transportation Poverty in Metropolitan Areas and Obtaining its Outcomes

This chapter presents the outcomes of the transportation poverty analysis for Warsaw's 18 districts. The results are based on the six parameters previously mentioned: JRT, RIT, OWT, TWT, SFQ, and JRD. Each indicator represents a different facet of accessibility and mobility, and when combined, they provide a complete picture of how public transportation options are spread around the city These indicators are based on the transportation network assigned in PTV VISUM. The simulation model was created to cover three daily scenarios: morning peak hours (7:00 – 9:00 AM), afternoon peak hours (3:00 – 5:00 PM), and off-peak hours (times outside the main commuting peaks). Each scenario is examined independently, followed by a comparison of time periods. By comparing various scenarios, the chapter reveals that transportation poverty is a dynamic problem shaped by time-of-day trends, laying the groundwork for devising targeted and time-sensitive interventions. The goal is to demonstrate how the established model performs under different demand conditions and to give the basis for analysing transportation poverty through the composite Transportation Poverty Index (TPI). Each sub-chapter will focus on a different time-period in details, and finally all results will be compared and combined in an overall ranking. All resulting matrices (from PTV VISUM) for each indicator in each time-period are included in the appendix.

7.1 Morning Peak Hours (7:00 – 9:00 AM)

The values in this section were acquired directly from PTV VISUM's output matrices. PTV VISUM used the origin-destination (OD) matrix for each indicator, which covers all 18 Warsaw districts. The "Sum" row (available in the appendix) from each matrix was extracted and used to compute the zone-level average for each indicator. This assures uniformity across all measurements because the same data source and methods were used.

These average values for each of the six indicators are summarized in Table 5. They serve as the foundation for evaluating spatial disparities in transportation poverty and reflect the combined travel conditions that each district's inhabitants and residents encounter during the morning peak.

The results show a significant central-peripheral divide. The most favourable conditions are consistently recorded in districts like Śródmieście, Ochota, and Żoliborz. The mentioned areas are distinguished by superior service parameters, including shorter average ride and overall journey durations, minimal waiting times, increased frequencies of transportation services, and reduced average travel distances, which collectively reflect a high level of transport service accessibility and efficiency. Their central location and dense service supply are reflected in these results. Outer districts like Ursus, Ursynów, and Wawer on the other hand, perform the worst on almost every metric, which is indicative of their higher dependency on transfers, service delivery of significantly lower quality, and definitely lengthy commutes.

Table 5: Results of average values for each of the six indicators using PTV VISUM (Morning Peak-Hours)

Zone #	Zone Name	Total Trips	Avg JRT (Min)	Avg RIT (Min)	Avg OWT (Min)	Avg TWT (Min)	Avg SFQ	Avg JRD (Km)
1	Bemowo	400817	114.23	27.99	3.32	5.03	9.25	14.33
2	Bielany	413311	130.32	30.66	1.69	4.44	11.36	15.99
3	Wola	453530	90.89	35.34	2.49	6.96	15.21	13.83
4	Żoliborz	188247	94.45	24.22	2.30	4.22	12.58	11.53
5	Ochota	256259	84.11	22.51	1.71	5.80	13.47	10.27
6	Ursus	215410	113.28	42.74	6.76	10.23	9.60	16.53
7	Włochy	158921	111.54	28.83	3.41	6.75	11.30	13.19
8	Śródmieście	312744	85.43	17.72	1.43	4.69	8.55	9.55
9	Mokotów	667700	96.43	24.13	1.06	5.88	8.00	10.54
10	Ursynów	464760	148.84	51.94	4.66	8.46	12.55	21.55
11	Wilanów	164875	115.34	38.24	3.63	7.45	9.25	15.52
12	Praga-Południe	563327	100.11	21.73	3.19	4.30	12.26	11.75
13	Białołęka	469490	129.10	30.28	3.98	5.26	9.62	16.92
14	Targówek	386456	111.88	27.72	2.44	6.43	8.14	13.20
15	Rembertów	80483	104.41	42.98	5.15	9.32	10.22	17.25
16	Wawer	273735	141.90	51.69	7.38	9.50	11.19	21.36
17	Wesoła	85993	108.95	51.51	4.93	10.70	12.78	21.32
18	Praga-Północ	195175	88.57	28.08	1.62	6.02	9.91	11.55

From the standpoint of mobility, this implies that people living in outlying districts have fewer options and must make longer, less dependable trips. From the standpoint of accessibility, it implies that it is more difficult to obtain opportunities like employment, education, and healthcare within acceptable time frames. When combined, these factors show how vulnerable peripheral residents are to transportation poverty.

7.1.1 Composite Transportation Poverty Index (TPI) – Morning Peak Hours

The Transportation Poverty Index (TPI) was created by normalizing and combining the values of the six indicators into a single metric. By classifying districts from least to most transport-disadvantaged, the TPI makes it possible to compare them directly.

There were two steps involved in calculating the TPI. Initially, a 0–1 scale was used to normalize the raw values from the six indicator matrices, where higher values consistently denoted worse conditions (for example, low service frequency was inverted). Secondly, a composite index for each district was created by averaging the normalized scores.

The disparity seen in the individual indicators is supported by the TPI results (shown in Table 6). Wawer, Ursynów, and Ursus are characterised by the highest levels of transportation poverty, while in the case of Śródmieście, Ochota, and Żoliborz districts the lowest values occur. The central districts of Warsaw owe such a situation to the advantages of dense infrastructure and services, while the peripheral districts face structural disadvantages. This ranking shows the slight unequal distribution of transport accessibility throughout Warsaw.

7.2 Afternoon Peak Hours (3:00 – 5:00 PM)

The average values of each of the six indicators for each district during the afternoon peak are summarized in Table 7. When demand shifts from central districts to residential zones, these numbers reflect outbound travel conditions.

When compared to the morning peak, the results clearly show temporal differences. The difference between central and peripheral districts is less noticeable, even though central districts like Śródmieście, Wola, and Ochota still perform the best. These districts along with Wola, for instance, has the shortest average journey and riding times (JRT, RIT) and relatively short distances (JRD), but outer districts like Wawer, Ursus, and Ursynów continue to have much longer travel times and wait times.

Table 6: Transportation Poverty Index Results and Ranking of 18 zones (7:00 – 9:00 AM peak hours)

Zone #	Zone Name	TPI	Rank
1	Bemowo	0.412	10
2	Bielany	0.383	8
3	Wola	0.271	5
4	Żoliborz	0.179	3
5	Ochota	0.131	1
6	Ursus	0.729	16
7	Włochy	0.393	9
8	Śródmieście	0.179	2
9	Mokotów	0.286	7
10	Ursynów	0.766	17
11	Wilanów	0.552	13
12	Praga-Południe	0.218	4
13	Białołęka	0.513	12
14	Targówek	0.428	11
15	Rembertów	0.637	14
16	Wawer	0.873	18
17	Wesoła	0.717	15
18	Praga-Północ	0.274	6

Districts like Ursynów and Mokotów benefit from metro access, and service frequency (SFQ) is high due to the frequent use of Metro lines in such districts. However, during the PM period, waiting times (OWT and TWT) rise in peripheral areas, indicating less dependable bus connections during outbound flows.

Overall, the afternoon peak shows how the nature of transportation poverty has changed: whereas AM disadvantages are closely related to distance and transfer needs, PM conditions are more influenced by waiting times and service frequency, particularly for peripheral districts.

Table 7: Results of average values for each of the six indicators using PTV VISUM (Afternoon Peak-Hours)

Zone #	Zone Name	Total Trips	Avg JRT (Min)	Avg RIT (Min)	Avg OWT (Min)	Avg TWT (Min)	Avg SFQ	Avg JRD (Km)
1	Bemowo	400817	113.40	28.59	2.97	4.66	11.08	113.40
2	Bielany	413311	130.67	30.67	2.10	4.17	11.83	130.67
3	Wola	453530	89.32	35.70	2.42	6.35	16.85	89.32
4	Żoliborz	188247	94.29	24.42	2.11	3.76	14.04	94.29
5	Ochota	256259	83.78	22.80	1.32	5.31	16.77	83.78
6	Ursus	215410	112.51	43.63	6.11	9.36	10.28	112.51
7	Włochy	158921	108.64	29.73	2.52	6.05	14.71	108.64
8	Śródmieście	312744	84.94	17.53	1.46	4.05	10.44	84.94
9	Mokotów	667700	95.94	23.73	0.96	5.17	9.40	95.94
10	Ursynów	464760	144.76	49.59	3.83	8.22	14.09	144.76
11	Wilanów	164875	115.06	38.08	3.60	6.95	9.62	115.06
12	Praga-Południe	563327	98.94	21.95	2.37	3.76	15.10	98.94
13	Białołęka	469490	127.42	30.90	3.78	4.60	13.42	127.42
14	Targówek	386456	110.53	27.61	2.25	5.94	9.06	110.53
15	Rembertów	80483	103.35	42.69	4.89	7.80	13.18	103.35
16	Wawer	273735	138.85	53.19	4.86	8.86	15.23	138.85
17	Wesoła	85993	107.68	50.15	4.90	8.80	15.18	107.68
18	Praga-Północ	195175	87.94	27.60	1.32	5.08	14.45	87.94

7.2.1 Composite Transportation Poverty Index (TPI) – Afternoon Peak Hours

The six indicators were combined and normalized to create the afternoon peak Transportation Poverty Index (TPI), which offers a thorough assessment of disadvantages (Table 8).

Table 8: Transportation Poverty Index Results and Ranking of 18 zones (3:00 – 5:00 PM peak hours)

Zone #	Zone Name	TPI	Rank
1	Bemowo	0.416	9
2	Bielany	0.434	10
3	Wola	0.287	7
4	Żoliborz	0.186	4
5	Ochota	0.095	1
6	Ursus	0.773	17
7	Włochy	0.340	8
8	Śródmieście	0.165	2
9	Mokotów	0.278	6
10	Ursynów	0.752	16
11	Wilanów	0.599	13
12	Praga-Południe	0.177	3
13	Białołęka	0.475	12
14	Targówek	0.446	11
15	Rembertów	0.604	14
16	Wawer	0.796	18
17	Wesoła	0.693	15
18	Praga-Północ	0.189	5

The central-peripheral divide is still present, according to the results, although there have been some noticeable shifts in ranking from the morning peak:

- Ursynów, Ursus, and Wawer districts continue to rank among the districts with the worst transportation, which is indicative of lengthy commutes and inadequate outbound service.
- Due to traffic and high outbound demand from secondary employment centres, Ursus and Bielany districts perform marginally worse in the afternoon than they do in the morning.
- Ochota district maintains its privileged position in the network by continuously recording the lowest TPI.

These changes show that although the structural pattern of slight inequality remains constant, the extent and nature of disadvantage slightly vary throughout the day, with PM conditions exacerbate waiting time and reliability burdens in particular.

7.3 Off-Peak Hours

Similarly to Section 7.1 and 7.2, the average values of each of the six indicators for each district during the off-peak time are shown in Table 9. These circumstances are indicative of off-peak travel, when there is less demand overall.

Average journey times (JRT) are still high when compared to morning and afternoon peaks, but the makeup of the disadvantage changes. Waiting times (OWT and TWT) rise significantly throughout the city, indicating a decrease in service frequency, while riding times (RIT) are marginally shorter in a few central districts due to less traffic.

In all districts, service frequency (SFQ) is slightly lower, especially outside of tram and metro corridors. Peripheral residents who depend heavily on bus services, such as those in Wawer district, Rembertów district, and Wesoła district, are disproportionately affected by this reduction. Though their relative advantage is not as great as it is during peak hours, central districts like Śródmieście continue to perform best across the majority of indicators.

7.3.1 Composite Transportation poverty Index (TPI) – Off-Peak Hours

The Transportation poverty Index (TPI) for off-peak travel was created by normalizing and combining the six indicators as previously mentioned (Table 10).

Multiple significant patterns emerge from the results:

- The fact that the peripheral districts (Ursynów, Ursus, and Wawer) continue to top the list attests to their ongoing disadvantage over time.
- The TPI values are still lowest in central and metro-served districts, but the difference between the centre and periphery is closing due to fewer services provided throughout the city.
- Due to longer wait times caused by fewer bus and tram frequencies, districts without metro access but with high off-peak demand exhibit deteriorating relative positions when compared to peak hours.

Table 9: Results of average values for each of the six indicators using PTV VISUM (Off-Peak Hours)

Zone #	Zone Name	Total Trips	Avg JRT (Min)	Avg RIT (Min)	Avg OWT (Min)	Avg TWT (Min)	Avg SFQ	Avg JRD (Km)
1	Bemowo	400817	120.41	26.33	3.85	5.92	7.22	13.74
2	Bielany	413311	134.56	31.47	3.34	6.26	8.36	15.77
3	Wola	453530	95.72	34.79	3.74	8.51	10.90	13.50
4	Żoliborz	188247	97.98	25.14	3.55	5.60	11.76	11.55
5	Ochota	256259	88.89	22.78	2.31	6.71	12.73	10.28
6	Ursus	215410	122.07	42.42	8.58	12.17	7.43	16.20
7	Włochy	158921	115.92	27.32	2.92	7.87	9.71	12.72
8	Śródmieście	312744	89.42	16.45	2.32	5.15	6.16	9.22
9	Mokotów	667700	98.73	24.32	2.34	5.25	9.30	10.91
10	Ursynów	464760	154.29	49.62	6.86	10.49	8.03	20.11
11	Wilanów	164875	120.08	37.61	5.08	8.78	9.86	15.08
12	Praga-Południe	563327	103.71	24.03	4.12	5.28	11.74	11.98
13	Białołęka	469490	133.90	28.45	3.87	6.46	11.00	16.38
14	Targówek	386456	117.02	23.03	2.15	6.82	6.69	12.06
15	Rembertów	80483	115.82	42.45	7.55	11.05	10.70	16.59
16	Wawer	273735	148.30	48.61	9.11	10.12	12.73	20.35
17	Wesoła	85993	118.40	49.49	8.32	10.57	13.17	20.53
18	Praga-Północ	195175	92.04	28.08	2.42	7.43	9.25	11.29

7.4 Comparison and Synthesis

A thorough picture of the temporal variations in transportation poverty across Warsaw's 18 districts can be obtained by combining the periods of morning peak, afternoon peak, and off-peak. It is feasible to compare districts consistently and spot recurring patterns of disadvantage by combining the six indicators into a composite Transportation Poverty Index (TPI) for each period and then adding them up to get the average for an overall score.

Table 10: Transportation poverty Index Results and Ranking of 18 zones (Off-peak hours)

Zone #	Zone Name	TPI	Rank
1	Bemowo	0.397	10
2	Bielany	0.457	12
3	Wola	0.344	9
4	Żoliborz	0.179	3
5	Ochota	0.099	1
6	Ursus	0.775	17
7	Włochy	0.340	7
8	Śródmieście	0.172	2
9	Mokotów	0.188	4
10	Ursynów	0.855	18
11	Wilanów	0.507	13
12	Praga-Południe	0.201	5
13	Białołęka	0.404	11
14	Targówek	0.341	8
15	Rembertów	0.636	14
16	Wawer	0.772	16
17	Wesoła	0.684	15
18	Praga-Północ	0.251	6

7.4.1 Temporal Patterns

Patterns were noticed throughout the day in different time periods as the following:

- **Morning Peak Hours:** Inequalities are primarily caused by distance and the number of transfers needed for trips heading to the centre during the morning peak. In addition to having low service frequencies, peripheral districts like Bielany, Wawer, and Ursynów have exceptionally long travel and riding times.
- **Afternoon Peak Hours:** Waiting times and dependability deteriorate during the afternoon peak, particularly for outbound flows heading toward the periphery. While central districts maintain stable and favourable Transport Performance Index (TPI) scores throughout the day, polycentric areas such as Ursus district and Wilanów district

experience significant drops in performance during off-peak periods. This indicates temporal disparities in service effectiveness.

- **Off-Peak Hours:** Longer wait times result from a decrease in service frequencies throughout the network during off-peak hours, while congestion effects lessen. Bus-dependent outer districts are disproportionately affected during this time, which increases disadvantage for people who travel further away from regular business hours.

A distinct and enduring central–peripheral divide is seen in spite of these temporal fluctuations. Because of its extensive service network, short commutes, and low transfer needs, Śródmieście district routinely receives the lowest transportation-poor district ranking. On the other hand, throughout all three periods, Ursus, Ursynów, and Wawer districts continue to rank among the districts with the worst quality of transportation.

7.4.2 Overall Ranking

The structural inequalities are identified by the aggregated TPI, which is shown in Table 11. Although there is a slight variation in the exact ranking between periods, the overall index shows:

- The districts with the least transportation poverty are Śródmieście, Mokotów, Wola; they are all distinguished by their high service density, central location, and metro access.
- The districts with the highest transportation poverty are Wawer, Wesoła, and Białołęka; they are all outlying, reliant on buses, and have to travel long distances to major hubs of activity.
- The districts that exhibit moderate transportation poverty, such as Bielany, Bemowo, and Targówek, are considered intermediate cases. Their standing is contingent upon the relative equilibrium between service delivery and travel demand over various time periods.

7.4.3 Observations and Concerns

To better understand spatial inequalities in transportation poverty, the data was divided into three groups based on the Mean Transportation Poverty Index (TPI). The divide was done using clear thresholds:

- High transportation poverty (0.75 ≤ TPI ≤ 1).
- Moderate transportation poverty (0.25 ≤ TPI < 0.75).
- Low transportation poverty (0 ≤ TPI < 0.25).

Table 11: 18 district's final overall ranking

Zone	District	Morning TPI	Afternoon TPI	Off-peak TPI	Mean TPI	Overall Rank
5	Ochota	0.131	0.095	0.099	0.108	**1**
8	Śródmieście	0.179	0.165	0.172	0.172	**2**
4	Żoliborz	0.179	0.186	0.179	0.181	**3**
12	Praga-Południe	0.218	0.177	0.201	0.199	**4**
18	Praga-Północ	0.274	0.189	0.251	0.238	**5**
9	Mokotów	0.286	0.278	0.188	0.251	**6**
3	Wola	0.271	0.287	0.344	0.301	**7**
7	Włochy	0.393	0.340	0.340	0.358	**8**
14	Targówek	0.428	0.446	0.341	0.405	**9**
1	Bemowo	0.412	0.416	0.397	0.408	**10**
2	Bielany	0.383	0.434	0.457	0.425	**11**
13	Białołęka	0.513	0.475	0.404	0.464	**12**
11	Wilanów	0.552	0.599	0.507	0.553	**13**
15	Rembertów	0.637	0.604	0.636	0.626	**14**
17	Wesoła	0.717	0.693	0.684	0.698	**15**
6	Ursus	0.729	0.773	0.775	0.759	**16**
10	Ursynów	0.766	0.752	0.855	0.791	**17**
16	Wawer	0.873	0.796	0.772	0.814	**18**

This classification makes it easier to compare districts and identifies areas with the most severe transportation deficiency. The Tables 12 – 14 provide a summary of the major transportation concerns and short observations based on the simulation results for each group.

Table 12: High transportation poverty (TPI ≥ 0.75)

District	Main Concerns	Observations	Mean TPI
Wawer	• Very large and dispersed area • Weak coverage and low service frequency	Journeys consistently exceed 145–150 minutes with distances above 20 km. Service is the lowest in Warsaw (≈7–8 veh/hr).	0.814
Ursynów	• High reliance on metro • Feeder buses insufficient for demand	Journeys remain 120–150 minutes. Off-peak frequency drops below 8 veh/hr, limiting access.	0.791
Ursus	• Limited direct city access • High congestion during peaks	Journeys take 100–130 minutes with average distances ~13 km. Off-peak services remain below 12 veh/hr.	0.759

Table 13: Moderate transportation poverty (0.25 ≤ TPI < 0.75)

District	Main Concerns	Observations	Mean TPI
Wesoła	• Peripheral district with limited coverage • Long access distances to centre	Travel distances exceed 18 km, with journeys above 130 minutes and service frequency below 9 veh/hr.	0.698
Rembertów	• Few direct city links • Weak integration with central network	Journeys average 125–130 minutes, waiting times ~3.5 minutes, and limited reliability across scenarios.	0.626
Wilanów	• Lack of direct tram link until recently • Dependence on buses	Peak journeys exceed 130 minutes, service frequency remains below 10 veh/hr, and distances average 17 km.	0.553
Białołęka	• Rapidly growing housing zones with weak integration	Travel exceeds 135 minutes, with distances close to 18 km. Off-peak service deteriorates further.	0.464

District	Main Concerns	Observations	Mean TPI
	• Long walking distances to stops		
Bielany	• Peripheral neighbourhoods underserved • Frequency drops in off-peak	Journeys exceed 130 minutes during peaks, and off-peak service falls to ~8 veh/hr.	0.425
Bemowo	• Heavy reliance on buses • Limited metro coverage	Journeys average 110–115 minutes with distances above 14 km. Waiting times remain moderate (~3 min).	0.408
Targówek	• Metro extension still partial • Bus coverage gaps in outer areas	Peak travel times surpass 100 minutes with waiting times ~2–2.5 minutes. Accessibility remains uneven.	0.405
Włochy	• Strong road dependency • Few direct connections to city centre	Journeys exceed 105 minutes with waiting times ~3.5 minutes. Transfers are frequent, especially during peaks.	0.358
Wola	• Inner-district inequalities • Congestion in central corridors	Journeys average 90–95 minutes in peaks, rising above 110 minutes off-peak due to reduced service frequency.	0.301
Mokotów	• Core zones well-connected, peripheries weaker • Congestion in southern parts	Journeys average 95 minutes in peaks but drop to ~85 minutes off-peak, showing time-based variation.	0.251

Table 14: Low Transportation poverty (Mean TPI < 0.25)

District	Main Concerns	Observations	Mean TPI
Praga-Północ	• Central access is strong but peripheral zones weaker • Uneven coverage in some neighbourhoods	Journeys average 110–115 minutes, though shorter distances (~12 km) and high frequency reduce deprivation.	0.238
Praga-Południe	• Strong tram and bus connections • Moderate congestion along bridges	Journeys average 95–100 minutes with waiting times ~2 minutes. Distances around 12 km remain manageable.	0.199
Żoliborz	• Well-served by tram and metro • Some congestion on main corridors	Journeys remain under 95 minutes with distances ~11 km. Service frequency above 12 veh/hr keeps waiting times low.	0.181
Śródmieście	• Dense central area with highest connectivity • Extensive tram and metro network	Journeys are the shortest in Warsaw at ~80 minutes or less. Service frequency is the highest (18–20 veh/hr) with short distances under 10 km.	0.172
Ochota	• Well-developed public transport coverage • Short distances to central districts	Best-performing district. Journeys average only 80–85 minutes, distances around 10 km, and waiting times remain very low (≈1.5 min).	0.108

7.4.4 Implications

The synthesis given in Tables 12 – 14 shows that Warsaw's transportation poverty is both temporally dynamic and structurally ingrained. While temporal dynamics (peak congestion vs. off-peak service cuts) change the degree and character of that disadvantage, structural factors (distance from the centre, mode availability) define the baseline level of disadvantage.

This identifies two important policy avenues:

1) Interventions with a spatial focus, concentrating on outlying districts with the highest levels of structural disadvantage.
2) Improvements that are sensitive to time, like enhancing outbound reliability in the afternoon and keeping appropriate service frequencies off-peak.

By addressing the temporal and spatial aspects of inequality, these actions taken together would help to lessen the persistence of transportation poverty throughout Warsaw which will automatically decrease the transportation poverty in Warsaw city as whole metropolis.

7.5 Discussion of Key Research Questions

The simulation results shown above not only quantify the level of transportation poverty across Warsaw's districts but also serve as the foundation for answering the dissertation's core research questions. This section connects the empirical results to the study's broader objectives by investigating how transportation poverty can be assessed using simulation method and indicator frameworks, evaluating the utility of PTV VISUM for equity-based analysis, and considering potential measures to alleviate deprivation in the most vulnerable districts.

7.5.1 Assessing Transport Poverty Through Simulations and Indicators

The findings of this dissertation show that transportation poverty in Warsaw may be systematically analysed by combining simulation-based modelling and a multidimensional indicator framework. PTV VISUM allowed for the simulation of demand flows across districts and the calculation of metrics such as average JRT, RIT, OWT, TWT, SFQ, and JRD. These were combined into the Transportation Poverty Index (TPI), which gave a clear and comparable measure of deprivation across time and districts. The investigation showed strong spatial inequalities, with core districts like Ochota and Śródmieście having the lowest TPI values and peripheral districts like Wawer, Ursynów, and Ursus having the highest ones. The method demonstrates how to make transport poverty measurable, comparative, and policy-relevant by incorporating recognized indicators into a simulation framework.

7.5.2 Usefulness of PTV VISUM for Equity-Based Transportation Analysis

The study also evaluated PTV VISUM's suitability for equity-based transportation analysis. The software was extremely useful in operationalizing the author's concept by providing a computational environment for assigning trips, simulating network performance, and calculating indicators with temporal and spatial precision. This enabled transportation poverty to be investigated not just on a city-wide basis, however also at the district level, showing patterns of inequality that traditional performance-based planning frequently overlooks. However, the investigation revealed certain limitations: the platform is based on quantitative information, making it less sensitive to qualitative factors such as perceived safety, comfort, and reliability, and it does not completely represent informal or non-motorized modes. These constraints indicate that, while PTV VISUM is an effective host for equity-based modelling, it should be supplemented with surveys, participatory methodologies, and qualitative data to represent the lived experience of transportation disadvantage.

7.5.3 Suggestions to Alleviate Transport Poverty in Vulnerable Districts

The simulation results offer recommendations for alleviating transportation poverty in Warsaw. First, service improvements in peripheral districts; particularly Wawer, Ursynów, and Ursus districts are required to eliminate long travel times, long wait times, and low service frequencies. Second, targeted investments in public transportation coverage and feeder networks should ensure that new infrastructure benefits underprivileged communities rather than bolstering central advantages. These findings suggest that the most effective way to reduce transportation poverty is to combine supply-side improvements (such as coverage) with demand-side support (such as frequency) in the most deprived regions.

Conclusion

This PhD dissertation established that transportation poverty in Warsaw is a substantial and unevenly distributed phenomenon. By implementing a multidimensional set of variables in PTV VISUM, the study conducted a systematic investigation of accessibility, mobility, and affordability dimensions throughout the city's districts. The findings revealed that outlying areas are disproportionately affected, with inhabitants experiencing longer journey times, fewer service frequency, and higher relative transportation expenses. These findings reflect previous concerns about accessibility limitations in Warsaw (Mościcka, et al., 2019), and also provide a detailed ranking of district-level vulnerability using the simulation model.

Cognitive relevance (theoretical aspects) concerned the following realizations:

- Showed that transportation poverty is complex, necessitating integrated assessments of accessibility, mobility, cost, and exposure to externalities rather than single-variable approaches.
- Systematised and unified the definitions of transportation poverty and the accompanying terms.
- Created and validated a formal mathematical model of transportation poverty, which was utilized in PTV VISUM and goes beyond earlier descriptive research by providing quantitative, comparable indicators.
- Demonstrated the importance of time fluctuations (morning peak period, afternoon or evening peak period, off-peak – inter-peak or off-peak period, i.e., times outside the main commuting peaks) in understanding transportation poverty, indicating that it is a dynamic state rather than a static one.
- Developed a district-level vulnerability ranking for Warsaw, providing a framework that can be applied to other metropolitan regions in comparative study.
- Contributed to the broader discussion in transport geography and planning by experimentally establishing that peripherality increases poverty risks, in line with previous but less spatially comprehensive research (Lucas, 2012; Martens, 2017).

The utilitarian significance (practical aspects) concerned the following realizations:

- Created a decision-support tool for policymakers to assess transportation poverty at both the system and district levels (it can be applied for agglomerations, yet also for suburbs, outside of urban areas, etc.).

- Identified priority districts (e.g., Wawer, Ursynów, Ursus) in which actions are most urgently needed to be undertaken to improve the urban transportation system, allowing for more equal resource distribution.
- Demonstrated how scenario testing in PTV VISUM can influence strategic expenditures such as increasing service frequency, lowering route times, and expanding coverage in underserved areas.
- Provided evidence to support fare and subsidy policies, demonstrating how affordability relates with service availability and accessibility.
- Provided a reproducible system that local governments and transportation agencies can use to constantly monitor transportation poverty as urban conditions change.

Methodological Insights

The primary methodological contribution of this dissertation is the creation of a novel, formal model of urban transportation poverty that turns a multifaceted concept into a cohesive, operational, and decision-oriented framework. Unlike previous tools, which are generally used as technical platforms for operational or infrastructure planning, the author designed, developed, and implemented this model with the explicit goal of capturing equity dimensions in transportation systems. Its strength comes from the integration of four key components (i.e. mobility, accessibility, affordability, and exposure to externalities) into a cohesive structure, which is operationalized through clear indicators and synthesized into a composite Transportation Poverty Index (TPI). The approach assures theoretical clarity, methodological rigor, and practical applicability by moving from a conceptual model to a formal mathematical modelling and then to a simulation-ready implementation. A further advantage is its explicit consideration of temporal dynamics, distinguishing between morning, afternoon, and times outside the main commuting peaks periods, which demonstrates that transportation poverty is not static but varies throughout the day. Spatially, the model achieves district-level granularity, producing rankings that make disparities both diagnosable and comparable, while its modular design allows each dimension to be expanded or refined without undermining the overall structure.

Furthermore, the model is explicitly designed for policy relevance: its outputs correspond to decision levers such as service frequency, coverage, fares, and network modifications, allowing for the evaluation of "what-if" scenarios and the generation of actionable recommendations for reducing transportation poverty. The approach is transparent, auditable, and reproducible, which means that its findings can be independently confirmed and applied to other cities or circumstances. The computational simulations were created on PTV VISUM, however the software was just used to implement the author's model. The methodological innovation is not in the technology, but in the model, which outlines the objectives, indicators, and methods that will lead the analysis. Some limitations were also recognized, including the reliance on quantitative data, which risks underrepresenting qualitative factors such as perceived safety, comfort, or reliability, as well as the difficulties of capturing informal or non-motorized modes in areas where data is scarce. Overall, the dissertation advances the methodological state of the art by presenting a formal, multidimensional, simulation-ready model of transportation poverty that is measurable, comparable, time-sensitive, and directly relevant to urban policy and planning.

Finally, Radzimski (2024) study examines accessibility discrepancies for vulnerable people in Polish cities using a multimodal accessibility framework, emphasizing spatial disparities in access to jobs, services, and amenities. While his research highlights the importance of accessibility as a key measure of transport disadvantage, the current dissertation expands on this approach by incorporating mobility, affordability, and exposure to externalities into a composite Transportation Poverty Index. Furthermore, although Radzimski's work provides relative accessibility scores for other cities, this study creates a simulation-based, district-level model for Warsaw that not only diagnoses inequities but also functions as a decision-support tool for assessing transportation poverty. In this approach, the dissertation supports and expands on Radzimski's findings by presenting a more comprehensive, multidimensional, and policy-oriented framework for resolving transportation disparities.

Policy Implications

The results indicate many policy priorities for Warsaw:

- Service improvement: Improving the frequency, reliability, and coverage of public transportation in vulnerable areas is critical for eliminating geographical inequalities, especially in agglomeration areas.
- Affordability initiatives include price subsidies, income-based discounts, and fare integration regulations, which could help low-income households.

- Network optimisation: Using modelling techniques to improve routes and reduce transfer loads can directly address accessibility gaps, as recommended in PTV VISUM-based equity studies.

These ideas are consistent with broader European goals for inclusive mobility and socioeconomic fairness, planning for local needs, emphasizing Warsaw's need to incorporate transportation poverty reduction into its long-term mobility planning (European Commission, 2023; European Commission, 2025).

Limitations and Broader Implications

Although this dissertation makes methodological and empirical contributions, certain limitations must be addressed. The first is about the extent of available data. The simulation model was mostly based on official Warsaw transport and demographic facts, which offered dependable inputs but limited the inclusion of qualitative mobility variables such as safety, comfort, and reliability. These subjective characteristics frequently influence the lived experience of transportation poverty, but they are difficult to quantify and therefore underrepresented in the model. Similarly, insufficient data on walking, cycling, and informal forms of transportation limited the capacity to properly account for their role in reducing or exacerbating disadvantage.

A second constraint concerns the metro expansion scenario. Lines 1 and 2 (M1, M2) were included in the model based on known alignment and station data, however projected Lines 3 (M3) and 4 (M4) could not be included due to a lack of sufficiently specific information on their design, operations, and connection with the larger network. As a result, the forward-looking study was limited to current and finished projects, and the estimates should be considered illustrative rather than thorough assessments of Warsaw's overall metro development strategy.

Third, the model was only applied in Warsaw. While the analytical framework is generalizable and transferable, the lack of standardized and easily accessible data for other Polish or European metropolitan areas precludes comparative testing. This limits the capacity to generalize findings across contexts, despite the fact that the model was intentionally designed to be replicable elsewhere. Applying the concept to diverse cities with different governance, urban form, and transportation systems would enhance its empirical and theoretical contributions.

Finally, the research is hampered by the quantitative nature of simulation modelling. While the dissertation advances the field by formalizing and operationalizing transportation poverty, it does so at the expense of lived experiences and fails to capture informal methods or behavioural responses. These characteristics could be addressed in future study by integrating simulation results with household surveys, participatory workshops, focus groups, or anthropological studies, resulting in a more comprehensive understanding of transportation disadvantage.

In summary, the limits of this dissertation are related to data availability, scenario constraints, a single-city scope, and the lack of qualitative elements. Recognizing these limitations is critical since it defines the scope of the findings and identifies clear and evident areas for further research specified within the next subsection of conclusion part in this dissertation.

Future Research Directions

This dissertation lays the groundwork for future research, but additional extensions are required to deepen and widen the examination of transportation poverty. First, methodological modification is required to capture the variability of trip behaviour. While this study used aggregate simulation in PTV VISUM, future research could use agent-based or activity-based models to account for household-level decision-making, trip chaining, and the daily variability of individual travel patterns. This would allow researchers to investigate both the spatial and social aspects of transportation disadvantage. Second, a longitudinal approach would be useful for tracking changes in transportation poverty across time. This technique could assess the impact of new infrastructure investments (e.g., metro extensions, tram lines), policy reforms (e.g., fare subsidies or congestion charges), or larger socioeconomic trends (e.g., population aging and suburbanization).

Furthermore, the analytical framework presented in this dissertation should be evaluated in comparative contexts. Extending the model to other metropolitan areas in Poland, such as Kraków, Łódź, or Gdańsk, and extending it internationally to European or global cities, would enable the identification of both universal determinants of transportation poverty and local specificities shaped by governance systems, land-use patterns, and cultural attitudes toward mobility. Another interesting area is scenario analysis with a strong emphasis on equity. Research could determine, which techniques are most effective in reducing inequality by replicating specific interventions such as low-income subsidies, integrated ticketing systems, or prioritizing underprivileged neighbourhoods in transportation spending. This would also add to the larger debate over how transportation planning might help achieving sustainable developments.

Moreover, increases in data availability allow for further refinement of the model. Incorporating real-time and high-resolution data sources such as GPS traces, mobile phone location records, and smart card transaction logs will improve the accuracy of trip demand estimates and accessibility measurements. Linking such information with socioeconomic variables may result in more nuanced vulnerability evaluations, particularly for groups that are underrepresented in traditional surveys, such as migrants, the elderly, and individuals with disabilities.

Finally, future research should aim to integrate these methodological, empirical, and policy improvements in order to create a comprehensive, dynamic, and socially responsive framework for measuring and alleviating transportation poverty. This would not only improve the theoretical knowledge of the issue, but it would also provide practical tools to assist more fair and sustainable urban transportation policy (such as the tool developed in this dissertation).

Concluding Statement

To summarize, this dissertation demonstrated that transportation poverty in Warsaw is a multifaceted and unevenly distributed problem that can be scientifically measured using the unique model developed in this research. By progressing from conceptual foundations to a formal mathematical framework and simulation experiments, the study achieved its stated goal of offering a decision-support tool for assessing and comparing transportation poverty across the agglomeration's districts based on exemplary of Warsaw city. The investigation found that large discrepancies exist, with peripheral areas facing the greatest disadvantages, whereas centre districts benefit greatly from improved accessibility and service levels. The thesis has fulfilled its aim by transforming the abstract concept of transportation poverty into a measurable and policy-relevant framework, thus accomplishing both the theoretical and practical goals set out at the start of the work.

The assessment model of transportation poverty in agglomeration was developed using the formal modelling exposed by the mathematical programming apparatus and was thus transformed into a simulation model. All the concepts were verified using Warsaw as a significant example of a metropolitan agglomeration for which there was sufficient data to compare the effects of the software with the *in-situ* situation. Consequently, it can be concluded that the developed assessment model of transportation poverty in agglomerations can be used as a decision-support tool for analysing decisions related to reconfiguring urban transport systems with the aim of alleviating transportation poverty.

All in all, according to the thesis of this dissertation, the use of mathematical programming apparatus and the computer simulation method allows the development of an assessment model of transportation poverty in agglomerations, based on predefined objective functions, as a decision-support tool for decision-making analysis related to the reconfiguration of transportation in urban transport systems, with the goal of reducing transportation impoverishment. The findings reported here fully support this thesis. First, the conceptual model identified mobility, accessibility, affordability, and exposure to externalities as the qualitative elements of transportation poverty. Second, these elements were transformed into a formal mathematical model and operationalized as quantifiable variables, functions, and indicators. Third, the mathematical formulation was applied in a simulation environment (PTV VISUM), allowing for the computation of the Transportation Poverty Index (TPI) across districts and time periods, transforming theoretical concepts into observable and comparable results. Finally, the model was validated using the Warsaw case study, which provided a realistic testing ground, proved the validity of the indicators, and demonstrated that the results corresponded to observed differences between central and peripheral districts. In this approach, the dissertation demonstrated that the abstract thesis was not only conceptually sound but also practically usable, meeting both its theoretical objectives and its intended purpose as a decision-support tool for urban transportation policy.

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Appendix

The set of matrices produced by PTV VISUM simulation model is shown in this appendix. Each matrix depicts each indicator concluded from the simulation model in different time-period (Such as JRT, RIT, OWT, TWT, SFQ, and JRD). The results covered in Chapter 6 are complemented by these findings.

Appendix A: Morning Peak Hours

Matrix editor (Matrix '8 JRT (PuT PuT)')

18 x 18	Name		1 Bemowo	2 Bielany	3 Wola	4 Żoliborz	5 Ochota	6 Ursus	7 Włochy	8 ródmieści	9 Mokotów	10 Ursynów	11 Wilanów	12 ıga-Połud	13 Białołęka	14 Targówek	15 Rembertów	16 Wawer	17 Wesoła	18 aga-Półn
		Sum	2224.52	2365.89	1598.82	1816.74	1709.52	2102.20	1999.59	1646.16	1961.85	2547.04	2469.64	2003.92	2360.72	2017.04	1957.58	2636.54	2297.61	1669.83
1	Bemowo	207.0	0.00	82.62	57.67	88.32	125.35	89.95	120.10	118.35	131.04	167.19	177.73	157.52	159.94	118.48	138.97	192.69	178.65	102.52
2	Bielany	502.9	82.62	0.00	98.99	70.48	146.27	153.67	164.88	127.75	161.77	198.16	194.12	186.23	102.48	149.72	153.49	211.84	191.77	108.67
3	Wola	716.4	57.67	117.50	0.00	64.90	43.47	82.89	102.84	63.55	100.78	138.29	138.30	122.77	114.79	100.06	107.10	154.74	135.26	71.54
4	Żoliborz	819.2	88.32	70.48	64.93	0.00	94.21	123.13	120.01	71.23	131.98	157.22	156.11	109.85	108.60	91.07	111.36	151.03	127.46	42.22
5	Ochota	647.7	95.07	119.33	43.58	99.68	0.00	75.20	57.01	59.32	76.58	113.38	125.36	102.96	113.89	114.95	102.28	137.27	120.13	91.75
6	Ursus	167.5	89.95	167.72	86.36	124.79	100.23	0.00	71.47	95.98	111.34	147.90	160.74	133.85	156.88	143.83	133.26	167.74	148.00	127.54
7	Włochy	105.3	120.10	167.38	102.81	110.83	56.92	71.47	0.00	105.13	99.96	118.05	138.99	142.29	165.82	138.02	138.84	175.82	154.37	98.60
8	Śródmieście	650.0	115.90	113.60	63.55	71.31	59.32	102.90	95.84	0.00	71.33	154.97	123.55	68.08	106.70	104.16	96.73	131.72	114.50	55.88
9	Mokotów	817.9	126.97	143.34	97.19	95.10	75.90	109.32	98.89	71.33	0.00	100.35	94.53	89.81	148.41	114.80	107.41	139.82	121.93	82.87
10	Ursynów	811.6	187.64	211.98	167.53	186.29	143.38	184.93	117.55	145.54	100.35	0.00	80.80	163.13	210.65	184.52	165.71	212.31	180.91	168.48
11	Wilanów	204.0	150.15	171.26	125.54	145.35	114.30	133.44	137.80	104.59	94.53	80.80	0.00	131.59	174.13	143.50	124.41	105.77	139.43	127.44
12	Praga-Południe	891.0	151.69	142.18	92.31	116.55	95.00	122.18	117.54	68.08	89.78	150.99	147.72	0.00	139.20	75.42	77.18	123.25	101.78	80.15
13	Białołęka	444.5	171.50	102.48	106.52	108.60	133.77	150.61	151.18	125.07	161.10	187.66	193.97	154.86	0.00	102.90	120.19	201.06	161.12	111.95
14	Targówek	112.9	151.23	134.05	95.95	106.40	102.85	146.30	136.00	103.81	152.02	178.79	164.80	75.42	96.51	0.00	95.51	190.13	131.71	51.43
15	Rembertów	991.8	153.20	150.98	91.12	108.59	106.84	135.51	125.06	101.17	109.69	153.56	160.35	77.18	114.89	97.87	0.00	118.78	91.46	95.60
16	Wawer	563.3	194.84	198.51	148.11	154.42	135.23	171.81	160.32	138.70	140.48	197.88	105.77	114.89	194.36	161.24	118.78	0.00	83.77	144.25
17	Wesoła	046.2	151.31	163.75	92.18	122.91	97.50	126.78	119.52	90.68	109.08	151.88	159.37	93.31	158.75	125.09	91.44	83.77	0.00	108.95
18	Praga-Północ	685.1	136.36	108.72	64.47	42.22	78.99	122.11	103.57	55.88	120.03	149.97	147.43	80.15	94.70	51.43	74.93	138.80	115.36	0.00

Figure 11: JRT Matrix from PTV VISUM (7:00 – 9:00 AM)

Matrix editor (Matrix '9 RIT (PuT PuT)')

18 x 18			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	Name		Bemowo	Bielany	Wola	Żoliborz	Ochota	Ursus	Włochy	ródmieśc	Mokotów	Ursynów	Wilanów	ga-Połuc	Białołęka	Targówek	embertó	Wawer	Wesoła	aga-Półr
		Sum	589.26	651.35	535.57	565.48	467.73	952.88	556.29	400.53	467.49	742.57	938.00	435.20	1030.08	595.01	821.95	898.12	978.72	576.50
1	Bemowo	558.32	0.00	0.00	0.00	0.00	1.02	0.00	0.00	29.47	46.28	48.84	79.93	41.82	51.85	18.17	53.23	92.17	77.38	18.17
2	Bielany	682.68	0.00	0.00	25.19	0.00	4.59	51.92	54.71	42.22	67.80	71.32	90.73	0.00	0.00	0.28	70.59	105.72	97.60	0.00
3	Wola	689.48	0.00	43.06	0.00	0.07	0.00	42.02	6.46	0.00	50.67	48.86	49.77	47.18	66.61	50.32	77.32	89.80	81.88	35.45
4	Żoliborz	570.26	0.00	0.00	0.19	0.00	42.38	66.94	44.61	0.00	51.12	55.44	78.50	27.15	0.00	18.17	53.23	72.99	59.53	0.00
5	Ochota	532.77	24.52	26.88	0.49	45.98	0.00	37.32	0.03	0.00	0.26	15.00	48.55	21.82	63.11	46.80	49.83	56.44	47.87	47.86
6	Ursus	867.10	0.00	7.88	41.23	66.68	26.14	0.00	0.00	24.34	51.12	48.82	83.22	46.01	95.77	71.37	78.36	80.49	74.84	70.82
7	Włochy	642.04	0.00	41.20	3.84	47.73	0.00	0.00	0.00	23.59	1.08	0.58	35.52	57.49	84.90	69.85	77.59	82.41	68.54	47.73
8	Śródmieście	430.78	35.09	31.89	0.00	0.09	0.00	53.91	26.65	0.00	0.00	24.99	49.77	0.00	50.02	4.31	49.83	56.44	47.78	0.00
9	Mokotów	466.76	43.61	46.79	45.47	24.15	0.00	55.03	2.37	0.00	0.00	0.00	0.00	0.00	74.80	40.21	59.71	0.00	50.47	24.15
10	Ursynów	962.13	69.17	84.10	78.89	84.14	0.00	6.43	0.00	53.55	0.00	0.00	0.00	61.51	107.75	80.60	83.35	97.17	74.95	80.52
11	Wilanów	790.21	52.46	64.43	56.98	64.38	48.34	64.42	41.92	35.20	0.00	0.00	0.00	32.70	92.08	60.42	62.54	0.00	54.03	60.33
12	Praga-Południe	401.81	53.38	33.03	30.22	2.42	38.82	66.99	38.59	0.00	0.00	44.15	0.00	0.00	51.68	0.00	0.00	0.00	42.53	0.00
13	Białołęka	659.90	12.48	0.00	12.00	0.00	39.77	65.02	42.83	31.26	45.80	56.18	82.96	40.64	0.00	0.00	58.60	90.31	82.04	0.00
14	Targówek	625.26	55.61	34.60	42.39	38.22	49.41	90.37	64.58	9.74	0.00	77.04	84.02	0.00	7.14	0.00	11.90	1.20	59.04	0.00
15	Rembertów	826.94	74.52	70.96	56.06	55.90	57.04	91.39	62.07	50.53	47.50	58.67	86.21	0.00	59.55	0.00	0.00	0.00	1.22	55.33
16	Wawer	933.21	91.38	86.04	56.91	69.40	63.70	97.24	70.79	56.40	1.56	69.02	0.00	24.18	106.34	69.23	0.00	0.00	0.00	71.03
17	Wesoła	947.54	76.83	80.16	53.33	66.33	53.08	80.99	49.68	44.23	47.58	60.09	85.35	34.70	84.52	65.29	0.26	0.00	0.00	65.11
18	Praga-Północ	615.57	0.21	0.33	32.38	0.00	43.43	82.89	50.98	0.00	56.72	63.57	83.47	0.00	33.97	0.00	35.60	72.99	59.03	0.00

Figure 12: RIT Matrix from PTV VISUM (7:00 – 9:00 AM)

Matrix editor (Matrix '43 OWT (PuT PuT)')

18 x 18			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	Name		Bemowo	Bielany	Wola	Żoliborz	Ochota	Ursus	Włochy	ódmieśc	Mokotów	Ursynów	Wilanów	ga-Połuc	iałołęka	argówek	embertó	Wawer	Wesoła	aga-Półr
		Sum	57.28	63.09	69.98	53.78	55.76	64.47	54.01	63.47	44.09	72.45	59.65	71.38	93.71	64.39	81.42	48.47	79.27	66.97
1	Bemowo	65.63	0.00	0.00	0.00	0.00	0.12	0.00	0.00	4.32	3.68	3.78	3.19	7.27	4.98	8.75	9.33	4.09	7.37	8.75
2	Bielany	32.61	0.00	0.00	3.75	0.00	0.35	2.90	3.09	1.91	3.75	3.75	1.93	0.00	0.00	0.04	3.75	3.75	3.64	0.00
3	Wola	48.80	0.00	3.45	0.00	0.01	0.00	8.23	0.93	0.00	3.94	3.58	4.24	3.31	2.53	3.47	3.98	2.83	2.64	5.67
4	Żoliborz	50.19	0.00	0.00	0.03	0.00	2.57	3.73	3.85	0.00	5.02	5.56	3.31	1.96	0.00	8.75	9.27	3.07	3.07	0.00
5	Ochota	37.68	2.07	1.67	0.06	1.45	0.00	2.18	0.05	0.00	0.38	6.07	6.11	3.34	2.21	1.25	5.08	1.12	3.55	1.09
6	Ursus	127.63	0.00	1.04	8.39	7.47	10.00	0.00	0.00	10.00	7.52	8.09	8.55	10.00	7.74	9.41	10.00	10.00	10.00	9.44
7	Włochy	64.22	0.00	6.15	3.32	0.93	0.00	0.00	0.00	6.96	1.39	0.23	6.94	6.85	9.48	1.46	6.15	7.45	5.96	0.93
8	Śródmieście	34.10	3.38	4.16	0.00	0.01	0.00	3.55	2.52	0.00	0.00	1.91	4.24	0.00	4.16	0.43	5.08	1.12	3.54	0.00
9	Mokotów	22.09	1.79	1.59	1.14	2.85	0.00	1.79	0.22	0.00	0.00	0.00	0.00	0.02	2.89	2.88	1.99	0.00	2.09	2.85
10	Ursynów	84.95	7.16	6.89	6.83	6.87	0.00	0.58	0.00	6.69	0.00	0.00	0.00	7.17	7.08	7.08	7.17	7.17	7.16	7.08
11	Wilanów	74.51	5.36	5.36	5.39	5.37	5.38	5.36	5.44	5.35	0.00	0.00	0.00	4.62	5.40	5.40	5.35	0.00	5.35	5.40
12	Praga-Południe	60.99	7.43	4.41	4.48	0.32	8.42	6.61	7.17	0.00	0.00	9.39	0.00	0.00	4.34	0.00	0.00	0.00	8.44	0.00
13	Białołęka	77.73	1.38	0.00	4.75	0.00	4.63	4.78	4.60	5.64	4.74	4.74	5.89	10.89	0.00	0.00	10.47	4.74	10.49	0.00
14	Targówek	42.81	2.79	2.58	6.01	2.85	2.58	2.55	2.93	1.67	0.00	2.46	2.78	0.00	9.80	0.00	0.94	0.04	2.82	0.00
15	Rembertów	93.13	10.00	10.00	9.96	10.00	4.34	4.89	4.95	5.71	4.38	4.39	4.34	0.00	10.00	0.00	0.00	0.00	0.19	10.00
16	Wawer	128.89	10.23	10.10	8.55	10.00	10.06	10.00	9.96	9.57	0.62	9.91	0.00	9.85	10.10	9.82	0.00	0.00	0.00	10.11
17	Wesoła	86.26	5.68	5.66	5.65	5.65	5.65	5.65	5.65	5.65	5.69	5.65	6.00	6.10	6.25	5.65	0.05	0.00	0.00	5.65
18	Praga-Północ	31.41	0.01	0.03	1.68	0.00	1.69	1.68	2.67	0.00	2.97	2.95	2.14	0.00	6.74	0.00	2.83	3.07	2.97	0.00

Figure 13: OWT Matrix from PTV VISUM (7:00 – 9:00 AM)

Matrix editor (Matrix '44 TWT (PuT PuT)')

18 x 18	Name		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
			Bemowo	Bielany	Wola	Żoliborz	Ochota	Ursus	Włochy	ódmieśc	Mokotów	Ursynów	Wilanów	ga-Połuc	ìiałołęka	Γargówel	embertó	Wawer	Wesoła	ıga-Półr
		Sum	97.39	119.50	83.03	83.35	79.31	237.89	84.96	70.97	62.99	154.70	200.54	86.63	303.00	141.83	186.64	211.60	186.96	111.54
1	Bemowo	98.15	0.00	0.00	0.00	0.00	0.16	0.00	0.00	5.77	3.75	9.66	14.44	6.45	16.62	1.41	5.61	21.36	11.53	1.41
2	Bielany	108.15	0.00	0.00	4.41	0.00	0.27	12.24	10.00	8.34	4.02	10.63	14.87	0.00	0.00	0.05	10.54	18.57	14.22	0.00
3	Wola	133.43	0.00	13.53	0.00	0.01	0.00	8.33	1.47	0.00	3.85	8.24	5.37	10.25	18.00	12.81	15.07	18.46	13.56	4.45
4	Żoliborz	107.01	0.00	0.00	0.03	0.00	8.46	15.82	5.86	0.00	5.72	6.28	17.06	5.93	0.00	1.41	5.68	21.89	12.87	0.00
5	Ochota	120.46	6.08	8.77	0.17	6.13	0.00	12.54	0.00	0.00	0.00	0.00	5.32	6.21	22.54	15.35	10.10	15.60	7.64	4.01
6	Ursus	200.85	0.00	2.00	12.12	13.37	3.32	0.00	0.00	2.76	10.57	14.64	19.33	9.14	26.21	19.77	17.40	18.21	12.37	19.65
7	Włochy	140.42	0.00	10.10	0.57	3.98	0.00	0.00	0.00	3.54	0.02	0.00	5.39	14.34	27.13	16.95	21.12	19.54	13.77	3.98
8	Śródmieście	101.11	12.39	4.09	0.00	0.00	0.00	16.91	3.27	0.00	0.00	6.05	5.37	0.00	18.73	0.99	10.10	15.60	7.61	0.00
9	Mokotów	113.28	7.88	6.79	15.11	0.11	0.00	16.97	0.25	0.00	0.00	0.00	0.00	0.00	20.79	10.09	21.78	0.00	13.43	0.11
10	Ursynów	166.37	8.13	9.66	12.97	9.75	0.00	1.38	0.00	4.59	0.00	0.00	0.00	9.23	24.15	13.61	23.08	21.89	14.35	13.58
11	Wilanów	167.30	8.10	9.09	10.88	9.09	7.62	17.77	10.73	4.14	0.00	0.00	0.00	5.54	22.94	12.51	22.62	0.00	13.85	12.43
12	Praga-Południe	77.21	6.47	4.14	0.95	0.28	5.96	14.91	5.77	0.00	0.00	13.27	0.00	0.00	19.08	0.00	0.00	0.00	6.36	0.00
13	Białołęka	130.98	3.19	0.00	0.00	0.00	5.37	19.96	7.59	3.85	6.18	6.12	10.63	10.33	0.00	0.00	16.93	18.17	22.66	0.00
14	Targówek	145.10	9.49	12.03	8.45	13.26	12.24	23.41	13.13	3.02	0.00	17.71	19.58	0.00	0.20	0.00	1.62	0.41	10.55	0.00
15	Rembertów	188.58	9.66	15.50	3.71	7.56	13.32	21.74	12.34	11.48	10.86	15.18	31.09	0.00	20.68	0.00	0.00	0.00	0.39	15.06
16	Wawer	164.99	13.82	10.55	6.19	8.85	6.82	18.75	3.32	14.40	0.00	20.80	0.00	0.14	28.44	16.30	0.00	0.00	0.00	16.62
17	Wesoła	203.00	12.15	13.16	2.90	10.94	6.20	15.54	6.28	9.08	9.48	13.61	27.94	9.05	25.71	20.58	0.14	0.00	0.00	20.24
18	Praga-Północ	136.44	0.04	0.11	4.59	0.00	9.56	21.64	4.96	0.00	8.54	12.51	24.16	0.00	11.79	0.00	4.86	21.89	11.81	0.00

Figure 14: TWT Matrix from PTV VISUM (7:00 – 9:00 AM)

Matrix editor (Matrix '45 SFQ (PuT PuT)')

18 x 18			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	Name		Bemowo	Bielany	Wola	Żoliborz	Ochota	Ursus	Włochy	ódmieśc	Mokotów	Ursynów	Wilanów	ga-Po łuc	3ia ło łęka	'argówel	embertó	Wawer	Weso ła	aga-Pó łr
		Sum	192.69	207.69	256.74	238.74	268.15	135.00	420.57	235.68	244.72	172.00	187.56	201.37	102.00	155.54	181.23	87.00	265.22	197.63
1	Bemowo	148.02	0.00	0.00	0.00	0.00	12.00	0.00	0.00	32.44	22.00	12.00	15.00	11.06	6.52	6.00	6.00	7.00	12.00	6.00
2	Bielany	211.31	0.00	0.00	20.00	0.00	22.00	16.00	22.00	36.31	22.00	12.00	15.00	0.00	0.00	3.00	14.00	7.00	22.00	0.00
3	Wola	250.97	0.00	18.39	0.00	10.00	0.00	8.00	24.00	0.00	30.00	12.00	15.00	57.05	9.55	12.00	8.00	7.00	29.98	10.00
4	Żoliborz	244.69	0.00	0.00	13.00	0.00	37.53	16.00	48.16	0.00	48.00	12.00	15.00	8.00	0.00	6.00	14.00	7.00	20.00	0.00
5	Ochota	279.88	25.89	14.00	10.00	42.00	0.00	8.00	8.00	0.00	12.00	12.00	11.99	32.00	5.00	12.00	8.00	7.00	34.00	38.00
6	Ursus	166.49	0.00	11.00	14.00	8.00	13.00	0.00	0.00	13.00	16.00	12.00	15.00	8.00	6.52	14.97	8.00	7.00	8.00	12.00
7	Włochy	210.34	0.00	30.00	12.00	28.00	0.00	0.00	0.00	21.00	12.00	12.00	15.00	14.00	5.00	10.34	8.00	7.00	8.00	28.00
8	Śródmieście	238.31	8.00	20.40	0.00	25.44	0.00	8.00	73.47	0.00	0.00	12.00	15.00	0.00	5.00	22.00	8.00	7.00	34.00	0.00
9	Mokotów	206.49	22.00	16.00	4.00	30.40	0.00	8.00	47.70	0.00	0.00	0.00	0.00	4.00	6.00	6.00	16.00	0.00	16.00	30.40
10	Ursynów	212.86	18.71	22.00	22.99	22.00	0.00	8.00	0.00	22.00	0.00	0.00	0.00	21.73	5.00	21.71	8.00	11.00	8.00	21.73
11	Wilanów	179.58	14.91	14.91	14.91	14.91	14.91	8.00	14.91	14.91	0.00	0.00	0.00	14.91	6.52	14.91	8.00	0.00	8.00	14.91
12	Praga-Po łudnie	220.61	26.58	26.40	35.90	26.40	34.60	8.00	33.74	0.00	0.00	12.00	0.00	0.00	9.00	0.00	0.00	0.00	8.00	0.00
13	Bia ło łęka	163.09	20.00	0.00	17.00	0.00	17.52	8.00	14.00	15.43	12.00	12.00	14.98	10.70	0.00	0.00	7.23	7.00	7.23	0.00
14	Targówek	188.32	20.00	3.00	19.34	3.00	21.59	8.00	27.50	5.00	0.00	12.00	15.00	0.00	5.89	0.00	30.00	6.00	12.00	0.00
15	Rembertów	202.40	8.00	8.00	16.00	8.00	42.40	8.00	27.00	35.00	8.00	8.00	8.00	0.00	6.00	0.00	0.00	0.00	12.00	8.00
16	Wawer	189.74	7.00	7.00	27.00	7.00	15.00	7.00	32.77	27.00	7.00	8.00	0.00	6.97	10.00	13.00	0.00	0.00	0.00	15.00
17	Weso ła	219.30	13.60	13.60	13.60	13.60	13.60	8.00	13.60	13.60	28.33	12.00	17.60	12.97	10.00	13.60	8.00	0.00	0.00	13.60
18	Praga-Pó łnoc	217.12	8.00	3.00	17.00	0.00	24.00	8.00	33.73	0.00	27.39	12.00	15.00	0.00	6.00	0.00	30.00	7.00	26.00	0.00

Figure 15: SFQ Matrix from PTV VISUM (7:00 – 9:00 AM)

Matrix editor (Matrix '17 JRD (PuT PuT)')

18 x 18			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	Name		Bemowo	Bielany	Wola	Żoliborz	Ochota	Ursus	Włochy	ódmieśc	Mokotów	Ursynów	Wilanów	ga-Połuc	iałołęka	argówel	embertó	Wawer	Wesoła	aga-Półr
		Sum	289.58	294.53	231.30	242.74	220.98	350.22	260.72	204.90	253.41	338.05	357.59	226.55	366.04	244.21	328.50	418.94	414.46	223.93
1	Bemowo	282.79	0.00	5.51	3.84	5.89	8.58	6.00	8.01	14.07	21.88	23.00	29.74	19.76	20.36	12.66	23.47	36.44	31.99	11.60
2	Bielany	330.87	5.51	0.00	11.68	4.70	11.02	20.21	22.22	17.20	28.70	29.10	31.25	12.42	6.83	10.05	28.43	44.32	40.00	7.24
3	Wola	270.81	3.84	14.23	0.00	4.34	2.90	14.33	8.13	4.24	20.18	19.84	19.46	17.15	22.31	14.94	25.68	35.88	32.24	11.11
4	Żoliborz	244.47	5.89	4.70	4.37	0.00	14.38	21.05	17.21	4.75	20.75	22.65	24.95	12.38	7.24	10.83	21.62	26.56	22.34	2.82
5	Ochota	226.90	10.89	12.16	2.99	15.39	0.00	12.40	3.81	3.95	5.14	10.59	18.69	11.19	21.41	14.95	19.90	25.55	22.59	15.29
6	Ursus	332.70	6.00	12.62	13.10	22.13	12.79	0.00	4.76	12.18	18.73	18.81	27.20	18.82	31.30	21.60	27.81	33.45	31.04	20.37
7	Włochy	275.98	8.01	18.33	7.48	16.56	3.79	4.76	0.00	11.98	6.83	7.99	16.28	20.55	28.06	19.84	27.15	33.66	28.95	15.75
8	Śródmieście	208.40	12.87	15.34	4.24	4.77	3.95	17.25	10.70	0.00	4.76	14.78	18.48	4.54	18.19	7.91	19.53	25.18	22.19	3.73
9	Mokotów	210.59	18.98	17.97	11.29	10.77	5.06	18.14	6.98	4.76	0.00	6.69	6.30	5.99	21.97	13.29	20.57	9.32	22.56	9.95
10	Ursynów	406.11	28.96	32.25	27.31	30.53	9.56	13.67	7.84	22.46	6.69	0.00	5.39	24.63	38.28	29.49	29.82	38.74	32.08	28.43
11	Wilanów	311.14	22.57	24.20	19.06	22.45	17.18	21.75	15.87	14.74	6.30	5.39	0.00	15.77	30.31	21.57	22.10	7.05	24.33	20.51
12	Praga-Południe	220.67	22.80	17.45	14.89	8.36	14.35	24.52	17.16	4.54	5.99	19.32	9.85	0.00	19.83	5.03	5.15	8.22	17.88	5.34
13	Białołęka	336.03	14.06	6.83	12.81	7.24	21.25	26.28	22.46	17.90	24.11	28.20	32.84	17.44	0.00	6.86	19.58	42.40	28.30	7.46
14	Targówek	271.85	23.33	15.54	15.17	14.40	16.27	28.21	22.00	8.67	10.13	27.17	27.52	5.03	8.62	0.00	9.45	12.92	23.99	3.43
15	Rembertów	325.93	29.68	26.51	21.43	21.64	19.39	30.39	23.92	18.19	20.24	25.00	27.36	5.15	18.85	6.52	0.00	7.92	6.35	17.40
16	Wawer	384.65	34.56	33.25	24.86	26.10	24.96	35.10	28.10	21.74	9.86	28.72	7.05	15.34	33.79	24.22	7.92	0.00	5.59	23.49
17	Wesoła	388.92	32.50	30.34	25.46	24.65	22.38	32.16	24.94	19.81	23.11	28.29	30.56	15.06	26.91	21.02	6.12	5.59	0.00	20.02
18	Praga-Północ	237.81	9.14	7.31	11.32	2.82	13.19	23.99	16.61	3.73	20.01	22.52	24.66	5.34	11.77	3.43	14.20	25.74	22.04	0.00

Figure 16: JRD Matrix from PTV VISUM (7:00 – 9:00 AM)

Appendix B: Afternoon Peak Hours

Matrix editor (Matrix '8 JRT (PuT PuT)')

18 x 18			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	Name		Bemowo	Bielany	Wola	Żoliborz	Ochota	Ursus	Włochy	ródmieści	Mokotów	Ursynów	Wilanów	ıga-Połud	3iałołęka	Targówek	Rembertóv	Wawer	Wesoła	aga-Półn
		Sum	2215.51	2366.02	1568.30	1809.52	1704.86	2076.32	1952.91	1639.10	1963.89	2516.05	2450.31	1959.37	2279.89	1992.53	1957.56	2619.47	2299.36	1650.99
1	Bemowo	2194.99	0.00	82.62	57.67	88.32	125.40	89.95	120.10	117.51	131.84	165.77	178.43	154.87	155.16	118.95	139.42	187.61	178.40	102.98
2	Bielany	2501.83	82.62	0.00	100.12	70.48	146.39	156.33	153.33	128.90	164.36	198.20	196.00	186.15	102.48	149.69	153.09	211.94	193.07	108.67
3	Wola	1691.44	57.67	117.51	0.00	64.89	43.47	81.77	95.04	63.55	101.37	136.43	139.66	115.73	109.97	97.29	105.69	152.97	136.99	71.44
4	Żoliborz	1818.07	88.32	70.48	64.91	0.00	93.85	123.77	119.72	71.23	131.86	157.51	156.33	108.22	108.60	91.53	111.35	149.23	128.95	42.22
5	Ochota	1647.85	97.25	124.31	43.58	101.20	0.00	74.28	56.95	59.32	76.83	111.90	125.22	97.60	112.26	112.98	103.82	135.82	121.94	92.59
6	Ursus	2161.01	89.95	168.61	86.63	125.11	101.90	0.00	71.47	97.47	110.77	144.68	159.68	130.47	154.41	140.16	136.83	167.56	151.26	124.05
7	Włochy	2066.38	120.10	159.46	99.50	111.58	56.92	71.47	0.00	106.41	99.80	118.17	138.16	134.59	148.06	134.46	139.46	175.43	153.47	99.35
8	Śródmieście	1645.78	115.81	114.79	63.55	71.34	59.32	101.35	95.51	0.00	71.33	150.78	124.91	68.08	103.59	104.67	98.27	130.27	116.29	55.91
9	Mokotów	1811.21	127.82	144.67	96.99	94.84	75.90	108.41	98.89	71.33	0.00	100.35	94.53	89.81	143.46	111.96	108.45	139.82	121.34	82.61
10	Ursynów	2749.51	177.43	211.31	145.49	179.52	143.37	182.56	117.55	145.36	100.35	0.00	80.80	160.23	206.35	184.15	163.66	210.24	178.26	162.88
11	Wilanów	2197.29	150.60	173.18	126.25	147.11	114.74	132.11	135.53	105.40	94.53	80.80	0.00	130.01	169.20	143.60	123.07	105.77	137.81	127.58
12	Praga-Południe	1872.15	149.95	143.38	91.06	116.61	93.43	118.87	115.60	68.08	89.78	145.04	147.72	0.00	134.98	75.42	77.18	123.29	101.60	80.15
13	Białołęka	2408.24	169.70	102.48	106.29	108.60	132.88	148.87	138.50	123.67	159.76	186.84	192.16	147.85	0.00	102.90	117.56	200.17	158.07	111.95
14	Targówek	2089.49	151.09	133.11	93.31	105.42	103.09	141.62	130.58	100.71	151.99	175.32	167.73	75.42	93.00	0.00	94.86	189.81	131.00	51.43
15	Rembertów	1965.28	154.90	152.25	92.53	108.85	105.09	132.26	122.09	99.41	107.59	150.96	149.23	77.18	110.61	97.87	0.00	118.78	91.30	94.38
16	Wawer	2510.85	193.90	196.20	143.53	151.33	132.76	167.09	157.89	133.67	140.78	193.16	105.77	113.30	185.97	154.66	118.80	0.00	83.77	138.29
17	Wesoła	2018.03	152.05	162.96	92.84	122.10	98.24	125.63	119.38	91.21	109.64	152.01	149.54	89.63	152.28	120.81	91.45	83.77	0.00	104.51
18	Praga-Północ	1672.58	136.36	108.71	64.06	42.22	78.11	119.99	104.79	55.88	121.30	148.12	144.44	80.23	89.51	51.43	74.62	136.98	115.85	0.00

Figure 17: JRT Matrix from PTV VISUM (3:00 – 5:00 PM)

Matrix editor (Matrix '9 RIT (PuT PuT)')

18 x 18			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	Name		Bemowo	Bielany	Wola	Żoliborz	Ochota	Ursus	Włochy	ródmieśc	Mokotów	Ursynów	Wilanów	ga-Połu	;iałołęk	'argówel	embertó	Wawer	Wesoła	aga-Półr
		Sum	593.70	673.25	539.47	566.83	471.01	930.62	576.04	416.54	469.77	743.08	928.33	459.71	984.70	576.30	833.05	887.53	975.81	565.18
1	Bemowo	567.01	0.00	0.00	0.00	0.00	1.34	0.00	0.00	32.51	47.14	47.57	81.28	45.57	51.89	18.70	54.66	89.76	77.89	18.70
2	Bielany	678.73	0.00	0.00	25.49	0.00	2.30	44.90	58.98	43.10	69.46	70.40	92.22	0.44	0.00	0.61	70.62	104.80	95.42	0.00
3	Wola	701.41	0.00	44.23	0.00	0.06	0.00	41.31	23.01	0.00	50.95	47.74	50.44	53.78	60.49	48.16	76.23	87.88	80.88	36.24
4	Żoliborz	576.24	0.00	0.00	0.12	0.00	42.20	66.35	45.13	0.00	49.29	56.54	79.62	30.30	0.00	18.70	54.72	71.92	61.35	0.00
5	Ochota	537.39	25.09	25.95	0.45	47.41	0.00	36.39	0.01	0.00	0.48	15.66	50.08	27.88	61.47	43.12	51.77	54.98	47.83	48.82
6	Ursus	879.02	0.00	6.80	44.16	68.94	27.31	0.00	0.00	25.60	52.70	48.72	84.01	52.03	96.03	68.14	81.91	80.07	74.90	67.70
7	Włochy	657.07	0.00	55.54	10.14	48.58	0.00	0.00	0.00	24.97	1.60	0.86	35.87	55.77	78.28	65.95	78.86	82.61	69.46	48.58
8	Śródmieście	428.71	35.14	33.07	0.00	0.12	0.00	52.22	26.75	0.00	0.00	27.28	50.44	0.00	46.92	2.31	51.77	54.98	47.68	0.03
9	Mokotów	460.55	44.06	48.15	45.42	24.38	0.00	53.90	2.58	0.00	0.00	0.00	0.00	0.00	70.57	37.82	59.91	0.00	49.37	24.38
10	Ursynów	930.31	60.80	85.65	62.14	79.99	0.15	9.11	0.00	55.23	0.00	0.00	0.00	59.44	105.62	82.69	82.28	96.35	73.31	77.57
11	Wilanów	784.51	52.93	66.37	57.63	66.19	48.48	63.11	39.20	36.02	0.00	0.00	0.00	32.54	87.41	60.56	61.22	0.00	52.34	60.51
12	Praga-Południe	406.42	54.66	34.50	32.14	2.32	39.72	66.02	38.68	0.00	0.00	43.15	0.00	0.00	50.03	0.00	0.00	0.23	44.96	0.00
13	Białołęka	662.73	16.41	0.00	12.60	0.00	40.53	64.12	41.90	31.08	45.23	56.18	81.27	45.98	0.00	0.00	57.55	90.23	79.66	0.00
14	Targówek	624.25	56.12	34.21	39.78	37.51	49.89	86.13	62.51	15.28	0.10	73.71	86.10	0.00	7.63	0.00	14.87	1.83	58.59	0.00
15	Rembertów	815.55	76.23	71.39	57.26	55.37	58.22	89.78	61.32	49.84	48.06	59.28	78.44	0.00	55.23	0.00	0.00	0.00	2.46	52.65
16	Wawer	951.08	94.37	87.29	65.66	69.97	64.97	96.25	72.90	58.71	3.23	73.79	0.00	25.06	101.83	68.07	0.10	0.00	0.00	68.88
17	Wesoła	920.99	77.60	79.81	54.26	66.00	53.10	79.96	49.68	44.21	46.16	59.86	77.75	30.80	78.93	61.48	0.27	0.00	0.00	61.14
18	Praga-Północ	608.93	0.29	0.28	32.24	0.00	42.81	81.06	53.40	0.00	55.36	62.32	80.79	0.12	32.37	0.00	36.30	71.91	59.70	0.00

Figure 18: RIT Matrix from PTV VISUM (3:00 – 5:00 PM)

Matrix editor (Matrix '43 OWT (PuT PuT)')

18 x 18			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	Name		Bemowo	Bielany	Wola	Żoliborz	Ochota	Ursus	Włochy	ódmieśc	Mokotów	Ursynów	Wilanów	ga-Połuc	iałołęki	argówel	embertó	Wawer	Wesoła	aga-Półr
		Sum	50.18	54.95	64.14	45.90	46.54	56.75	45.17	56.48	40.80	59.36	55.75	63.01	79.82	56.80	77.29	43.54	72.73	58.92
1	Bemowo	60.00	0.00	0.00	0.00	0.00	0.14	0.00	0.00	2.99	3.61	3.65	3.12	5.17	5.25	8.69	9.15	3.00	6.53	8.69
2	Bielany	40.61	0.00	0.00	4.58	0.00	0.22	3.18	4.58	2.35	4.68	4.72	2.31	0.02	0.00	0.06	4.58	4.78	4.56	0.00
3	Wola	47.93	0.00	3.16	0.00	0.01	0.00	8.00	2.41	0.00	3.90	3.11	4.93	2.71	3.69	2.77	3.64	2.41	2.39	4.79
4	Żoliborz	45.80	0.00	0.00	0.03	0.00	2.31	4.70	3.28	0.00	4.67	4.70	2.32	1.68	0.00	8.69	8.75	2.34	2.34	0.00
5	Ochota	31.35	2.01	1.53	0.06	1.35	0.00	2.19	0.02	0.00	0.41	3.92	4.44	1.42	2.21	1.15	4.68	1.13	3.88	0.97
6	Ursus	118.67	0.00	0.63	6.86	5.63	10.39	0.00	0.00	10.22	5.65	6.46	7.38	10.31	5.82	9.16	10.24	10.24	10.42	9.25
7	Włochy	47.68	0.00	5.05	2.61	0.81	0.00	0.00	0.00	5.74	1.32	0.22	5.48	4.12	5.55	1.76	4.26	5.98	3.97	0.81
8	Śródmieście	34.69	3.55	4.16	0.00	0.01	0.00	3.71	1.96	0.00	0.00	2.31	4.93	0.00	4.16	0.20	4.68	1.13	3.88	0.00
9	Mokotów	20.90	2.07	1.32	1.00	2.36	0.00	2.06	0.15	0.00	0.00	0.00	0.00	0.02	2.43	2.43	2.30	0.00	2.40	2.36
10	Ursynów	68.76	5.70	4.73	7.45	5.17	0.03	0.76	0.00	5.13	0.00	0.00	0.00	6.49	4.97	5.06	6.24	6.18	6.15	4.71
11	Wilanów	73.99	5.33	5.34	5.35	5.35	5.34	5.33	5.36	5.33	0.00	0.00	0.00	4.52	5.35	5.35	5.33	0.00	5.33	5.35
12	Praga-Południe	44.32	5.21	4.23	3.61	0.29	5.84	4.33	5.00	0.00	0.00	5.73	0.00	0.00	4.23	0.00	0.00	0.03	5.82	0.00
13	Białołęka	71.56	1.36	0.00	3.92	0.00	3.09	3.93	3.19	5.61	3.92	3.92	5.77	13.34	0.00	0.00	9.78	3.92	9.81	0.00
14	Targówek	40.06	2.53	2.34	5.58	2.58	2.16	2.11	2.57	2.73	0.01	2.32	3.69	0.00	7.78	0.00	1.05	0.06	2.55	0.00
15	Rembertów	87.69	10.46	10.84	10.15	10.80	3.27	3.25	3.29	4.23	3.45	3.45	3.42	0.00	10.39	0.00	0.00	0.00	0.26	10.42
16	Wawer	83.61	6.29	6.38	6.08	6.34	6.36	6.27	6.37	6.12	0.78	6.52	0.00	7.03	6.38	6.30	0.01	0.00	0.00	6.37
17	Wesoła	85.06	5.65	5.21	5.47	5.21	5.94	5.53	5.50	6.03	6.04	6.01	6.13	6.11	5.82	5.18	0.04	0.00	0.00	5.19
18	Praga-Północ	25.45	0.01	0.02	1.40	0.00	1.44	1.40	1.50	0.00	2.35	2.34	1.83	0.06	5.78	0.00	2.56	2.34	2.44	0.00

Figure 19: OWT Matrix from PTV VISUM (3:00 – 5:00 PM)

Matrix editor (Matrix '44 TWT (PuT PuT)')

18 x 18			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	Name		Bemowo	Bielany	Wola	Żoliborz	Ochota	Ursus	Włochy	ódmieśc	Mokotów	Ursynów	Wilanów	ga-Połuc	iałołęka	argówel	embertó	Wawer	Wesoła	aga-Półr
		Sum	100.79	129.87	82.78	84.82	78.09	210.02	85.44	72.58	57.99	124.04	184.32	77.52	236.08	116.35	165.36	185.72	161.10	95.39
1	Bemowo	89.82	0.00	0.00	0.00	0.00	0.16	0.00	0.00	5.35	4.69	8.28	14.11	6.62	13.66	1.46	5.21	18.70	10.14	1.46
2	Bielany	100.47	0.00	0.00	3.69	0.00	0.16	9.24	12.05	8.54	5.05	8.44	15.29	0.07	0.00	0.12	8.17	16.67	12.96	0.00
3	Wola	123.03	0.00	13.83	0.00	0.01	0.00	6.72	5.94	0.00	4.69	6.44	5.40	11.34	12.97	9.67	12.39	16.11	13.67	3.83
4	Żoliborz	98.05	0.00	0.00	0.02	0.00	7.40	13.73	7.08	0.00	5.16	5.47	16.16	5.04	0.00	1.46	5.60	18.07	12.87	0.00
5	Ochota	110.04	6.08	9.13	0.13	5.90	0.00	10.64	0.00	0.00	0.00	0.07	5.62	8.26	18.42	12.25	10.41	12.60	6.87	3.65
6	Ursus	182.97	0.00	1.76	11.82	13.71	3.45	0.00	0.00	2.61	11.01	12.27	17.88	10.36	22.13	15.86	17.54	14.98	11.88	15.70
7	Włochy	125.19	0.00	16.26	2.23	3.70	0.00	0.00	0.00	3.92	0.03	0.00	5.51	10.94	19.72	12.54	18.74	17.32	10.59	3.70
8	Śródmieście	89.18	11.36	4.88	0.00	0.00	0.00	14.27	2.88	0.00	0.00	5.36	5.40	0.00	14.61	0.56	10.41	12.60	6.84	0.00
9	Mokotów	97.22	8.34	7.69	15.08	0.09	0.00	15.00	0.23	0.00	0.00	0.00	0.00	0.00	15.26	6.93	18.31	0.00	10.19	0.09
10	Ursynów	162.70	11.03	10.64	12.06	11.97	0.03	2.29	0.00	4.93	0.00	0.00	0.00	5.97	20.50	13.85	20.03	24.41	11.06	13.92
11	Wilanów	152.69	8.46	9.93	11.31	9.67	7.92	15.81	9.73	4.21	0.00	0.00	0.00	4.95	18.26	11.36	19.42	0.00	10.36	11.29
12	Praga-Południe	68.74	6.38	4.96	1.33	0.32	6.01	12.88	5.52	0.00	0.00	9.42	0.00	0.00	15.62	0.00	0.00	0.03	6.28	0.00
13	Białołęka	113.89	4.15	0.00	0.00	0.00	5.55	17.88	7.36	4.88	4.28	4.44	10.98	8.48	0.00	0.00	12.97	15.66	17.27	0.00
14	Targówek	133.26	9.67	11.52	7.00	12.59	12.59	21.34	9.44	4.20	0.02	14.82	19.13	0.00	0.05	0.00	1.74	0.51	8.66	0.00
15	Rembertów	159.80	9.58	14.83	3.43	6.47	13.14	19.79	10.63	10.32	8.40	10.59	25.57	0.00	14.91	0.00	0.00	0.00	0.66	11.47
16	Wawer	153.92	14.07	11.47	7.40	9.77	7.12	17.75	3.49	14.59	0.02	18.75	0.00	0.27	22.27	13.41	0.04	0.00	0.00	13.52
17	Wesoła	170.70	11.62	12.87	3.17	10.61	6.11	13.54	5.60	9.02	7.02	9.33	23.73	5.17	19.13	16.87	0.15	0.00	0.00	16.74
18	Praga-Północ	116.53	0.06	0.09	4.10	0.00	8.44	19.14	5.46	0.00	7.61	10.36	19.53	0.04	8.57	0.00	4.25	18.08	10.81	0.00

Figure 20: TWT Matrix from PTV VISUM (3:00 – 5:00 PM)

Matrix editor (Matrix '45 SFQ (PuT PuT)')

18 x 18			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	Name		Bemowo	Bielany	Wola	Żoliborz	Ochota	Ursus	Włochy	ródmieśc	Mokotów	Ursynów	Wilanów	ga-Połuc	iałołęk	Targówel	embertó	Wawer	Wesoła	aga-Półr
		Sum	189.67	208.82	277.77	290.82	321.74	210.00	495.59	250.87	300.70	285.33	203.55	262.78	110.00	202.60	218.04	137.87	254.21	270.73
1	Bemowo	182.40	0.00	0.00	0.00	0.00	15.64	0.00	0.00	43.32	17.69	20.00	16.00	15.75	7.00	6.00	10.00	11.00	14.00	6.00
2	Bielany	216.94	0.00	0.00	18.00	0.00	17.74	15.00	18.00	32.87	17.80	17.80	16.00	8.00	0.00	8.73	18.00	11.00	18.00	0.00
3	Wola	282.51	0.00	17.07	0.00	8.00	0.00	14.00	28.00	0.00	37.60	20.00	15.77	45.60	7.00	27.00	10.00	11.00	26.47	15.00
4	Żoliborz	269.28	0.00	0.00	8.00	0.00	42.64	16.00	50.76	0.00	52.97	20.00	16.00	12.00	0.00	6.00	15.91	11.00	18.00	0.00
5	Ochota	320.24	22.00	10.00	15.00	57.20	0.00	14.00	2.00	0.00	20.00	19.20	16.00	44.00	7.00	12.00	7.00	11.00	21.64	42.20
6	Ursus	186.46	0.00	13.80	15.00	13.00	13.59	0.00	0.00	7.87	13.60	20.00	16.00	7.87	7.00	16.00	11.00	7.87	7.87	16.00
7	Włochy	275.01	0.00	19.00	16.95	38.00	0.00	0.00	0.00	21.87	20.00	19.20	16.00	21.00	7.00	20.00	15.00	11.00	12.00	38.00
8	Śródmieście	275.82	11.00	18.00	0.00	35.25	0.00	14.00	77.16	0.00	0.00	20.00	15.77	0.00	7.00	23.00	7.00	11.00	21.64	15.00
9	Mokotów	257.93	14.96	18.00	4.00	35.25	0.00	14.00	73.00	0.00	0.00	0.00	0.00	4.00	7.00	12.00	17.00	0.00	23.47	35.25
10	Ursynów	255.46	15.19	26.49	15.66	33.57	4.00	14.00	0.00	22.00	0.00	0.00	0.00	29.51	7.00	24.00	7.00	17.00	14.00	26.05
11	Wilanów	191.28	12.00	15.48	15.48	15.48	15.48	14.00	15.48	15.48	0.00	0.00	0.00	15.48	7.00	15.48	7.00	0.00	12.00	15.48
12	Praga-Południe	270.41	31.87	30.00	44.32	18.00	44.07	14.00	42.15	0.00	0.00	20.00	0.00	0.00	7.00	0.00	0.00	7.00	12.00	0.00
13	Białołęka	224.50	21.00	0.00	19.20	0.00	27.12	14.00	24.47	21.63	19.20	19.20	16.00	17.41	0.00	0.00	7.13	11.00	7.13	0.00
14	Targówek	206.01	21.00	3.00	10.00	3.00	33.01	14.00	8.00	8.00	4.00	20.00	16.00	0.00	7.00	0.00	38.00	7.00	14.00	0.00
15	Rembertów	265.04	7.00	7.00	22.00	7.00	46.60	14.00	34.00	38.00	15.00	12.00	12.00	0.00	7.00	0.00	0.00	0.00	14.00	29.44
16	Wawer	254.77	11.00	12.00	39.37	11.00	22.00	11.00	36.80	27.00	11.00	17.93	0.00	9.66	10.00	16.00	4.00	0.00	0.00	16.00
17	Wesoła	254.04	14.65	15.98	14.80	16.08	12.84	14.00	14.80	12.84	31.84	20.00	16.00	22.50	9.00	16.39	6.00	0.00	0.00	16.31
18	Praga-Północ	302.97	8.00	3.00	20.00	0.00	27.00	14.00	70.97	0.00	40.00	20.00	16.00	10.00	7.00	0.00	38.00	11.00	18.00	0.00

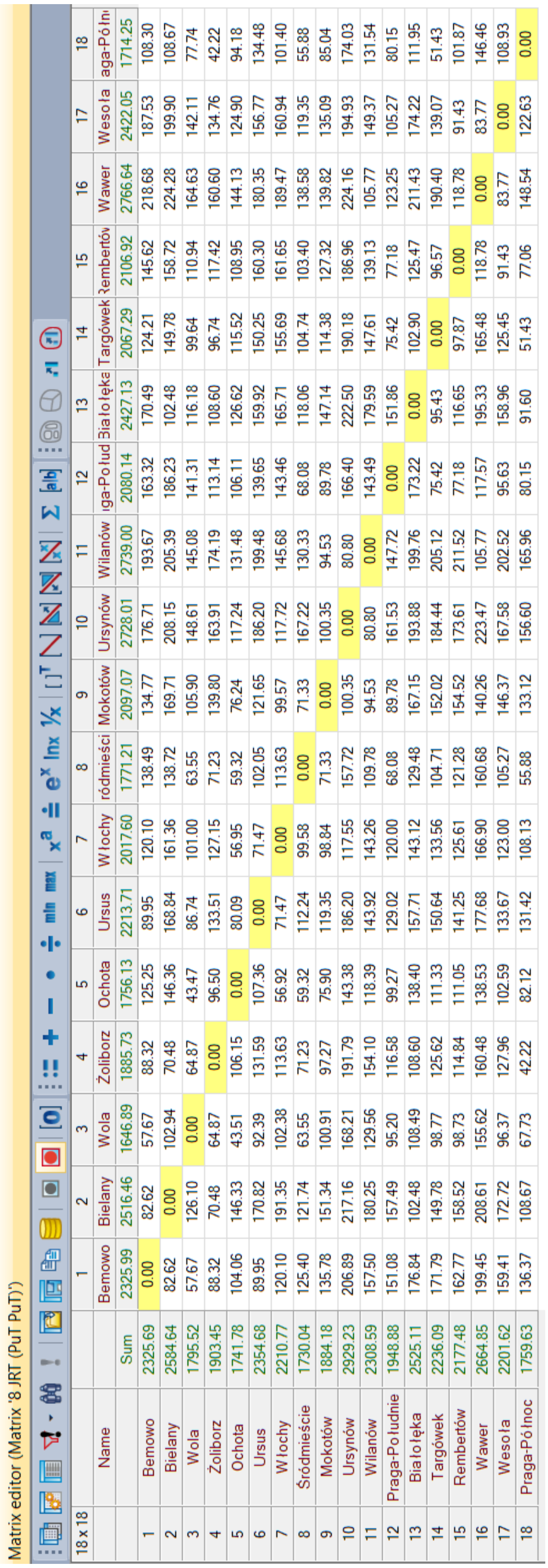
Figure 21: SFQ Matrix from PTV VISUM (3:00 – 5:00 PM)

Matrix editor (Matrix '17 JRD (PuT PuT)')

18 x 18			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	Name		Bemowo	Bielany	Wola	Żoliborz	Ochota	Ursus	Włochy	ódmieśc	Mokotów	Ursynów	Wilanów	ga-Połuc	iałołęka	argówel	embertó	Wawer	Wesoła	aga-Półr
		Sum	287.29	294.28	227.42	239.45	220.97	348.34	267.80	205.32	252.67	338.33	354.29	231.74	365.60	242.78	330.64	418.23	410.69	220.06
1	Bemowo	284.56	0.00	5.51	3.84	5.89	8.65	6.00	8.01	14.64	21.88	22.99	30.24	19.88	20.95	12.66	23.61	36.39	31.81	11.60
2	Bielany	326.96	5.51	0.00	11.83	4.70	10.38	19.07	21.61	16.91	28.74	28.98	31.23	12.52	6.83	10.12	28.62	44.25	38.42	7.24
3	Wola	273.94	3.84	14.27	0.00	4.34	2.90	14.34	10.69	4.24	20.09	19.85	19.46	18.95	22.02	14.96	25.65	35.79	31.44	11.11
4	Żoliborz	245.44	5.89	4.70	4.35	0.00	14.48	21.02	17.96	4.75	19.83	22.66	25.51	12.82	7.24	10.83	21.66	26.79	22.15	2.82
5	Ochota	226.77	10.83	11.97	2.98	15.56	0.00	12.40	3.80	3.95	5.21	10.59	18.70	11.74	21.61	14.42	19.90	25.58	22.19	15.34
6	Ursus	332.86	6.00	12.40	13.37	22.09	12.68	0.00	4.76	12.18	18.77	18.79	27.11	19.57	31.92	21.43	27.93	33.48	30.12	20.26
7	Włochy	275.11	8.01	18.37	8.14	16.59	3.79	4.76	0.00	11.86	6.94	8.05	16.17	20.40	26.55	20.18	27.06	33.56	28.90	15.77
8	Śródmieście	207.78	12.89	15.36	4.24	4.78	3.95	17.23	10.71	0.00	4.76	15.02	18.48	4.54	18.19	7.39	19.53	25.21	21.78	3.73
9	Mokotów	210.79	19.06	17.78	11.29	10.77	5.06	18.16	7.02	4.76	0.00	6.69	6.30	5.99	22.00	13.29	20.83	9.32	22.54	9.95
10	Ursynów	387.99	25.33	32.11	20.88	27.39	9.58	13.99	7.84	22.46	6.69	0.00	5.39	24.63	38.22	28.96	29.83	37.57	32.06	25.06
11	Wilanów	310.78	22.63	24.44	19.00	22.67	17.05	21.75	15.20	14.74	6.30	5.39	0.00	15.70	30.38	21.59	22.07	7.05	24.32	20.51
12	Praga-Południe	221.78	22.90	17.52	15.31	8.32	14.54	24.51	17.24	4.54	5.99	19.32	9.85	0.00	20.03	5.03	5.15	8.28	17.93	5.34
13	Białołęka	336.14	14.77	6.83	12.81	7.24	21.41	26.25	21.83	16.47	24.11	28.20	31.45	18.91	0.00	6.86	20.25	42.43	28.84	7.46
14	Targówek	276.94	23.40	15.57	14.78	14.39	16.30	27.50	26.71	9.80	10.15	26.03	27.86	5.03	8.79	0.00	10.16	13.06	23.99	3.43
15	Rembertów	325.48	29.74	26.65	21.52	21.47	19.60	30.29	24.01	18.22	20.44	25.32	25.76	5.15	18.89	6.52	0.00	7.92	6.62	17.37
16	Wawer	386.68	34.56	33.02	26.22	25.82	24.93	34.94	28.19	22.21	10.40	29.64	7.05	15.49	33.20	24.20	7.94	0.00	5.59	23.30
17	Wesoła	387.03	32.78	30.50	25.55	24.62	22.45	32.19	24.97	19.86	22.78	28.40	28.73	15.06	26.78	20.90	6.12	5.59	0.00	19.76
18	Praga-Północ	238.86	9.16	7.30	11.33	2.82	13.22	23.94	17.27	3.73	19.58	22.42	25.00	5.36	12.02	3.43	14.32	25.96	22.00	0.00

Figure 22: JRD Matrix from PTV VISUM (3:00 – 5:00 PM)

Appendix C: Off-Peak Hours



Matrix editor (Matrix '8 JRT (PuT PuT)')

18 x 18	Name	Sum	1 Bemowo	2 Bielany	3 Wola	4 Żoliborz	5 Ochota	6 Ursus	7 Włochy	8 ródmieści	9 Mokotów	10 Ursynów	11 Wilanów	12 ıga-Połud	13 3iałołęka	14 Targówek	15 ₹embertóv	16 Wawer	17 Wesoła	18 aga-Półn
			2325.99	2516.46	1646.89	1885.73	1756.13	2213.71	2017.60	1771.21	2097.07	2728.01	2739.00	2080.14	2427.13	2067.29	2106.92	2766.64	2422.05	1714.25
1	Bemowo	2325.69	0.00	82.62	57.67	88.32	125.25	89.95	120.10	138.49	134.77	176.71	193.67	163.32	170.49	124.21	145.62	218.68	187.53	108.30
2	Bielany	2584.64	82.62	0.00	102.94	70.48	146.36	168.84	161.36	138.72	169.71	208.15	205.39	186.23	102.48	149.78	158.72	224.28	199.90	108.67
3	Wola	1795.52	57.67	126.10	0.00	64.87	43.47	86.74	101.00	63.55	105.90	148.61	145.08	141.31	116.18	99.64	110.94	164.63	142.11	77.74
4	Żoliborz	1903.45	88.32	70.48	64.87	0.00	96.50	133.51	127.15	71.23	139.80	163.91	174.19	113.14	108.60	96.74	117.42	160.60	134.76	42.22
5	Ochota	1741.78	104.06	146.33	43.51	106.15	0.00	80.09	56.95	59.32	76.24	117.24	131.48	106.11	126.62	115.52	108.95	144.13	124.90	94.18
6	Ursus	2354.68	89.95	170.82	92.39	131.59	107.36	0.00	71.47	102.05	121.65	186.20	199.48	139.65	159.92	150.25	160.30	180.35	156.77	134.48
7	Włochy	2210.77	120.10	191.35	102.38	113.63	56.92	71.47	0.00	113.63	99.57	117.72	145.68	143.46	165.71	155.69	161.65	189.47	160.94	101.40
8	Śródmieście	1730.04	125.40	121.74	63.55	71.23	59.32	112.24	99.58	0.00	71.33	167.22	130.33	68.08	118.06	104.74	103.40	138.58	119.35	55.88
9	Mokotów	1884.18	135.78	151.34	100.91	97.27	75.90	119.35	98.84	71.33	0.00	100.35	94.53	89.78	147.14	114.38	127.32	139.82	135.09	85.04
10	Ursynów	2929.23	206.89	217.16	168.21	191.79	143.38	186.20	117.55	157.72	100.35	0.00	80.80	166.40	222.50	190.18	186.96	224.16	194.93	174.03
11	Wilanów	2308.59	157.50	180.25	129.56	154.10	118.39	143.92	143.26	109.78	94.53	80.80	0.00	143.49	179.59	147.61	139.13	105.77	149.37	131.54
12	Praga-Południe	1948.88	151.08	157.49	95.20	116.58	99.27	129.02	120.00	68.08	89.78	161.53	147.72	0.00	151.86	75.42	77.18	123.25	105.27	80.15
13	Białołęka	2525.11	176.84	102.48	108.49	108.60	138.40	157.71	143.12	129.48	167.15	193.88	199.76	173.22	0.00	102.90	125.47	211.43	174.22	111.95
14	Targówek	2236.09	171.79	149.78	98.77	125.62	111.33	150.64	133.56	104.71	152.02	184.44	205.12	75.42	95.43	0.00	96.57	190.40	139.07	51.43
15	Rembertów	2177.48	162.77	158.52	98.73	114.84	111.05	141.25	125.61	121.28	154.52	173.61	211.52	77.18	116.65	97.87	0.00	118.78	91.43	101.87
16	Wawer	2664.85	199.45	208.61	155.62	160.48	138.53	177.68	166.90	160.68	140.26	223.47	105.77	117.57	195.33	165.48	118.78	0.00	83.77	146.46
17	Wesoła	2201.62	159.41	172.72	96.37	127.96	102.59	133.67	123.00	105.27	146.37	167.58	202.52	95.63	158.96	125.45	91.43	83.77	0.00	108.93
18	Praga-Północ	1759.63	136.37	108.67	67.73	42.22	82.12	131.42	108.13	55.88	133.12	156.60	165.96	80.15	91.60	51.43	77.06	148.54	122.63	0.00

Figure 23: JRT Matrix from PTV VISUM (Off-Peak)

Matrix editor (Matrix '9 RIT (PuT PuT)')

18 x 18	Name		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
			Bemowo	Bielany	Wola	Żoliborz	Ochota	Ursus	Włochy	ódmieśc	Mokotów	Ursynów	Wilanów	ga-Połuc	iałołęka	argówel	embertó	Wawer	Wesoła	aga-Półr
		Sum	533.47	602.64	525.93	594.75	472.79	960.10	582.79	374.80	424.20	726.39	854.57	373.65	1015.05	588.84	941.32	988.41	1054.44	592.66
1	Bemowo	557.93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.07	49.73	56.03	92.63	41.42	18.89	19.59	55.57	107.43	84.02	19.55
2	Bielany	693.28	0.00	0.00	24.93	0.00	0.25	10.78	62.95	50.14	71.57	77.18	100.50	0.00	0.00	0.00	79.12	114.03	101.83	0.00
3	Wola	704.50	0.00	50.28	0.00	0.00	0.00	44.46	13.10	0.00	54.85	48.82	51.64	24.40	64.29	49.39	79.52	97.01	84.78	41.97
4	Żoliborz	606.94	0.00	0.00	0.00	0.00	43.89	66.79	48.42	0.00	54.85	59.53	93.88	18.59	0.00	19.52	55.93	80.32	65.22	0.00
5	Ochota	543.91	20.54	0.00	0.11	49.60	0.00	40.99	0.01	0.00	0.10	14.94	50.78	33.68	73.39	44.02	53.92	62.46	49.82	49.56
6	Ursus	868.08	0.00	0.00	50.61	68.02	24.75	0.00	0.00	25.12	58.53	0.00	64.91	62.08	97.70	74.46	106.84	87.08	74.07	73.91
7	Włochy	653.97	0.00	0.36	0.39	49.56	0.00	0.00	0.00	16.94	0.39	0.15	37.99	58.36	93.99	73.53	102.76	93.97	76.01	49.56
8	Śródmieście	423.99	29.99	36.20	0.00	0.00	0.00	57.36	27.18	0.00	0.00	0.00	51.64	0.00	55.34	0.09	53.92	62.46	49.82	0.00
9	Mokotów	481.41	44.49	52.34	45.01	24.01	0.00	60.37	0.66	0.00	0.00	0.00	0.00	0.00	71.03	37.05	69.07	0.00	53.39	24.01
10	Ursynów	945.60	44.15	86.23	70.43	77.27	0.00	0.00	0.00	38.58	0.00	0.00	0.00	61.59	116.66	83.24	96.07	105.07	83.83	82.48
11	Wilanów	814.82	57.04	70.43	50.35	70.11	48.51	72.13	42.43	37.80	0.00	0.00	0.00	11.58	95.15	61.97	74.17	0.00	61.29	61.87
12	Praga-Południe	438.17	54.81	54.56	29.98	0.00	40.43	70.82	38.58	0.00	0.00	57.04	0.00	0.00	46.71	0.00	0.00	0.00	45.24	0.00
13	Białołęka	667.73	0.34	0.00	12.05	0.00	43.13	69.93	44.91	35.22	49.66	60.47	86.53	6.46	0.00	0.00	66.22	98.54	94.27	0.00
14	Targówek	540.93	27.33	0.00	44.18	57.75	48.20	93.65	64.43	0.38	0.00	81.74	40.57	0.00	7.29	0.00	9.77	0.00	65.64	0.00
15	Rembertów	836.67	81.92	73.08	59.76	57.52	61.36	96.92	63.77	68.62	11.31	73.88	74.81	0.00	56.91	0.00	0.00	0.00	0.00	56.81
16	Wawer	898.59	91.77	93.02	49.44	72.14	64.65	100.38	72.62	38.59	0.83	54.93	0.00	22.40	104.47	62.92	0.00	0.00	0.00	70.45
17	Wesoła	894.92	81.10	86.13	54.51	68.79	54.31	84.86	50.02	50.35	25.93	72.94	27.31	33.08	80.02	63.06	0.00	0.00	0.00	62.50
18	Praga-Północ	635.37	0.00	0.00	34.19	0.00	43.32	90.66	53.71	0.00	46.45	68.74	81.37	0.00	33.21	0.00	38.44	80.05	65.23	0.00

Figure 24: RIT Matrix from PTV VISUM (Off-Peak)

Matrix editor (Matrix '43 OWT (PuT PuT)')

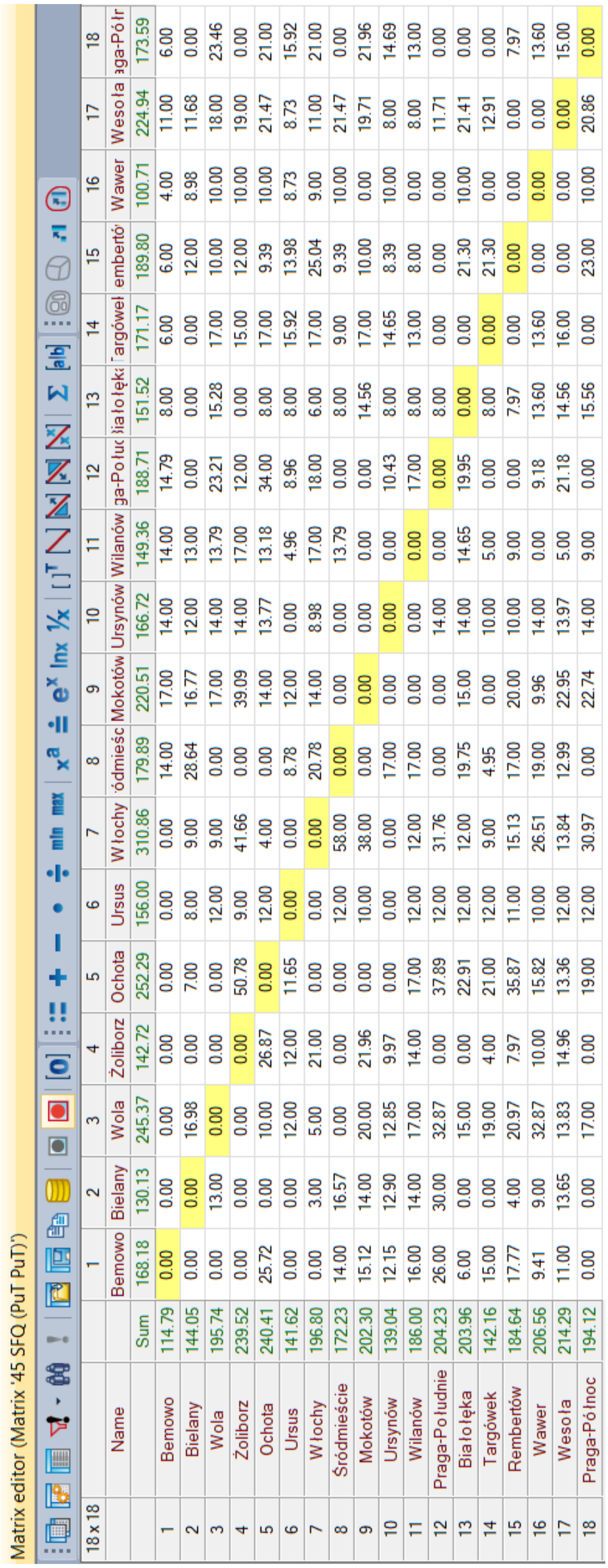
18 x 18			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	Name		Bemowo	Bielany	Wola	Żoliborz	Ochota	Ursus	Włochy	ródmieśc	Mokotów	Ursynów	Wilanów	ga-Połuc	Białołęka	Targówek	embertó	Wawer	Wesoła	aga-Półr
		Sum	72.35	81.83	97.46	76.40	81.53	91.62	79.01	82.71	62.45	89.51	99.73	77.50	124.55	97.41	116.14	75.59	110.08	96.37
1	Bemowo	84.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.65	3.72	4.52	4.29	7.76	4.16	13.05	14.47	8.50	9.50	13.02
2	Bielany	61.54	0.00	0.00	7.96	0.00	0.04	1.18	7.58	3.73	7.92	7.89	3.42	0.00	0.00	0.00	7.88	7.88	6.06	0.00
3	Wola	72.70	0.00	5.67	0.00	0.00	0.00	9.91	2.19	0.00	5.65	6.35	9.16	4.20	5.65	3.98	5.62	4.46	4.48	5.37
4	Żoliborz	79.06	0.00	0.00	0.00	0.00	4.96	7.32	5.41	0.00	7.87	8.20	5.35	2.25	0.00	13.07	13.63	5.32	5.70	0.00
5	Ochota	53.01	2.54	0.00	0.02	1.98	0.00	3.40	0.02	0.00	0.23	9.91	9.68	3.57	3.72	1.98	7.58	1.96	4.49	1.92
6	Ursus	167.05	0.00	0.00	9.53	9.48	15.46	0.00	0.00	15.28	9.80	0.00	10.95	15.45	10.09	13.88	11.24	16.02	16.10	13.77
7	Włochy	62.15	0.00	0.03	0.22	1.92	0.00	0.00	0.00	5.56	0.91	0.10	11.24	7.78	7.48	6.87	7.15	5.69	5.28	1.92
8	Śródmieście	55.46	6.04	7.99	0.00	0.00	0.00	7.53	2.54	0.00	0.00	0.00	9.16	0.00	8.15	0.01	7.58	1.96	4.49	0.00
9	Mokotów	47.15	2.81	3.50	5.32	5.16	0.00	2.95	0.06	0.00	0.00	0.00	0.00	0.00	5.61	5.61	5.52	0.00	5.44	5.16
10	Ursynów	128.05	6.71	10.69	10.90	10.34	0.00	0.00	0.00	7.44	0.00	0.00	0.00	11.83	11.19	11.07	12.79	11.63	12.39	11.07
11	Wilanów	108.40	8.13	8.36	8.17	8.37	8.13	8.13	8.61	7.93	0.00	0.00	0.00	2.39	8.01	7.95	8.27	0.00	8.00	7.95
12	Praga-Południe	78.10	7.84	8.29	6.59	0.00	10.69	9.65	10.04	0.00	0.00	9.26	0.00	0.00	6.53	0.00	0.00	0.00	9.22	0.00
13	Białołęka	80.15	0.05	0.00	6.67	0.00	5.30	6.96	5.26	5.99	6.70	6.67	8.11	1.66	0.00	0.00	9.95	6.87	9.94	0.00
14	Targówek	39.43	1.64	0.00	5.93	2.72	3.30	3.61	3.62	0.06	0.00	3.40	1.28	0.00	9.39	0.00	0.89	0.00	3.59	0.00
15	Rembertów	136.47	12.64	15.42	13.81	14.71	7.10	6.35	4.86	14.48	1.98	9.77	6.00	0.00	14.57	0.00	0.00	0.00	0.00	14.79
16	Wawer	163.50	14.45	13.22	10.45	13.38	12.72	12.74	15.57	11.00	0.41	10.43	0.00	11.07	13.22	11.71	0.00	0.00	0.00	13.14
17	Wesoła	146.50	9.51	8.65	8.78	8.34	8.90	8.67	8.78	9.60	12.24	8.59	17.82	9.53	10.58	8.23	0.00	0.00	0.00	8.25
18	Praga-Północ	48.88	0.00	0.00	3.12	0.00	4.93	3.23	4.46	0.00	5.03	4.41	3.27	0.00	6.18	0.00	3.57	5.30	5.38	0.00

Figure 25: OWT Matrix from PTV VISUM (Off-Peak)

Matrix editor (Matrix '44 TWT (PuT PuT)')

18 x 18			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	Name		Bemowo	Bielany	Wola	Żoliborz	Ochota	Ursus	Włochy	ódmieśc	Mokotów	Ursynów	Wilanów	ga-Połuc	iałołęka	argówek	embertó	Wawer	Wesoła	aga-Półr
		Sum	114.98	138.16	87.25	132.04	100.27	296.60	113.20	98.38	76.60	186.97	202.57	86.97	295.30	142.18	248.55	304.32	267.10	123.95
1	Bemowo	126.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.48	7.29	15.29	21.79	8.04	5.83	3.30	7.82	31.74	18.53	3.29
2	Bielany	150.27	0.00	0.00	3.99	0.00	0.03	3.04	17.71	11.80	8.07	16.90	25.99	0.00	0.00	0.00	15.09	28.21	19.45	0.00
3	Wola	171.32	0.00	20.78	0.00	0.00	0.00	10.78	4.31	0.00	8.34	10.63	7.94	5.63	17.81	11.80	17.01	27.67	19.10	9.52
4	Żoliborz	140.31	0.00	0.00	0.00	0.00	10.57	18.36	8.70	0.00	9.72	10.39	19.55	4.11	0.00	3.24	8.62	29.89	17.16	0.00
5	Ochota	143.61	5.89	0.00	0.04	6.31	0.00	16.45	0.00	0.00	0.00	0.00	7.62	14.10	25.43	15.21	14.42	21.74	10.49	5.91
6	Ursus	236.09	0.00	0.00	16.46	16.37	3.31	0.00	0.00	3.49	17.91	0.00	19.08	19.18	31.44	20.65	26.63	25.50	15.84	20.22
7	Włochy	173.11	0.00	0.08	0.12	5.90	0.00	0.00	0.00	3.90	0.00	0.00	7.57	16.20	38.02	17.79	26.95	31.06	19.62	5.90
8	Śródmieście	120.94	10.92	8.03	0.00	0.00	0.00	21.40	4.46	0.00	0.00	0.00	7.94	0.00	21.52	0.02	14.42	21.74	10.49	0.00
9	Mokotów	109.78	11.60	13.10	5.45	0.03	0.00	23.31	0.12	0.00	0.00	0.00	0.00	0.00	16.77	7.09	16.26	0.00	16.03	0.03
10	Ursynów	222.27	8.66	19.79	15.90	17.52	0.00	0.00	0.00	5.59	0.00	0.00	0.00	8.48	24.55	15.64	36.84	30.08	23.93	15.30
11	Wilanów	215.62	12.70	14.26	10.01	13.77	10.00	24.23	15.75	6.78	0.00	0.00	0.00	2.32	23.10	13.70	34.27	0.00	21.13	13.60
12	Praga-Południe	96.74	9.64	9.23	1.29	0.00	8.59	20.00	6.87	0.00	0.00	18.06	0.00	0.00	15.16	0.00	0.00	0.00	7.90	0.00
13	Białołęka	172.89	0.13	0.00	0.00	0.00	9.17	25.35	10.51	7.75	10.39	10.48	17.10	1.21	0.00	0.00	21.58	26.88	32.33	0.00
14	Targówek	164.75	7.01	0.00	11.34	32.91	14.35	30.79	11.81	0.16	0.00	24.85	11.95	0.00	0.06	0.00	1.79	0.00	17.72	0.00
15	Rembertów	221.46	16.79	16.26	5.95	10.06	17.07	28.52	14.39	26.46	4.42	23.22	26.14	0.00	16.72	0.00	0.00	0.00	0.00	15.46
16	Wawer	181.12	15.26	16.84	5.99	14.50	7.76	24.27	4.20	15.94	0.00	21.24	0.00	0.07	25.40	14.02	0.00	0.00	0.00	15.62
17	Wesoła	194.01	16.37	19.79	4.58	14.67	8.66	20.67	6.98	13.02	0.69	18.10	0.31	7.63	23.71	19.72	0.00	0.00	0.00	19.09
18	Praga-Północ	174.71	0.00	0.00	6.14	0.00	10.74	29.43	7.40	0.00	9.78	17.82	29.59	0.00	9.80	0.00	6.85	29.79	17.37	0.00

Figure 26: TWT Matrix from PTV VISUM (Off-Peak)



Matrix editor (Matrix '45 SFQ (PuT PuT)')

18 x 18	Name	Sum	1 Bemowo	2 Bielany	3 Wola	4 Żoliborz	5 Ochota	6 Ursus	7 Włochy	8 ódmieśc	9 Mokotów	10 Ursynów	11 Wilanów	12 ga-Połu	13 iałołęk	14 argówe	15 emberto	16 Wawer	17 Wesoła	18 aga-Półr
		Sum	168.18	130.13	245.37	142.72	252.29	156.00	310.86	179.89	220.51	166.72	149.36	188.71	151.52	171.17	189.80	100.71	224.94	173.59
1	Bemowo	114.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14.00	17.00	14.00	14.00	14.79	8.00	6.00	6.00	4.00	11.00	6.00
2	Bielany	144.05	0.00	0.00	16.98	0.00	7.00	8.00	9.00	28.64	16.77	12.00	13.00	0.00	0.00	0.00	12.00	8.98	11.68	0.00
3	Wola	195.74	0.00	13.00	0.00	0.00	0.00	12.00	9.00	0.00	17.00	14.00	13.79	23.21	15.28	17.00	10.00	10.00	18.00	23.46
4	Żoliborz	239.52	0.00	0.00	0.00	0.00	50.78	9.00	41.66	0.00	39.09	14.00	17.00	12.00	0.00	15.00	12.00	10.00	19.00	0.00
5	Ochota	240.41	25.72	0.00	10.00	26.87	0.00	12.00	4.00	0.00	14.00	13.77	13.18	34.00	8.00	17.00	9.39	10.00	21.47	21.00
6	Ursus	141.62	0.00	0.00	12.00	12.00	11.65	0.00	0.00	8.78	12.00	0.00	4.96	8.96	8.00	15.92	13.98	8.73	8.73	15.92
7	Włochy	196.80	0.00	3.00	5.00	21.00	0.00	0.00	0.00	20.78	14.00	8.98	17.00	18.00	6.00	17.00	25.04	9.00	11.00	21.00
8	Śródmieście	172.23	14.00	16.57	0.00	0.00	0.00	12.00	58.00	0.00	0.00	0.00	13.79	0.00	8.00	9.00	9.39	10.00	21.47	0.00
9	Mokotów	202.30	15.12	14.00	20.00	21.96	0.00	10.00	38.00	0.00	0.00	0.00	0.00	0.00	14.56	17.00	10.00	0.00	19.71	21.96
10	Ursynów	139.04	12.15	12.90	12.85	9.97	0.00	0.00	0.00	17.00	0.00	0.00	0.00	10.43	8.00	14.65	8.39	10.00	8.00	14.69
11	Wilanów	186.00	16.00	14.00	17.00	14.00	17.00	12.00	12.00	17.00	0.00	0.00	0.00	17.00	8.00	13.00	8.00	0.00	8.00	13.00
12	Praga-Południe	204.23	26.00	30.00	32.87	0.00	37.89	12.00	31.76	0.00	0.00	14.00	0.00	0.00	8.00	0.00	0.00	0.00	11.71	0.00
13	Białołęka	203.96	6.00	0.00	15.00	0.00	22.91	12.00	12.00	19.75	15.00	14.00	14.65	19.95	0.00	0.00	21.30	10.00	21.41	0.00
14	Targówek	142.16	15.00	0.00	19.00	4.00	21.00	12.00	9.00	4.95	0.00	10.00	5.00	0.00	8.00	0.00	21.30	0.00	12.91	0.00
15	Rembertów	184.64	17.77	4.00	20.97	7.97	35.87	11.00	15.13	17.00	20.00	10.00	9.00	0.00	7.97	0.00	0.00	0.00	0.00	7.97
16	Wawer	206.56	9.41	9.00	32.87	10.00	15.82	10.00	26.51	19.00	9.96	14.00	0.00	9.18	13.60	13.60	0.00	0.00	0.00	13.60
17	Wesoła	214.29	11.00	13.65	13.83	14.96	13.36	12.00	13.84	12.99	22.95	13.97	5.00	21.18	14.56	16.00	0.00	0.00	0.00	15.00
18	Praga-Północ	194.12	0.00	0.00	17.00	0.00	19.00	12.00	30.97	0.00	22.74	14.00	9.00	0.00	15.56	0.00	23.00	10.00	20.86	0.00

Figure 27: SFQ Matrix from PTV VISUM (Off-Peak)

Matrix editor (Matrix '17 JRD (PuT PuT)')

18 x 18			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	Name		Bemowo	Bielany	Wola	Żoliborz	Ochota	Ursus	Włochy	ódmieśc	Mokotów	Ursynów	Wilanów	ga-Połuc	iałołęka	Targówel	embertó	Wawer	Wesoła	aga-Półr
		Sum	270.91	280.32	230.22	235.62	220.06	339.76	266.04	196.54	236.73	324.62	343.47	215.01	358.20	243.91	342.74	417.83	413.50	224.08
1	Bemowo	275.89	0.00	5.51	3.84	5.89	8.35	6.00	8.01	11.84	21.85	23.25	31.59	19.33	14.90	12.66	23.60	36.08	31.58	11.59
2	Bielany	324.09	5.51	0.00	11.65	4.70	9.82	13.13	21.44	19.50	28.63	27.84	31.18	12.42	6.83	9.99	29.62	44.32	40.28	7.24
3	Wola	267.63	3.84	14.19	0.00	4.32	2.90	14.35	8.91	4.24	20.11	19.23	19.46	14.22	21.90	15.01	25.65	35.72	31.82	11.76
4	Żoliborz	249.98	5.89	4.70	4.32	0.00	14.26	20.58	19.47	4.75	20.78	22.61	29.74	10.90	7.24	10.83	21.62	26.61	22.86	2.82
5	Ochota	226.31	10.35	9.75	2.92	16.05	0.00	12.40	3.80	3.95	5.09	10.59	18.67	12.05	23.61	14.22	19.90	25.56	22.14	15.27
6	Ursus	328.51	6.00	11.39	14.16	21.64	12.56	0.00	4.76	12.18	18.77	12.41	24.08	20.50	30.67	22.21	32.91	33.45	29.66	21.15
7	Włochy	273.14	8.01	12.82	6.87	16.57	3.79	4.76	0.00	10.50	6.67	7.88	16.31	20.23	26.56	22.53	31.48	33.43	28.97	15.76
8	Śródmieście	203.33	12.35	15.48	4.24	4.75	3.95	17.08	10.68	0.00	4.76	11.15	18.48	4.54	18.67	7.00	19.53	25.19	21.77	3.73
9	Mokotów	215.08	18.22	17.49	15.72	10.77	5.06	17.81	6.69	4.76	0.00	6.69	6.30	5.99	22.00	13.29	23.13	9.32	21.90	9.95
10	Ursynów	382.48	22.96	29.58	24.08	25.79	9.56	12.41	7.84	18.81	6.69	0.00	5.39	24.65	37.77	28.96	29.73	38.53	32.04	27.70
11	Wilanów	305.56	22.38	24.38	18.17	22.77	16.91	21.93	14.63	14.74	6.30	5.39	0.00	11.87	30.52	21.58	22.09	7.05	24.33	20.52
12	Praga-Południe	223.90	22.84	21.34	14.70	7.77	14.45	24.51	17.19	4.54	5.99	21.04	9.85	0.00	17.99	5.03	5.15	8.22	17.95	5.34
13	Białołęka	331.40	11.85	6.83	12.81	7.24	21.49	26.26	21.82	18.05	24.09	28.24	31.68	12.91	0.00	6.86	21.06	42.41	30.36	7.46
14	Targówek	252.35	17.15	9.99	14.84	14.49	15.74	27.10	26.57	7.04	10.13	25.68	20.96	5.03	8.70	0.00	8.81	12.69	24.00	3.43
15	Rembertów	320.23	29.46	25.94	21.64	20.76	20.44	30.41	23.89	19.43	12.18	26.47	27.69	5.15	18.87	6.52	0.00	7.92	6.10	17.35
16	Wawer	370.96	34.13	33.48	23.43	25.11	25.13	34.86	28.26	17.15	9.61	24.01	7.05	14.80	33.41	23.40	7.92	0.00	5.59	23.64
17	Wesoła	373.62	30.89	30.21	25.51	24.19	22.48	32.17	24.96	21.35	17.57	29.47	21.70	15.08	26.60	20.40	6.10	5.59	0.00	19.36
18	Praga-Północ	235.09	9.09	7.24	11.31	2.82	13.18	24.00	17.12	3.73	17.50	22.67	23.35	5.34	11.97	3.43	14.43	25.75	22.17	0.00

Figure 28: JRD Matrix from PTV VISUM (Off-Peak)

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