Andrzej HANUSIK

Navigating urban complexity: Area delimitation in transport policy and statistical modelling

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Introduction

Research on urban areas constitutes a highly significant field of study in contemporary science. It is worth noting that such research cannot be unequivocally assigned to a single scientific discipline; rather, it embodies an interdisciplinary character. The chosen research direction is therefore highly individual, and the obtained results will shape further understanding of various aspects of urban areas' functioning in social, economic, political, and transportation contexts. However it should be emphasized, that in the context of the ongoing phenomenon of suburbanization and the increasing challenges faced by contemporary urban areas, such research appears not only as an intriguing direction for scientific reflection but also as one of the fundamental determinants of transportation policy.

This monograph is dedicated to the exploration of various dimensions of the city, with particular emphasis on the role of delimitation as a tool in transportation policy, simultaneously serving as a determinant of the compatibility of econometric models in polycentric agglomerations. It is also worth emphasizing that the issue of urban area delimitation is often only marginally addressed in scientific literature. Such an approach seems inadequate, as delimitation will largely determine the steps taken within the implemented urban policy. This monograph serves as a response to the identified research gap and may be regarded as a catalyst for a deeper academic debate in this area.

The theoretical aim of this study is to systematize information concerning urban areas, with particular emphasis on the phenomenon of suburbanization and delimitation processes. To achieve this goal, a systematic review of scientific literature in the discussed scope was conducted. The research aim of the monograph is to attempt to determine the extent to which area delimitation may influence the fit of econometric models. The research in question is limited to polycentric regions – dispersed urban areas characterized by the highest degree of spatial-administrative complexity. The Metropolis GZM has been selected as a kind of research testing ground. The monograph seeks to address the following research hypothesis – "the process of area delimitation affects the fit of econometric models in polycentric-dispersed agglomerations."

The monograph begins with a chapter enlightened by the city and its essence as a potential area of scientific research. The deliberations commence with reflections on the city's position within the discipline of economics. An analysis is conducted concerning issues related to urban allocation and its position in both a network and systemic context. Additionally, the chapter presents a two-dimensional model of urban areas, emphasizing their spatial aspects.

The second chapter focuses on the process of delimitation as a significant element of implemented transportation policy. It begins with a synthetic literature review on the issue of suburbanization of urban areas and its impact on transportation policy. This review also encompasses the phenomenon of delimitation, examining the context in which this concept has appeared in previous scientific research. The chapter concludes with a review of transportation plans for the ten largest Polish cities and the largest metropolitan area in the country, namely the Metropolis GZM. These plans were analysed regarding the manner in which they addressed area delimitation – key delimitation factors were identified, and the extent to which the delimitation process influenced the final shape of the transportation plan was synthetically described.

In the final chapter, the focus was on examining area delimitation as a key factor influencing the compatibility of econometric models in polycentric-dispersed agglomerations. The Metropolis GZM was chosen as the research testing ground. The first subsection presents the methodology of the conducted analysis. Subsequently, the obtained results are discussed, with a focus on differences in the fit of econometric models depending on the method of delimitation. Additionally, praxeology is presented as a potential alternative to classical approaches based on quantitative models.

The work is based on a query of English-language literature, transportation plans, and research findings conducted in the Metropolis GZM area. The monograph is aimed at individuals involved in urban transportation policy, urban planners, public administration bodies, urban logisticians, and all those interested in transportation policy issues.

1. City as a research area

1.1. City allocation in the discipline of economics

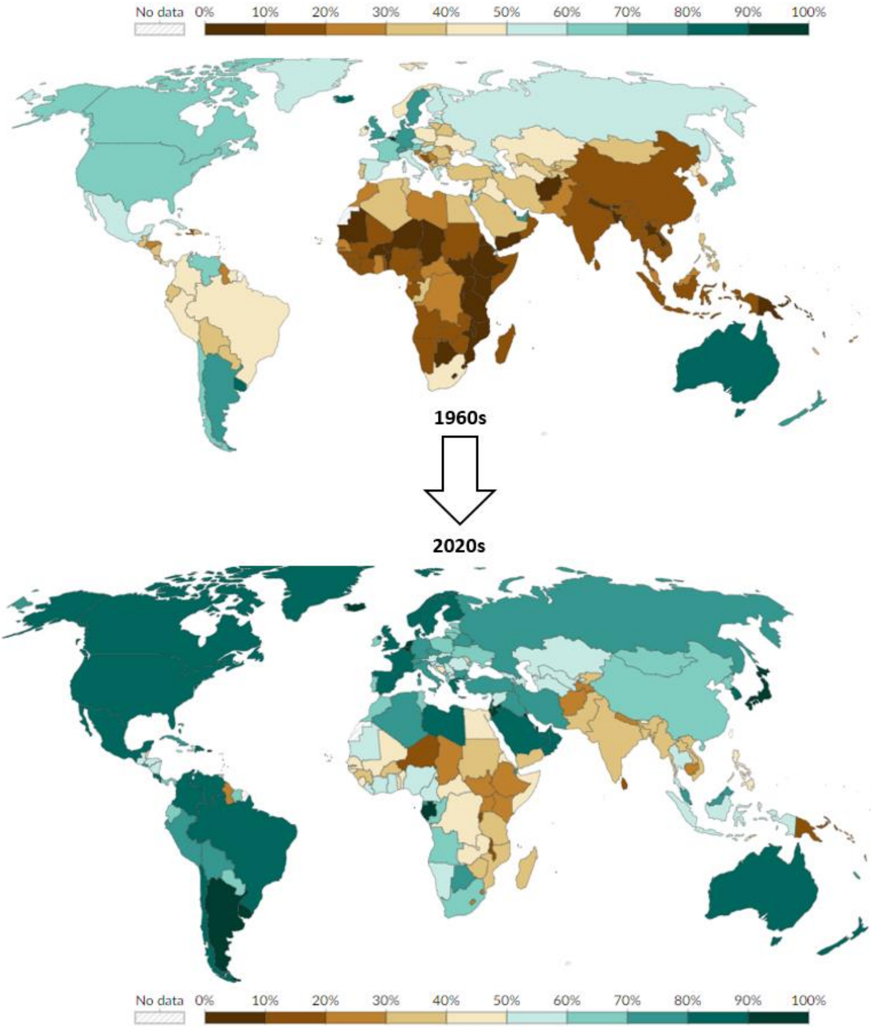
Cities undeniably play a significant role in the modern economy. Urban areas provide the backdrop for economic activities of individual consumers, small businesses, large corporations, and public administration entities (Hanusik, 2022a). It is essential to emphasize that the very concept of an urban area represents a kind of novelty for the human species – before 1850, there was practically no society characterized by an inherently urban character (Davis, 1959). However, this does not mean that urban social structures did not exist earlier – the first evidence of urban areas dates back over 5500 years. The initial cities were mainly located in Mesopotamia, the Nile Valley, the Indus Valley, the Yellow River Valley, and the Mediterranean basin. Examples of large agglomerations from those times include:

- Babylon – around 250,000 inhabitants,
- Patna – a population fluctuating around 350,000 people,
- Rome – with a peak population of around 650,000 individuals (Chandler and Fox, 1974).

During the medieval period, the number of cities significantly increased, although these were primarily relatively small cities. It is also worth noting that the population living in cities until 1850 fluctuated between 4% and 7% (Lowry, 1991).

However, this situation has changed significantly in the last 150 years. The main factor driving the development of urban lifestyle was the Industrial Revolution. It led to the mechanization of agricultural production, contributing to a significant increase in its efficiency. This situation resulted in the migration of rural populations to urban centers. Furthermore, technological advancements allowed for the establishment of cities in locations relatively distant from major energy resource deposits (McVey and Kalbach, 1995). Currently, the vast majority of societies practice an urban way of life, and the world is becoming an increasingly urbanized place. This pattern is more pronounced the more economically advanced a society is (Frey and Zachary, 2001). Historical evidence also supports this, indicating that the development of urban communities occurred much later in less developed countries (Chandler, 1987; Gilbert and Gugler, 1982; Gugler, 1988; Harris, 1992; Kasarda and Parnell, 1993; McGee and Robinson, 1995). It is worth noting that the proportion of people living in cities has undergone a sharp increase in the last 60 years, and the divergence between developed, developing, and underdeveloped countries has significantly diminished. Figure 1 illustrates the share of the urban population from the 1960s compared to the 2020s.

Figure 1. Population living in the cities – a comparison between the 1960s and the 2020s



Source: *Our world in data*, https://ourworldindata.org/grapher/share-of-population-urban (2.02.2024).

Thus, there is a visible trend of urbanization present practically worldwide. Societies that were previously weakly urbanized are developing their urban areas. This situation is observable in all contemporary countries, but the dynamics of the entire process vary. The most significant urban development is observed in countries in the Far East (e.g., China, Mongolia), Latin America (e.g., Brazil, Colombia, Venezuela), and Central-Eastern Europe (mainly former Soviet Union countries). Considerable progress in urbanization processes is also noticeable in Africa; however, it is important to highlight significant differences between the more dynamic exterior of the continent and the less dynamic interior. It should be noted that in both cases, significant development of urban areas has been observed, with the difference lying only in the pace of this development.

Significant development of urban areas is an undeniable phenomenon. However, when discussing the role of urban areas in the economy, one cannot limit the perspective solely to considering cities as the backdrop for economic activities – they also constitute one of the fundamental determinants shaping the directions of these activities (Carlino, 2001). It is precisely urban areas that influence the individual mobility and economic decisions of both consumers and businesses (Song, 1992). The spatial characteristics of urban areas also have a primary impact on the strategy of a given company (Śleszyński, 2018) – both in the short term, medium term, and long term.

The city, from an economic perspective, can be examined on various dimensions, including social (both in terms of demographics and culture), spatial, economic, technical, and political (Arribas-Bel and Sanz-Gracia, 2014). To unequivocally position urban areas in economic analysis, it is essential to analyze each of these dimensions.

One of the first attempts in contemporary science to define the urban environment from a social perspective is the work of Wirth (1938), in which he identifies three main factors characterizing the urban area – these factors are outlined in Table 1.

Table 1. Factors defining the character of an urban area from a sociological perspective according to Wirth

Factor	Meaning
Size	It concerns the actual size of the city – understood in demographic terms (population). Large cities increase the likelihood of the emergence of an impersonal entity with transient and temporary relationships
Density	It concerns the actual size of the city – understood in geographical terms (surface area). Similar to the demographic criterion – a large geographical size increases the likelihood of the emergence of an impersonal entity with transient and temporary relationships
Diversity	Ethnic and cultural diversity characterizing a given urban community. On the one hand, it allows for achieving the synergy effect of interculturality; on the other, it serves as a potential ground for ethnic conflicts

Source: Elaboration based on Wirths (1938).

Wirth's definition is often criticized in scientific literature (Paddison, 2001). It is also worth noting that these factors allow for determining the role of a city in the socio-economic landscape of a given region, but they seem to be a catalogue that is too limited and insufficient for the needs of modern economic analysis. It should also be emphasized that they only relate to social relations, omitting purely economic relationships[1]. Interesting conclusions are also drawn by Pahl (1970), where he points out that "urbanity" is not a category that can be confined to spatial frameworks because urban characteristics are present both in cities and in rural areas, making it impossible to unequivocally define what a city is in sociological terms[2]. This approach suggests the existence of certain common factors for both urban and rural areas. This is related to the previously mentioned change in the demographic model, visible since the industrial revolution. However, it should be noted that contemporary societies seek to define the differences between rural and urban character, pointing primarily to differences in professed values (Paddison, 2001).

Another way to define urban areas is through a spatial approach. Formal frameworks for modelling the spatial structure of urban areas began in the 1960s. This approach dynamically developed in the 1970s, with a primary focus on shaping the central business district and non-central residential-service areas. The 1980s defined spatial modelling of urban areas in a different way – polycentric models of cities were developed, in which the location and number of business districts were not predetermined by spatial planning but rather resulted from the endogenous characteristics of a given area. The current approach within the so-called "new economic geography" focuses on explaining the spatial character of the entire city, where residential and business functions mutually penetrate each other (Mori, 2006). External factors also need to be added to the spatial model (Takashi, Tomoya, and Yuki, 2015), such as the interaction with other urban areas or the transportation network. It is also worth noting that the spatial allocation of a city (and thus the dispersal of urban activities and resources) affects the characteristics of the urban society itself (Huai, Lo, and Ng, 2021). There is, therefore, a kind of feedback loop where society influences the spatial characteristics of urban areas, which in turn affect the character of the society. However, it should be noted, that a spatial approach should rather complement other methods, rather than be the sole method used. This is because, in addition to spatial factors, the shape of the urban fabric is also influenced by other elements that are not necessarily related to spatial aspects (e.g., legal regulations,

1 However, it is undeniable that all economic relationships arise from social relations.

2 "In an urbanized society, urbanity is everywhere and nowhere: the city cannot be defined, and thus, urban sociology cannot be defined" (Pahl, 1970, p. 209).

culture, residents' customs, economy, etc.). Nevertheless, the spatial approach may better illustrate the presence of asymmetries in individual factors (Hanusik, 2020).

Another approach discussed in the paper for defining urban areas is the economic approach. When companies decide on the location of their branches, they typically assess both the spatial aspects of a given area (e.g., transportation networks) and with continuously decreasing transportation costs and industrial transformation, the existence and characteristics of the so-called central business district (Ahlfeldt and Wendland, 2021). Defining urban areas from an economic perspective also involves highlighting the roles they can play (Table 2).

Table 2. Urban areas roles from an economic perspective

Role	Description
Business	• Regions that serve as the economic centre of a given region – a large concentration of businesses generating a significant portion of the region's GDP. • Abundance of office space. • Presence of high-tech industry businesses
Industry	• Industrial hub areas (mainly heavy industry such as mining or metallurgy). • Abundance of industrial space. • Mainly traditional (low-tech) businesses - potential application of high-tech solutions (mainly for developed countries)
Services	• Areas focused on services – e.g., shopping centers, cultural facilities, entertainment venues. • Abundance of commercial and service space. • Coexistence of small, local businesses or large, international chains
Housing	• Accommodations areas. • Abundance of residential space. • Mainly businesses catering to the immediate needs of residents – shops, basic services, education, healthcare, etc.

It's worth noting that a given urban area very rarely fulfils only one of the roles mentioned. The economic character of a city will be the result of the roles presented in Table 2 – in some cases, it may be possible to identify a dominant role. Furthermore, some cities will play the role of so-called "network intermediaries" – their main role will be to fill the structural gap between other cities in the region (Sigler, Neal, and Martinus, 2021). A significant trend in defining cities on the economic level is also the development of shared solutions, which practically redefine the functioning of urban networks (Hanusik, 2023). Similarly to the spatial approach, basing the analysis solely on economic factors will provide an incomplete picture of the urban situation. The results of an economic analysis will be influenced by factors such as demographics, where, for example, different generations may place varying degrees of importance on a given factor (Hanusik, 2019). Moreover, the economic approach alone does not reflect the spatial diversity of a given urban centre, making it advisable to complement it with the previously discussed spatial approach.

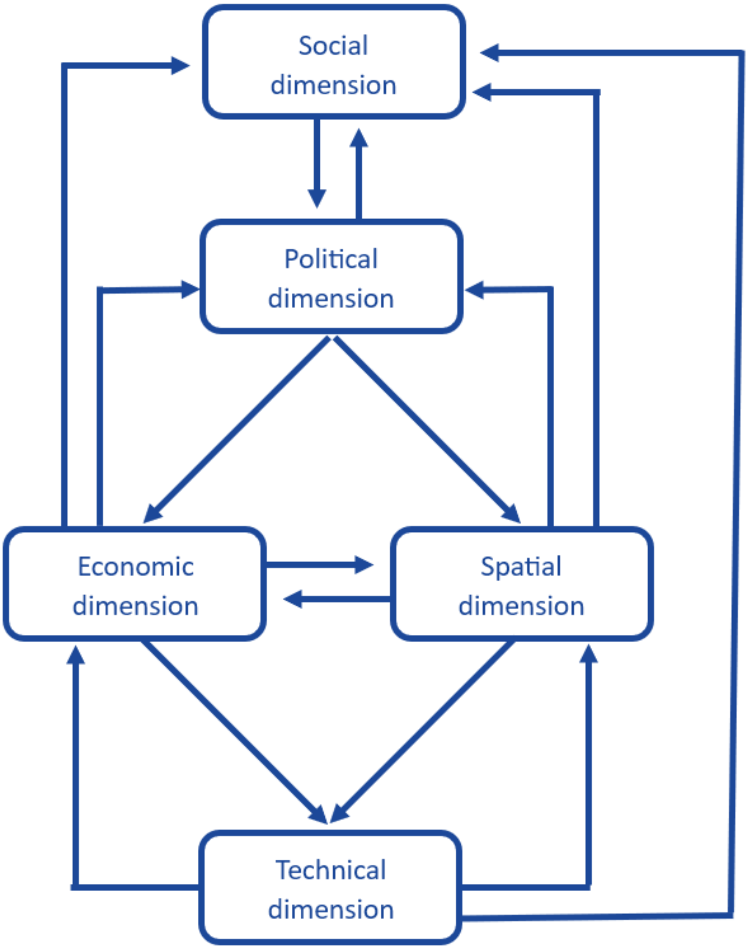
When it comes to the technical definition of urban areas, the focus should primarily be on infrastructure solutions and the role of digital platforms in cities. The infrastructural approach to urban issues is related to the analysis of physically existing solutions in the structure of a given city (such as road systems, public utility areas, parking systems, or various toll collection systems). The platformization of urban space, on the other hand, has a virtual character – platforms are like micro-markets allowing communication and exchange between different entities (Woźnica, 2024). It is also worth noting that platformization can be considered another stage in the process of urbanization, significantly influencing the social, economic, technical, and political aspects of urban areas (Strielkowski et al., 2020). Considering urban areas from a technical perspective is again an incomplete approach. Just like the economic approach, it should be supplemented with other factors – spatial analysis would be a good choice. However, it should be noted that in the case of virtual entities (e.g., platforms), the spatial approach cannot be applied. This situation suggests that the technical aspect of urban areas should be regarded as another dimension of their definitional structure.

The last definitional approach to urban areas discussed here is the political dimension, which is associated with the actions of public administration. A good example of this dimension is the transport policy of a given region, which can lead or accompany structural changes (Berg et al., 2017). It is also worth noting that this area is closely related to the technical dimension (e.g., within the framework of infrastructure investments[3]). However, it should be emphasized that the research area of local politics has been marginalized in political science – a situation that is concerning, as the local level is a source of many significant political outcomes, even on a global scale. Moreover, analyzing politics at the subnational level can generate a completely different set of problems than focusing solely on the national level (Trounstine, 2009). This situation again suggests that the political dimension should not be treated as a separate definitional plane, but rather serve as a complement to other ways of understanding how urban centers function. Moreover, political decisions should directly stem from existing spatial, economic, or technical conditions to ensure that potential actions lead to a synergistic effect. Ignoring these areas can result in the selection of ineffective solutions, and in some cases, even harmful ones for the efficiency of the city.

3 Which are often challenging to implement due to the need for financing, especially in the context of limited financial resources of local government entities (Sperling and Claussen, 2004).

Summarizing considerations related to defining urban areas in the described five dimensions, it is necessary to create a relational model between the discussed categories. It is important to emphasize the need for simultaneous application of the various dimensions in order to gain a better understanding of how urban centers function. An attempt to synthesize such is presented in Figure 2.

Figure 2. Relational model between the dimensions of urban areas analysis



Relations between different dimensions of urban areas analysis are characterized by multiple feedback loops. The primary determinant of their characteristics is the social dimension, which influences political actions. The first feedback loop occurs here, as enacted laws over time become norms embraced by society, allowing society to shape them. The political dimension will influence the spatial dimension (e.g., through spatial planning and other regulations governing construction and infrastructure) and the economic dimension (this influence is related to monetary and fiscal policies, tariffs, subsidies, grants, and various solutions supporting or restricting the development of both private and public businesses). Both of these areas are characterized by feedback loops – the economic condition of a given area will influence political decisions, and spatial conditions can significantly limit the enactment or application of specific laws. There is also a mutual relationship between the economic and spatial dimensions – on the one hand, space determines economic conditions, and on the other, economic conditions can shape the spatial structure of a given area. Both dimensions affect technical solutions – the economic dimension determines the acquisition of funds for investments, while the spatial dimension determines their location. Again, there is a feedback loop between these dimensions. Technological development supports economic growth and influences the spatial structure of a city (as well as traffic flows within a given transport network). It is also crucial to emphasize the existence of a feedback loop between the technical and social dimensions. On the one hand, society shapes technology (through legal regulations or economic decisions), and on the other, technical solutions influence the shape and form of social relations. This feedback loop is characterized by significant strength[4] and can lead to the formation of asymmetries (Hanusik, 2022b).

Urban areas are pivotal to the modern economy, serving as hubs for diverse economic activities and influencing both consumer behavior and business strategies. Historically, urbanization has evolved from early large agglomerations in ancient civilizations to the rapid urban growth driven by the Industrial Revolution and subsequent technological advances. Today, urbanization is a global phenomenon, with varying rates of development across different regions, particularly pronounced in economically advancing nations and dynamic areas like East Asia and Latin America.

The study of urban areas incorporates several dimensions: social (demographics and culture), spatial (geographic distribution and urban structure), economic (business and industrial roles), technical (infrastructure and digital platforms), and political (policy and administrative actions). It should be noted that the discussed definitional structure does not exhaust the topic of the place of urban areas in economic sciences. The choice of the five main definitional dimensions was dictated by the overarching goal of a monograph. However, it is possible to approach the subject in both a more general and more detailed manner. It should also be emphasized that the five discussed definitional categories

[4] A prime example of this could be the shaping of technology by a specific generation and its impact on that generation and subsequent ones (e.g., differences in the approach to technology among Baby Boomers, Millennials, and Generation Z representatives).

directly correspond to economics as a scientific discipline and can be considered components of economic analysis. Each dimension interacts with others, creating complex feedback loops that shape urban dynamics. Effective urban analysis requires integrating these dimensions to fully understand and address the multi--faceted nature of urban environments.

1.2. Urban areas in a network and systemic perspective

The contemporary economy is characterized by increasingly extensive and highly dynamic networked relationships, and the classical, linear understanding of processes in the modern market is becoming less and less relevant. The statement that in today's market, competition does not revolve around individual companies but entire networks is gaining popularity and widespread acceptance, both in the scientific and business environments. Such a situation contributes to attributing a network character as a predominant property, which significantly determines the success (or lack thereof) of the majority of market enterprises[5]. All the characteristics mentioned above necessitate the recognition, exploration, and description of the economy in a networked perspective.

The concept of networks is not a new one, as they have existed not only since the dawn of humanity but, likely, since the beginning of our known world. Furthermore, networks are omnipresent – one can speak of networks at the level of a single organism (nervous system, circulatory system), networks at the microscale (a good example being certain animal structures, like spider webs), mesoscale networks (river systems, connections within ant colonies, or the more abstract dimension of a network, such as a food chain – probably better described as a "food network"), and macroscopic networks – networks of physical interdependencies between various large objects, such as stars, planets, galaxies, clusters, which ultimately form a complex web of connections, as is the universe[6]. Networks can also have a more human character – our entire civilization

[5] It can be debated whether all enterprises are truly characterized by network connections. For example, a monopoly, by definition, lacks direct competitors, and its primary goal may not necessarily be to enhance competitive advantage (e.g., through quality, pricing, or customer service). This situation implies that it may not engage in activities contributing to the improvement of its network efficiency. However, this does not mean that a monopoly is not part of any network – it participates in network relationships with its environment, customers, suppliers, and even forms a complex network of connections between various departments and employees. Therefore, it can be argued that every enterprise, regardless of its market position, is a component of some network. The market position, however, influences the range of actions taken to optimize network efficiency or improve its position within the network.

[6] Some physicists are also proponents of the theory of the so-called multiverse, an entity composed of an infinite number of universes that can differ from each other in practically every as-

is a network of social connections that determines the strength and nature of relationships between individuals. Observing the modern world, one can come to one conclusion – networks are not entities that exist independently of each other. Some networks are part of other, larger structures, others share some common elements, and yet others seem completely unrelated[7]. The characteristics of networks presented above effectively illustrate the complexity of this phenomenon and allow us to conclude that understanding and enhancing one's network efficiency is the key to success, both in business and in society. However, it is impossible to take any action within a network (not to mention amultisystem) without understanding the basic characteristics that define the network.

The foundations of network theory can be attributed to graph theory, and the initial researchers who delved into the realm of network connections, thus establishing a set of theorems that can be considered the beginning of network theory, were J.B. McMillan and G. Reisbeck (after: Newcomb, 1963; Ciesielski, 2013). Graph theory primarily developed in the 18th century – without addressing some problems in a network, many challenges arising in the daily economic and social life of people in that era could not be solved. An example of a problem and its solution using graphs is the famous seven bridges of Königsberg problem – Leonhard Euler pondered whether it was possible to traverse all seven bridges over the Pregel River in a way that each bridge is crossed only once. Despite the seemingly trivial nature of the problem, it turns out to be not easily solvable without the right tools. One could attempt to solve it by listing all possible combinations (which is very time-consuming) or create a tool that helps determine all possible paths. Importantly, this tool can be used for any number of bridges (Euler, 1953). This gave rise to the theory of graphs.

Every graph consists of two crucial groups of elements – nodes, representing individual actors in a given relationship, and edges, representing connections between individual nodes. The relationship connecting nodes can take the following forms:

- undirected relation – no direction is specified, nodes operate on the basis of cooperation (e.g., a team aiming to solve a problem in a company or co-authors of a scientific article),
- directed relation – a one-sided direction of the relationship is specified, nodes operate by utilizing information or resources from other nodes (e.g., the aforementioned team using a textbook that offers various problem-solving methods or authors of a scientific article citing another researcher),

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pect. These relationships can also be multiplied – a multiverse may be part of an even larger entity, which, in turn, is just a small node in another network (Carr and Ellis, 2008).

[7] However, the lack of connection is apparent – we are likely able to trace a path between any two networks, just as it occurs between individual nodes within one network.

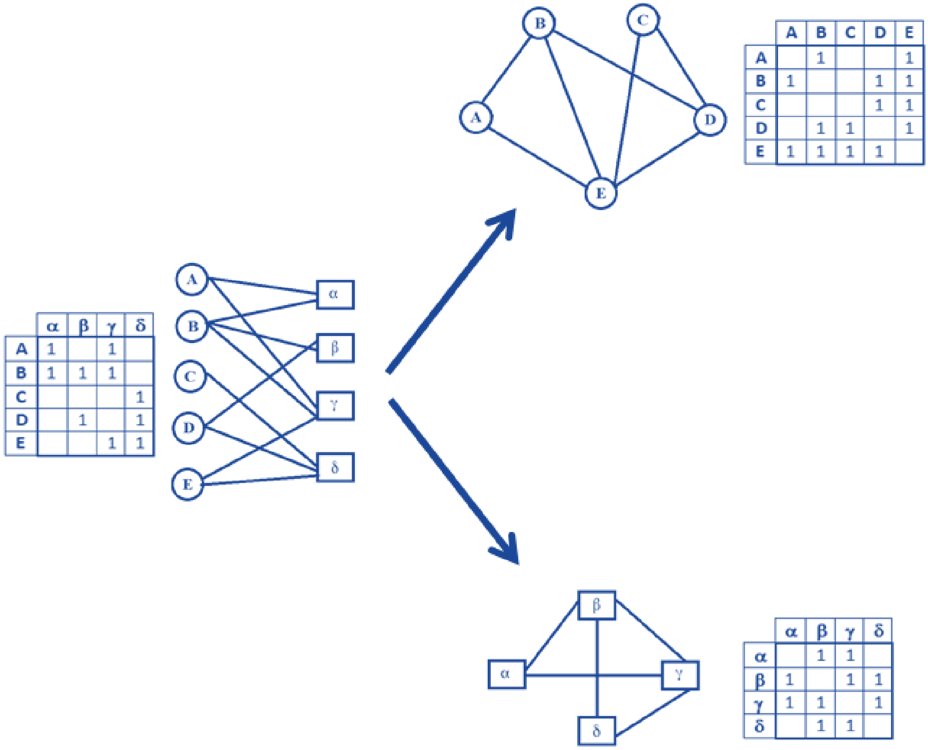
- mutual relation – a two-sided direction of the relationship is specified, nodes operate by exchanging information or resources with other nodes (e.g., the described team enters into a paid collaboration with an external expert or scientists mutually cite each other in their publications) (Płoszaj, 2013).

Moreover, each relationship (whether undirected, directed, or mutual) doesn't have to be solely binary (zero or one). Each connection can be further specified by the strength of the interaction (Płoszaj, 2013), for example, the number of hours an expert will dedicate to supporting the described group and the fee they will demand for this service[8], or the number of references in their publications to the works of another researcher.

Another very important element of networks is their modality. The first networks analyzed were unimodal structures, which are connections between elements of the same type (e.g., city residents, employees of a particular company, organizations operating in the same market, etc.). Unimodal networks offer extensive research possibilities and are relatively straightforward to analyze. However, in practice, network connections between different groups of entities are frequently encountered (e.g., connections between city residents and the companies where they work). Such networks, called bimodal, allow for analysis at a different level. Moreover, their decomposition allows obtaining two unimodal networks that provide data on relationships between the same entities (Lee and Sohn, 2016). The ability to decompose turns out to be one of the greatest advantages of bimodal networks because it enables the creation of a relationship map, obtaining information about which in a traditional way would be very difficult or even impossible. For example, having information about people and the training they participated in (bimodal network), we can decompose it and obtain two unimodal networks: one that provides information about connections between individuals (assuming that people who attended the same training probably know each other and have similar interests or professions), and the other that provides information about connections between individual trainings, allowing us to determine which types or themes are related. This makes it easier, for example, to create an offer for individuals interested in a particular training while informing them about other trainings that may interest them. Figure 3 illustrates a sample bimodal network and its decomposition into two unimodal networks. The networks are presented graphically and in matrix form.

[8] Describing one graph with different values expressed in various units, as is the case when comparing price (expressed, for example, in Polish złoty) and work (expressed in hours), is not possible. It is necessary to create a single synthetic measure; otherwise, the graph will be inaccurately described.

Figure 3. Example of decomposing a bimodal network into two unimodal networks (graphic and matrix representation)



The modality of a network is thus a crucial characteristic, as it allows obtaining information that would be beyond the reach of a researcher in another conventional way. It should also be noted that networks can function in a greater number of dimensions. For example, a four-modal network could be created, representing the structure of relationships between businesses, residents, non--governmental organizations, and authorities in a given urban area. Nevertheless, such a network would be very complex – even the identification of individual relationships could prove to be too challenging[9]. Furthermore, practically impossible would be its representation in a form other than graphical – a sample matrix would have to operate in at least 4 dimensions. However, this does not mean that such a network cannot be created. There are already computer programs that operate in four-dimensional space[10]. This situation is possible because subse-

9 The concept of networks more complex than two-modal networks is practically not addressed in scientific publications. An attempt should be made to further define this concept and establish its theoretical foundations.

10 A very good example of the effective use of four dimensions is the computer game Miegakure, in which the player-controlled character moves in four dimensions. This example demonstrates that it is possible to create a four-dimensional space in a computer program (Miegakure, 2024).

quent dimensions can be described in a mathematical way. The problem would arise in the way of presenting the data and effective work on them – at any given moment, the user does not see all the data, and navigating between them, for entities in three dimensions, is very unintuitive. It should be noted, however, that four-modal networks are a vast source of data. During their decomposition, it is possible to create four three-modal networks, 12 two-modal networks, and 24 one-modal networks[11], which provides extensive opportunities for their analysis, comparing results, and drawing conclusions[12].

The concept of a network is undeniably linked to the theory of systems. A system is a kind of organism composed of a complex of elements between which various interactions occur (Bertalanffy, 1984). Therefore, the definitions of networks and systems are very similar, however, a system is a significantly broader concept. It can be recognized that every network is a system, but not every system is a network. As mentioned in the previous subsection, networks most commonly limit themselves to elements of one type (unimodal networks) or two types of elements (bimodal networks). In practice, however, multimodal networks are not used – this situation is due to the need for multiple calculations and functioning in a space of more than three dimensions. The theory of systems is extremely important because it points to the fundamental element of a network, i.e., relationships and the interactions associated with them, which are significantly more complex than the relationships in linear models. This situation leads to increased competition between different entities and contributes to the formation of cooperative alliances, enabling the emergence of new ways of functioning in the market.

In order to illustrate the various types of relationships that may occur between organizations participating in a network, it is necessary, in the first place, to specify the characteristics of the network of organizations. Among the most important features of the network of organizations, we can include:

- Autonomy of participating entities – all entities within the network structure have independence in making their decisions, and there is no overarching entity. It should be noted, however, that entities vary in size and influence on other network participants; nevertheless, they do not have the absolute power to dictate the decisions of other entities.

[11] The formula for a combination without repetition was utilized.

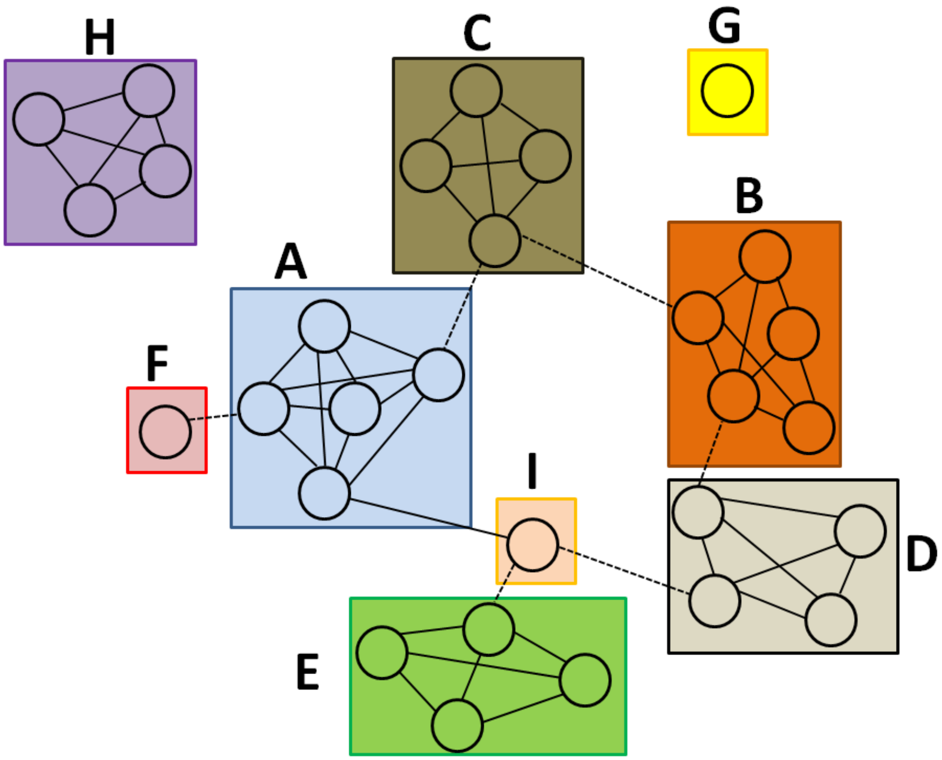
[12] The quality of the data obtained from the decomposition will depend primarily on the assumptions adopted when creating the main network.

- Discretion of membership in the structure – entities autonomously decide whether to engage in relationships with other entities[13]. They also have (in theory) an unlimited ability to terminate any relationship – in practice, severing connections entirely often proves to be difficult.
- Collaboration – the network operates through cooperation, which contributes to the formation of new relationships. Collaboration can be both formalized or devoid of official formal structures.
- Division of labor (fragmentation) – each entity participating in the network structure possesses specific skills and competencies. Collaborative action allows achieving a synergistic effect, which is the result of the individual participants' efforts.
- Common goal orientation – the network enables the realization of projects that would be unattainable for entities operating individually. Greater resources, interdisciplinary project teams, experience from various fields, and the synergy effect allow the achievement of various, often very challenging and distant goals.
- Horizontally oriented structure – the network structure lacks hierarchical features; each entity is equal. Nevertheless, in practice, the decisive voice is often held by entities with the most significant resources.
- Decentralization – the network does not have a polycentric character; there is no single entity or group of entities at the centre of power. However, the network is susceptible to manipulation by the largest entities with the most extensive resources or the most numerous connections with other network participants.
- Self-regulation – the laws on which the entire network structure is based and the procedures for its functioning are determined by the members of the network, not by an external entity.
- Self-control – the network is managed and directed by all its members. To improve network efficiency, members elect representatives who make decisions on their behalf.
- Cognitivity – the network has its own knowledge resources and the ability to learn, allowing it to dynamically adapt to changes in the environment. This characteristic, known as flexibility, is crucial for effective competition in the modern market (Alter and Hage, 1993; Chisholm, 1998; Hill, 2002; Kilduff and Tsai, 2007).

[13] However, it must be emphasized that very often the decision not to join the network is synonymous with a significant loss of competitive advantage.

Another extremely important characteristic of a network is the structure of its nodes. The network can be homogeneous (a path can be determined between any two nodes) or consist of several, a dozen, or hundreds of components. The structure of the network is directly related to the relationships between different entities – forming new relationships can lead to the inclusion of a component in the main network, while breaking them can result in its detachment (Płoszaj, 2013). The situation described above shows how complex and dynamic the network structure is. Furthermore, the network is characterized by varying strength of relationships between individual entities, which influences the dynamics of ongoing changes. Figure 4 presents an example of a network structure (including the main network and individual components), taking into account different positions of its nodes and the strength of relationships.

Figure 4. Sample network structure



The presented network is characterized by both strong connections (solid lines) and weak connections (dashed lines). Additionally, 9 sets of nodes (clusters) have been marked, labelled with letters from A to I and different colors (Table 4). The identified clusters have distinct characteristics, influencing the overall structure of the network in different ways (Table 3).

Table 3. Clusters in network relationships

Cluster	Description
A	It is one of the two main sets in the described network. It is characterized by strong connections with the nodes that are part of this cluster. Furthermore, it is linked to neighboring clusters through two weak connections (with clusters C and F) and one strong connection with cluster I
B	It has a structure similar to set A; however, it is characterized by less strength, having only two weak connections with neighboring clusters (with sets C and D). It is important to note that despite the fact that clusters A and B are not directly linked, there is a possibility to determine a path between nodes from both sets
C	It is one of the smaller sets. Its characteristic feature is that it connects other clusters. Breaking the bond between cluster C and set A or B will result in the emergence of a structural gap. Although it will still be possible to reach any point in the network (as the presented structure is circular), the path may be extended. Furthermore, the link between the described cluster and the rest of the network is a single node. If this node is eliminated, the described set will be separated from the network and become an isolated component
D	The set is very similar to cluster C; however, one key difference can be observed – there are two different nodes serving as connectors between the network and the set. Therefore, the risk of separation from the network is significantly lower (both nodes would have to be eliminated). This situation makes the position of cluster D stronger than the position of cluster C
E	The set is very similar to clusters C and D; however, it has the worst position in the mentioned group – it has only one node connecting it to the rest of the network (similar to cluster C). Additionally, the connecting node has a relation with only one node outside the network, so the risk of breaking the connection is multiplied (removing the connecting node or micro--cluster G is enough for the described set to become an isolated component). Furthermore, there is a high risk of relationship extinction since it is a connection of weak durability. Such a cluster, like set E, is called a peripheral cluster as it lies on the edge of the network
F	It is a micro-cluster (a cluster consisting of one element) similar to set E, meaning it has a peripheral character. However, the strength of this single-element set is significantly lower – it has only one weak relation. In case of the weakening or removal of the connecting node from set A, the described cluster will take on the character of set G
G	It is a single-element isolated component of the described network. The position of this node is very unfavorable – it lacks connections to the network, and establishing new relations, due to the absence of other connected nodes, may prove to be very difficult
H	Similar to micro-cluster G, this set is an isolated component of the analyzed network. Nevertheless, it has several nodes connected by strong relationships, so it is enough for any node to establish a connection with another node in the network, and the entire cluster will become an integral component of the network
I	This is a one-element set, characterized by the fact that despite being considered a separate cluster, it has many connections with other neighboring sets, serving as a connector between elements of the network. Its position is not related to the strength of ties or the size of the cluster but rather to the capabilities and threats it brings to the network – facilitating flows within the network (of information, products, etc.). In the event of the disappearance of this node, the entire network will suffer a significant loss of efficiency (making it a typical structural hole or bottleneck). Therefore, it is in the interest of all network participants to maintain this set in good condition and establish strong relationships with it

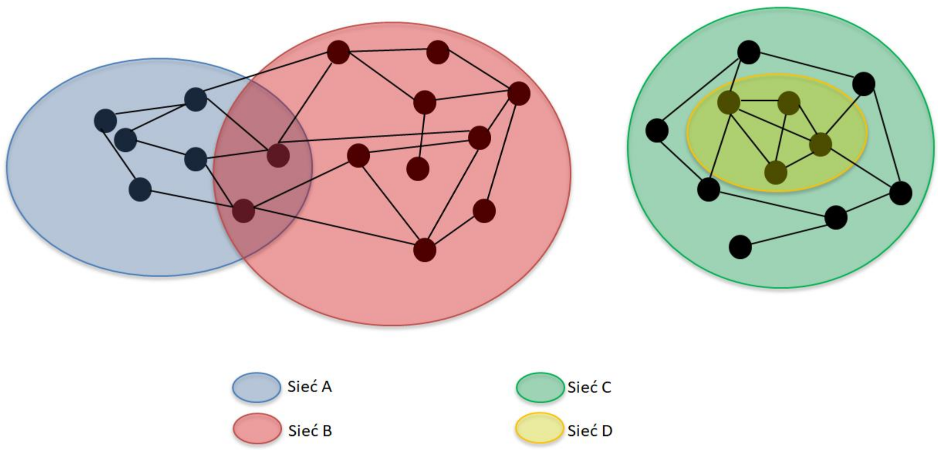
Strong relationships form the foundation of virtually every network. They significantly influence the efficiency of participating entities, determine the possibilities for structural development, and enable effective problem-solving. The aforementioned characteristics lead to the conclusion that the main goal of every network participant is to maintain and establish strong relationships. However, this does not mean that weak relationships are insignificant. Strong connections are often static structures, unchanging in the short term. While they facilitate efficient functioning within the structure, they may not provide significant opportunities for developing connections or exploring new lucrative propositions. The main advantage of weak ties is the access to a vast amount of information, which can be crucial in building a competitive advantage. Nodes characterized by a high number of weak ties can often become key elements for other entities participating in the network, and establishing relationships with them is often a priority, as they provide access to additional, often unknown, elements of the network. It may turn out that nodes with the highest number of weak ties occupy a central position in the structure of a given network (Christakis and Fowler, 2011). A notable example of this phenomenon is a study conducted in 1973 by M. Granovetter (1973). The study focused on employees who obtained their positions through recommendations from acquaintances. The aim was to determine whether these individuals owed their new positions to close friends (strong ties) or to individuals with whom they had much less frequent contact (weak connections). Only 17% of the respondents stated that they frequently interacted with the person who recommended them, while the rest indicated that these were rather distant acquaintances, often from their academic years or former colleagues with whom their contact was limited to their time in school or previous employment (Granovetter, 1973). Weak relationships also provide another, sometimes difficult to grasp but measurable benefit – the influence of a given entity typically extends to the second or third degree of separation[14]. Nevertheless, entities seeking innovation, new job opportunities, or novel solutions often commence their investigations from the second or even third degree of separation. This is because this area of the network is frequently hidden just beyond the perceptual horizon of a given node and has a crucial impact on its economic situation (Christakis and Fowler, 2011).

Another crucial characteristic of network relationships is that different networks can, to a greater or lesser extent, overlap. This situation is often observed in networks of organizations, where individual nodes may be part of several

[14] An exception to this can be nodes with very high strength of interaction. A prime example of such a node in social networks is what we commonly refer to as influencers. Leveraging social media platforms, influencers wield a broad sphere of influence over other entities.

networks simultaneously. Figure 5 illustrates example structures of relationships between different networks.

Figure 5. Sample relationships between different networks



In Figure 5, various types of relationships that may occur between different networks have been identified, as presented in Table 4.

Table 4. Types of network relationships

Relation	Description
1	*2*
A with B	This structure connects two separate organizational networks through two distinct nodes that are part of both networks (furthermore, there don't need to be any direct relationships between the connecting elements) and through a relationship between two entities belonging to different networks. Connector nodes should not have access to sensitive corporate data, as it increases the risk of data leaks or industrial espionage (which is why companies often hesitate to agree to such a relationship structure). The situation looks entirely different for cooperating enterprises – shared nodes facilitate communication, increase the efficiency of both companies, and strengthen collaboration. Furthermore, organizational entities themselves can also serve as connector nodes – this occurs in the structure of relationships between companies participating in various consortia or European Union Framework Programs. More commonly, however, are relationships between different nodes belonging to different networks. Despite the absence of connector nodes in such cases, networks of different organizations are still interconnected. Although these relationships are numerous, they are more challenging for management to identify and often impossible to utilize in achieving the business goals of the enterprise
C with D	This structure is actually one network that has a separate and distinct organizational unit within its structure. In the described case, network D can be an autonomous structure that independently makes decisions (both operational and often strategic). Network D, therefore, has an enclave character – all nodes belonging to its structure are simultaneously part of network C, and there are no direct connections with external entities. Of course, a situation is possible where one or more nodes of network D are outside the boundaries of network C – in such a case, network D would not be an enclave. The following types of relationships can occur between network C and network D:

Table 4 cont.

1	2
	• Network C is superior to network D – this is the most common situation. For example, network C could be a city that has designated a separate organizational unit within its structure, which, despite some degree of autonomy, fully submits to the decisions of the city management. • Network C is subordinate to network D – a situation much less frequently encountered in economic practice. However, organized crime organizations are a good example of such a relationship. In the core structure, the most important individuals in the organization make decisions, and they are protected by the network C structure. It is impossible to access the enclave directly from the outside – the entire structure is characterized by a very extensive and complicated network of hierarchical connections, which makes it difficult, sometimes even impossible, to decipher the core of the criminal cell. External entities are often used, which, on their own account, carry out actions commissioned by nodes belonging to the core of the organization. They appear to be fully autonomous units, but in practice, they are completely subordinate. In the case of police investigations into criminal groups, these apparent autonomous units are often the ones that get arrested. Establishing their connection to the actual organization is a very difficult task. • Network C is equal to network D – this situation is also rarely encountered. An example could be creating an independent subsidiary from one department of a company. However, in economic practice, the subsidiary is, to a greater or lesser extent, dependent on the main company
Cluster A/B with cluster C/D	In the example presented in the diagram, there is no connection between the cluster of network A and B with the cluster of network C and D – these are structures completely independent of each other. However, there is a possibility to connect both structures in three ways: • Establishing a relationship between any node in the cluster of networks A and B with the cluster of networks C and D – this situation occurs when one node that is part of one cluster establishes a relationship with another node that is part of the second cluster. Similar to the relationships between networks A and B, such relationships will mainly have a private character. • Including any node from one cluster in the structures of the second cluster – this situation occurs when an employee is employed simultaneously by two companies from two clusters, or in the case of a network of organizations when several nodes form a consortium. It is worth noting that in the case of creating a connection with network C, networks A and B automatically gain indirect access to the nodes of network D. • Establishing a relationship between any node in the cluster of networks A and B with the cluster of networks C and D while simultaneously including any node from one cluster in the structures of the second cluster – this situation is a combination of both examples described above. In the case of forming a consortium, private relationships are naturally created. In the case of establishing relationships between employees, there may also be, in the longer term, collaboration between entire companies, especially when the private relationship concerns individuals high in the hierarchy of both companies

The modern market could not function without network relationships as they significantly determine the efficiency of individual businesses, facilitate the flow of information, contribute to better results in collaboration between different entities, and play a crucial role in the creation and transfer of innovations. The characteristics of network relationships mentioned above compel entities to understand the fundamental principles on which these relationships are based. A good understanding of the basic features of networks allows for the optimization of the structure of one's own organization and the maintenance of a competitive advantage. Therefore, it is crucial to comprehend the theoretical foundations of how these undoubtedly complex and dynamically changing "organisms" – networks – operate.

Efficiently conducting network analysis in urban areas requires a precise specification of the research scope. One crucial aspect of the functioning of every city is logistics, which encompasses both the flow of goods and semi-finished products from their place of production to the ultimate consumer (Kauf et al., 2016) and the mobility of city residents, as well as decisions related to logistic planning made by city authorities (Banister, 2008). When analyzing logistical connections in cities, it seems natural to create the term "urban logistic networks," which would encompass both of these aspects. However, this is still a very broad issue, and its analysis should separate the aspect of residents' mobility from the flow of goods. Subsequently, by applying inductive methods, an attempt can be made to formulate a coherent definition of an "urban logistic network."

One of the elements of urban logistic networks is mobility, a term directly related to the travels of city residents. There are many factors that influence the mobility patterns of the population, including the availability of transportation means, individual preferences, or conditions related to employment or education (Gonzáles, Hidalgo, and Barabási, 2008). To conduct an analysis of urban logistic networks, it is essential to identify entities associated with urban mobility. The classification of urban mobility entities is presented in Table 5.

Table 5. Examples of urban mobility entities

Entity	Examples
1	*2*
Entities related to legal regulations (at the level of the European Union, country, province, municipality)	• ministers, marshals, • county offices, city offices, municipal offices, • environmental protection agencies, • cadastral agencies, • other entities related to legal regulations
Entities related to public procurement	• local government administration, • territorial government administration, • central government administration, • public law entities, • other entities related to public procurement
Transport companies	• local carriers, • national carriers, • international carriers, • other transport companies

Table 5 cont.

1	*2*
Traffic management and control centers	• road managers, • city transportation departments, • intelligent transportation systems centers, • other entities in the field of traffic management and control
Traffic safety institutions	• privileged services – police, emergency medical services, fire department, • municipal guard, • road transport inspection, • other traffic safety institutions
Working individuals	• entrepreneurs, • employees, • state officials, • freelancers, • other working individuals
Authorities responsible for linear-based infrastructure	• entities responsible for motorways, • entities responsible for expressways, • entities responsible for national roads, • entities responsible for voivodeship roads, • entities responsible for local roads, • entities responsible for private roads, • entities responsible for bicycle paths, • entities responsible for railway tracks, • entities responsible for tram tracks, • other entities responsible for linear infrastructure
Authorities responsible for point-based infrastructure	• entities responsible for industrial buildings, • entities responsible for service buildings, • entities responsible for residential buildings, • entities responsible for parking spaces, • other entities responsible for point infrastructure
Entities responsible for transport services in cities	• buses, • taxis, • metro, • rental cars (e.g., carsharing), • city bikes, • trains, • ferries, • aircraft, • other entities responsible for urban transport services
Residents – private transportation	• pedestrians, • private cars, • bicycles, • motorcycles, scooters, • scooters, • residents using other means of transportation
Transit traffic	• regular transit traffic, • irregular transit traffic
External traffic	• external traffic related to work/business (regular and irregular), • external traffic related to family (regular and irregular), • external traffic related to tourism, • other types of external traffic

Table 5 cont.

1	*2*
Mobility hubs	• bus stops, • interchange centers, including Park&Ride and Kiss&Ride, • airports, • metro stations, • bus terminals, • railway stations, • other types of mobility hubs
Lobbying groups	• people with disabilities, • elderly individuals, • children, • cyclists, • athletes, • environmental activists, • non-governmental organizations, • other types of lobbying groups
Research centers	• higher education institutions, • research centers, • chambers of commerce, • internal units within the R&D sector, • other types of research entities
Other urban mobility entities	• entities not described in the provided classification

Source: Based on: Flügge (2017).

The second element of urban logistics networks, which should be taken into account when defining the scope of this concept, and whose analysis is essential in their subsequent study, is the component related to businesses operating in a given network. These entities, similar to residents, significantly influence the final structure of the urban logistics network, impact the flows occurring within it, and contribute to the increase (or decrease) of its efficiency. Entities associated with economic activities in urban logistics networks are presented in Table 6.

Table 6. Sample entities related to economic activities in urban logistics networks

Entity	**Example**
1	*2*

Logistic entities	• freight and transport companies;
	• logistics operators:
	  ○ First Party Logistics (1PL) – an internal unit of a specific company that handles basic logistics processes (transport and warehousing) as part of so-called logistics self-service,
	  ○ Second Party Logistics (2PL) – an external entity that handles basic logistics processes for a client (transport, warehousing, freight forwarding),
	  ○ Third Party Logistics (3PL) – an external entity that manages complex logistics processes for a client, utilizing its resources and collaborating with other third-party entities – this is known as contract logistics,

Table 6 cont.

1	2
	○ Fourth Party Logistics (4PL) – an external entity that coordinates all logistics processes for a client, engaging other third-party entities, e.g., 2PL and 3PL operators. The operation of 4PL operators involves information systems, know-how, and a departure from traditional supplier-client relationships in favor of partnership relationships. Operators serving global shippers and determining logistics efficiency are called Lead Logistics Providers (LLP) (Kempny, 2008; Smyk, 2016), ○ Fifth Party Logistics (5PL) – the next evolution of logistics operators, primarily associated with transforming the supply chain into a supply network and focusing on meta-analysis (Hosie et al., 2012). • combined transport operators; • warehouse centers; • distribution centers; • entities providing postal and courier services; • entities serving a specific mode of transport or operating multimodally, including ports and airlines with ground logistics support; • railways; • seaports, liner and tramp shipping, river ports, and inland shipping companies; • entities specializing in logistics optimization; • other logistics entities
Sharing economy entities	• entities related to transportation; • entities related to residential and office spaces; • entities related to skills and expertise; • other entities offering services in the sharing economy
Other economic entities	• manufacturing enterprises; • trading enterprises; • service enterprises; • other economic entities
Other non-economic entities	• local and central government; • non-governmental organizations; • lobbying groups; • other non-economic entities
Logistic technical equipment	• linear-based transport infrastructure; • point-based transport infrastructure; • transport vehicles; • technical logistics equipment – e.g., loading devices; • technical logistics facilities – e.g., operational bases or workshops; • other technical logistics equipment
Other technical equipment	• residential buildings; • commercial and service buildings; • production buildings; • public utility buildings; • structures related to security; • communication elements (telephone, internet, or cable television networks); • facilities providing water, electricity, or sewage disposal; • other technical equipment
Types of connections and relationships	• intra-industry relations between enterprises; • inter-industry relations between enterprises; • relations between enterprises and administrative authorities; • relations between enterprises and the environment of the system; • other types of occurring relationships

Table 6 cont.

1	2
Conditions for conducting economic activities	• financial standards – e.g., fiscal burdens, funding principles, settlement methods; • legal standards – e.g., laws and regulations; • cultural standards – e.g., conditions regarding the conduct of activities, applied practices, or motivation systems; • social standards – e.g., conditions related to pro-social actions (cultural or sports events); • environmental standards – e.g., conditions related to environmental protection; • economic standards – e.g., decisions regarding the initiation or abandonment of economic activities; • other conditions for conducting economic activities (Jedynka, 2015; Kordel and Kuriata, 2018)
Other actors related to economic activities	• entities not described in the provided classification

Source: Based on the provided sources.

The considerations presented regarding the actors associated with the functioning of urban logistics networks demonstrate that this is a very broad and highly complex concept. Nevertheless, it is necessary to identify and organize the entities participating in urban logistics structures, which will enable future research in this thematic area. It should be emphasized, however, that the high level of complexity of urban logistics networks requires research to be focused on one of their areas. Such narrowing of the topic will allow for a thorough research process, significantly influencing the quality and clarity of the entire study.

The modern economy is characterized by complex and dynamic network relationships, which makes classical, linear approaches to market processes increasingly obsolete. Today, competition is no longer between individual firms but between entire networks. This concept is widely accepted in both academic and business environments. Networks, understood as connections between various entities, have become a key determinant of market success.

This subchapter discusses the fundamentals of network theory, including graph theory, and various types of relationships within networks, such as unidirectional, bidirectional, and relationships of varying strength. An important aspect of network analysis is also its modality, which refers to the number of types of elements within a network. Monomodal networks consist of elements of a single type, while multimodal networks connect elements of different types, allowing for a deeper analysis and understanding of relationships between different entities. Networks can also operate in multiple dimensions, leading to complex structures that require advanced mathematical tools for analysis. The structure of nodes within a network and the strength of connections also play a crucial role in the network's efficiency. Therefore, understanding and effectively managing networks is essential for the efficient management of the modern economy, both on a micro and macro scale.

1.3. Two-dimensional model of urban areas in spatial terms

Issues of centrality and concentration of urban agglomerations are one of the key elements of contemporary urban planning (Abozeid and AboElatta, 2021). When analyzing a given urban agglomeration, it is necessary to first assign it to one of the urban archetypes. These archetypes are related to the role played by individual cities and the number of cities participating in a given urban agglomeration. For the purposes of this study, a two-dimensional classification model for urban areas will be proposed. The fundamental assumptions of the model are presented in Table 7.

Table 7. The concept of a two-dimensional model of urban areas

Axis	Factor	Description
X	monocentric vs. polycentric	This factor describes the centrality of a given urban area. It can manifest in agglomerations with a single economic core, where the majority of economic activities in the region are concentrated, as well as in areas with multiple, mutually complementing centers
Y	centralized vs. dispersed	This factor describes the degree of dispersion of urban areas within a given agglomeration. It can involve a small number of cities and towns as well as a larger cluster containing even several dozen or several hundred centers

Such an approach to the model of urban areas in spatial terms can serve as the basis for further analyses. The first type of agglomeration discussed within the proposed model will be the monocentric-centralized agglomeration. Figure 6 illustrates the position of the discussed agglomeration in the proposed two-dimensional model.

The presented situation occurs when there is only one city of primary socio-economic significance in a given area. Although there may be several smaller urban or rural areas around it, they do not form close connections with the central city. The analysis of such areas is relatively straightforward, and the process of any division of boundaries will take place only within the boundaries of the central city.

Another type of agglomeration discussed within the proposed model is the Polycentric-Centralized agglomeration. Figure 7 illustrates the position of the discussed agglomeration in the proposed two-dimensional model.

Figure 6. Two-dimensional model of urban areas in spatial terms – part 1

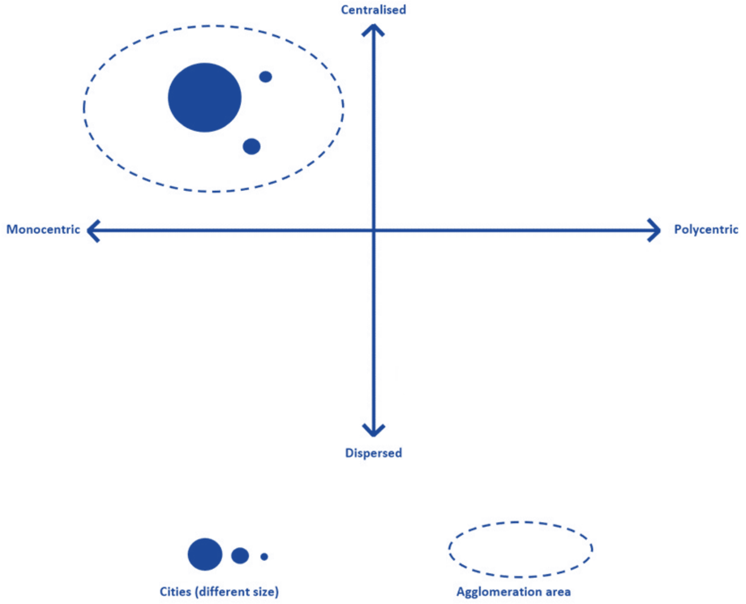
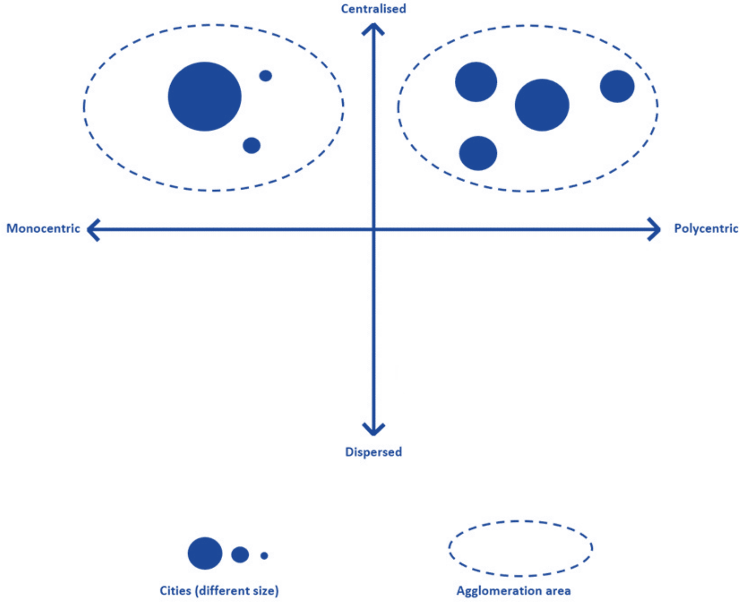


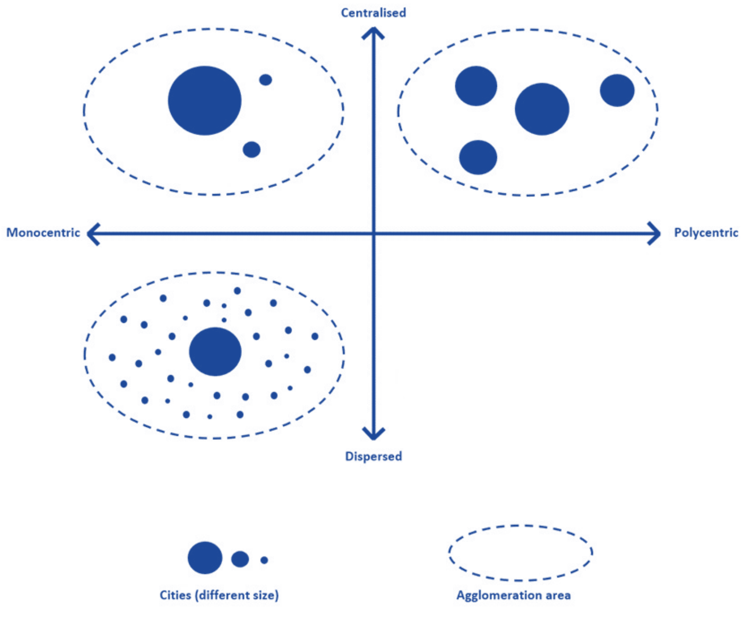
Figure 7. Two-dimensional model of urban areas in spatial terms – part 2



The presented situation occurs when there are several cities in a given area, each playing a significant socio-economic role, making it impossible to distinguish one dominant city. Additionally, apart from these central areas, there are practically no other cities or rural areas that would be closely connected to the discussed arrangement. Again, there may be cities or villages in their vicinity, but they do not form close connections with the central city. The analysis of such areas is decidedly more challenging than in the case of the Monocentric-Centralized agglomeration, as individual areas that administratively belong to a particular city may be functionally more associated with another. However, it should be noted that the relatively small number of urban centers still makes this analysis relatively straightforward.

Another type of agglomeration discussed within the proposed model is the Monocentric-Dispersed agglomeration. Figure 8 illustrates the position of the discussed agglomeration in the proposed two-dimensional model.

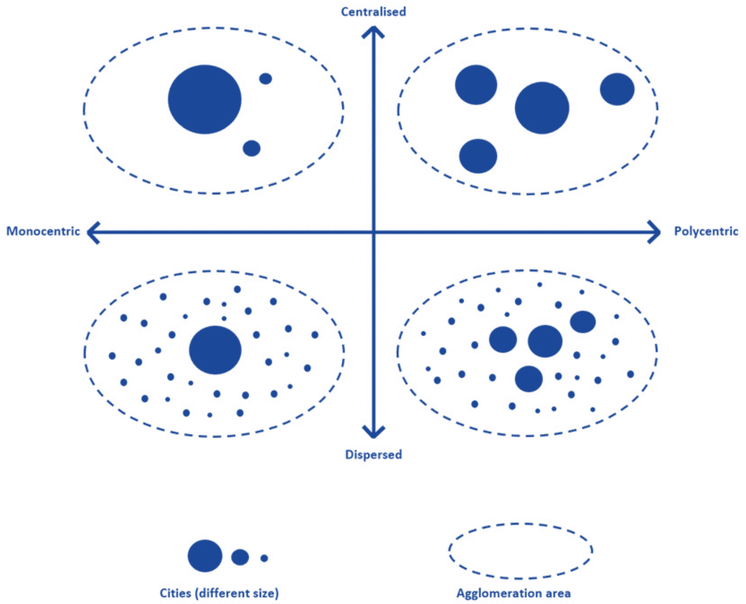
Figure 8. Two-dimensional model of urban areas in spatial terms – part 3



The presented situation occurs when there are many cities in a given area, but only one of them plays a significant socio-economic role. It is essential to emphasize the strong connection of the central city with satellite areas – these areas often fulfil certain functions within the structure of the central city, so the analysis of the discussed area should also encompass these smaller areas. In this case, there is also a situation where the classification of areas based on the criterion of performed functions does not coincide with the administrative boundaries of individual urban (or rural) areas.

The last type of agglomeration discussed within the proposed model is the polycentric-dispersed agglomeration. Figure 9 illustrates the position of the discussed agglomeration in the proposed two-dimensional model.

Figure 9. Two-dimensional model of urban areas in spatial terms – part 4 (final)



The presented situation occurs when there are several cities in a given area, each playing a significant socio-economic role, making it impossible to distinguish one dominant city. Additionally, within the metropolitan system, many other cities or villages operate, which are structurally and functionally connected with the discussed dominant areas. Such a situation makes the potential analysis of these areas very challenging since making a clear division of cities based on performed functions will be practically impossible. Moreover, in such a system, the process of blurring administrative boundaries is very noticeable – while they operate within the legal framework, they do not reflect the functional relationships between individual entities.

This form of a two-dimensional model of urban areas in spatial terms allows for the precise categorization of a given agglomeration and the adjustment of analytical methods to the characteristic features of a specific area. It should be noted, that the main advantage of this model – its simplicity – also represents a significant drawback. A two-dimensional approach to urban centers will overlook other important characteristics of urbanized areas, such as building height, population density, the layout of the transportation network (streets, sidewalks, bike paths, or public transport lines), the concentration of functions performed by the city within the metropolitan system, and so on. Additional differentiation could also be introduced at the intra-city level (e.g., at the level of individual districts). However, it must be emphasized that an overly complex model could introduce chaos into the research structure in a given area, potentially leading to complete decision paralysis. The choice of an analytical model for an urban area should always be tailored to the purpose of the analysis. A good approach might also be to select several alternative models and compare the results obtained from them.

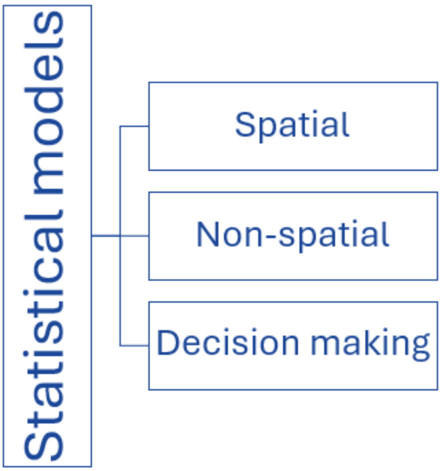
It is also worth noting that the European macro-region (especially its western and central part) differs from other macro-regions in the world by the presence of many medium and large-sized cities and towns (Dijkstra, Garcilazo, and McCann, 2013). In order to fully benefit from metropolitanization and compete with unified urban areas, managing polycentric regions requires solid strategic planning (Boussauw et al., 2018). This situation leads European planners to mainly focus on a polycentric planning approach (Zhang, Sun and Li, 2017). However, the polycentric and dispersed nature of such urban areas causes some problems during quantitative analysis of these areas. This is due to the significant diversity of individual urban nodes, which may result in the proposed analytical model being only applicable to a certain part of the area. The situation is very similar when suggesting optimization actions – factors that will work in a certain area (e.g., in the core of the agglomeration) may not be effective in peripheral cities. Therefore, it is necessary to take actions related to the delimitation of a given area, which will allow for the identification of relatively homogeneous spatial structures. It should also be noted that all analyses of the area should spatially encompass only those delimited areas. The two-dimensional model of urban areas presented in the subchapter can thus serve as a foundation for the delimitation process. However, it should be emphasized again that the factors determining the delimitation of a given area should always be individually tailored to the area being analyzed, to best reflect its characteristics. In some cases, the two-dimensional approach proposed in this study may prove insufficient or entirely inappropriate (e.g., in extreme cases such as megacities). To summarize, the choice of the number and types of dimensions in the model that will serve as the foundation for the delimitation process will always be a unique decision. However, there are likely factors that will be significant in every case – identifying these factors is an interesting direction for future research.

1.4. Statistical models in urban planning

Statistical models appear to be highly effective tools for enhancing the efficiency of urban policy implementation. They can provide cost-effective forecasts and policy analysis for metropolitan areas (Rubin, 1981). However, it is important to note that the application of statistical modelling in urban policy may be significantly constrained by the choice of appropriate tools among numerous alternatives and potential issues related to endogeneity. Despite these challenges, statistical models in urban planning continue to evolve, offering increasingly detailed and dynamic solutions for understanding and predicting urban development patterns (Picard and Antoniou, 2014). It is worth noting, however, that statistical models are primarily used by researchers in their studies and are published in peer-reviewed journals and scientific monographs. They are relatively infrequently employed in the strategic documents of urban centers. This situation is disadvantageous, as statistical models are valuable tools for forecasting the impact of implemented policies on a given region (Echenique, 2004).

Statistical models can vary in nature, and their taxonomic classification can depend on various distinguishing features, resulting in different outcomes each time. For the purposes of this study, a specific classification of statistical models used in urban research has been proposed, as illustrated in Figure 10.

Figure 10. Sample taxonomy of statistical models in urban planning



The proposed classification divides econometric models into three main groups. The first group includes methods based on spatial approaches, often utilizing GIS software. The second group comprises other statistical models that employ advanced statistical techniques, but are not specifically focused on spatial aspects. The final group analyzed in this subsection consists of models that facilitate decision-making. This classification largely covers the types of econometric models used in urban planning.

One of the most commonly used groups of statistical models are those related to spatial analysis. Spatial regression is frequently employed in scientific literature (Weng et al., 2019; Graells-Garrido et al., 2021; Aristizábal, Sarache, and Escobar, 2023; Hardi and Murad, 2023; Knap et al., 2023). Spatial regression is an statistical method used in the analysis of geographic data that accounts for spatial dependencies between observations. Traditional regression models assume that observations are independent, but in reality, spatial data often exhibit spatial autocorrelation, meaning that the values of the dependent variable are more similar to each other in geographically proximate locations. Spatial regression accounts for this dependency, allowing for more accurate estimation of the effects of independent variables on the dependent variable. Spatial regression models, such as the Spatial Autoregressive Model (SAR) and the Spatial Error Model (SEM), incorporate the neighborhood structure through a spatial weight matrix, enabling a better capture of complex spatial relationships in studies of geographic phenomena such as property prices, resource distribution, or urban development.

Another frequently used spatial model is the Two-Step Floating Catchment Area (2SFCA) (Liu et al., 2022; Knap et al., 2023; Zhang et al., 2023; Liu et al., 2024). It is designed to assess the spatial availability of services, such as healthcare facilities, by integrating both the supply (e.g., service capacity) and demand (e.g., population needs) within a defined catchment area. The 2SFCA method operates in two stages: first, it calculates the supply-to-demand ratio at each service location by considering the population within its catchment area; second, it aggregates these ratios for each population location based on the service providers within the population's catchment area. This approach allows for the estimation of service accessibility by accounting for the spatial distribution and interaction between service locations and population groups, offering a more nuanced understanding of accessibility disparities across different regions.

Within the group of spatial models, multi-index models frequently appear, with a primary focus on specific themes. An example of such models includes those related to pedestrian movement:

- Walk Score (Weng et al., 2019; Abdelfattah, Deponte, and Fossa, 2022; Yang et al., 2023) – is a measure developed to assess how walkable a particular area is by considering its closeness to key amenities and services. It calculates the ease with which residents can reach daily necessities like supermarkets, schools, parks, and public transit without relying on a car. Locations with higher Walk Scores are typically more accessible by foot and conveniently located near a variety of essential facilities, thus encouraging walking as a feasible and convenient form of transportation.

- The Walkability Big Building Index (Balletto et al., 2021, 2022) – serves as a metric for evaluating how conducive urban areas are to pedestrian activity, especially in regions dominated by large structures. WBBI considers factors like the presence of sidewalks, availability of pedestrian crossings, access to services and infrastructure, and the relationship between buildings and public spaces to gauge the ease and safety of walking in a specific location. This index is composed of several sub-indices, including the Porosity Index, Crossing Index and Attractiveness Index, which collectively contribute to its overall assessment.
- Walkability Index (Gorrini et al., 2023) – is a metric that determines how suitable an area is for walking, taking into account factors like the closeness of amenities, the quality of pedestrian pathways, and general safety. It measures the ease with which people can reach important services, such as stores, schools, parks, and transit options, without needing to depend on a car.
- The Walkability Evaluation System (Jeong et al., 2023) – provide a comprehensive measure of an area's walkability. The validity of this model is established through geo-weighted regression analysis, which confirms local coefficient variations. Additionally, environmental advantages are identified by linking improvements in this model to shifts in public transportation usage.

Another example of spatial models that focus on a specific research area is the Proximity Index (Guzman et al., 2021; Balletto et al., 2023; Jaroszewicz et al., 2023). The Proximity Index is a metric used to evaluate how near and accessible essential resources and services are to a specific location. It calculates the distance to important amenities like stores, schools, medical centers, parks, and public transit stops, providing insight into the ease with which these facilities can be accessed.

Gravity-based accessibility metrics are another commonly used group of spatial models (Borghetti et al., 2021a, 2021b; Graells-Garrido et al., 2021). They are a type of spatial analysis method designed to assess how readily individuals can access different opportunities or services by evaluating both their proximity and the appeal of those services. Modelled after gravity concepts in physics, these metrics determine accessibility by factoring in the distance to a service and its significance or scale. Typically, these metrics involve computing a weighted aggregate of opportunities, where the influence of each opportunity diminishes with distance and increases with the service's magnitude or importance.

Another example includes models based on Kernel Density Analysis (Li, Zheng, and Zhang, 2019). It is a statistical technique used to estimate the density of a variable across a geographic area or a set of data points. It is commonly applied in spatial analysis to visualize the distribution and concentration of events, phenomena, or attributes within a given space. The method generates a smooth, continuous surface that represents the likelihood of occurrences or values at different locations.

The final spatial models identified for the purposes of this monograph are The Space Syntax Method (Körmeçli, 2023; Murgante, Patimisco, and Annunziata, 2024; Murgante, Valluzzi, and Annunziata, 2024). It is set of analytical tools used to understand and evaluate the spatial configuration of environments, particularly urban spaces and buildings. This method focuses on how spatial arrangements influence human movement, behavior, and social interaction. The core idea of Space Syntax is that the layout of spaces affects their usage and accessibility. By analyzing spatial configurations, such as streets, rooms, or building layouts, the method reveals patterns of connectivity and accessibility. Space Syntax utilizes tools such as axial maps, which represent the longest lines of sight and movement within a space, and visibility graphs, which analyze the visual connections between different areas.

It should be noted that the examples of spatial models presented above do not constitute a comprehensive catalogue. For the purposes of this study, only a few of the many available tools were selected, focusing on those that frequently appear in urban planning literature.

Another broad category of models includes those that apply various statistical methods not directly related to spatial analysis. This group of models is also frequently encountered in scientific practice. The simplest types of these models are basic statistics, such as mode share (Gerten and Fina, 2022; Poorthuis and Zook, 2023) or facility-to-population ratio (Wu and Divigalpitiya, 2023). However, due to their simplicity, these models should be considered more as complementary tools rather than standalone solutions. Utilizing such statistics is also an effective way to provide background context for the analyzed problem.

Among the frequently encountered non-spatial methods are those related to variance analysis (Bartzokas-Tsiompras and Bakogiannis, 2023; Urrutia-Mosquera, Flórez-Calderón, and Paredes, 2023). They are a statistical approach employed to evaluate whether there are significant differences in mean values across two or more groups. By analyzing the variance within and between groups it determines if the differences in means exceed what would be expected due to random fluctuations. This technique allows for the assessment of the impact of one or more independent variables on a dependent variable, including exploring potential interactions among these variables.

Another example of non-spatial models is the one utilizing the p-Median Problem (Song et al., 2022). It involves determining the optimal locations for a fixed number of facilities (p) to minimize the total distance or cost of serving a set of demand points, while considering capacity constraints at each facility.

Next example of non-spatial models includes those based on Gini and Pseudo-Gini coefficients (Vale and Lopes, 2023). They are statistical measures used to assess the inequality of a distribution. While the traditional Gini coefficient measures income or wealth inequality by comparing the cumulative distribution of a population's wealth to a perfectly equal distribution, the Pseudo-Gini coefficient adapts this concept for different applications or data types.

Within this group, multi-index models can also be distinguished. An example is the 15MinCityIndexes (Badii et al., 2021), which encompasses 13 different functions such as: education, health, food, economy/sustainability, sport, entertainment, slow mobility, fast mobility, environment, safety, housing viability, cultural and cult services, and government services. Another example is the Climate Change and Conflict Model Index (Bertoni et al., 2021). It is a tool used to evaluate the likelihood of conflicts arising from climate change. This index combines data on climate, environmental conditions, economic factors, and social dynamics to forecast and analyze potential conflicts resulting from climate impacts on natural resources, population displacement, and other variables.

Just as with spatial models, it is not possible to describe all the potential tools used in scientific practice within the category of non-spatial models. The examples provided above represent only a small fraction of the available models but effectively illustrate the key characteristics of this group.

The final group of models discussed in this subsection will be those primarily aimed at supporting decision-making processes. These tools are predominantly used to address complex problems, which often involve multiple categories of variables.

The first examples of models in this category are those based on the Preference Ranking Organization Method for Enrichment Evaluations (Bartzokas--Tsiompras and Bakogiannis, 2022, 2023). This method for multi-criteria decision-making is employed to evaluate and choose the optimal options from a pool of alternatives based on multiple factors. It facilitates a thorough ranking process by taking into account the decision-maker's preferences and assessing the relative advantages of each option through pairwise comparisons across different criteria. The outcome is expressed as preference flows, both positive and negative, which demonstrate the extent to which one option is favored over another. The net difference between these flows results in a final ranking, allowing for a clear and comprehensive ordering of all the alternatives.

Another example of decision-making models is the Analytic Hierarchy Process (Ogrodnik, 2019; Zhang et al., 2023). This decision-making method is designed to address complex problems by organizing them into a hierarchical structure of criteria and alternatives. It decomposing the problem into smaller, more manageable components, assessing these elements through pairwise comparisons, and then integrating the results to identify the most advantageous choice. By prioritizing and assigning weights to various factors based on their relative significance, this approach provides a systematic and quantitative framework for making decisions that involve multiple criteria.

Another example within this group includes models based on the estimation of a multinomial logit (Urrutia-Mosquera, Flórez-Calderón, and Paredes, 2023). This model examines how individuals select from multiple alternatives by estimating the likelihood of each choice based on a range of factors. Commonly employed in discrete choice analysis, the Multinomial Logit model helps predict and interpret decision-making behavior across various contexts, such as selecting a mode of transport or a preferred product. It operates under the assumption that choice probabilities adhere to a logistic distribution, with each option's utility shaped by both measurable attributes and unobserved influences. By estimating this model, researchers can assess the effects of different variables on the probabilities of choices, providing valuable insights into the decision-making process.

The final example in this group consists of Weighted Linear Combination models (Abdullahi et al., 2015). This approach is a multi-criteria decision--making tool used to assess and prioritize options by considering multiple criteria. In this technique, each criterion is given a specific weight to represent its importance, and alternatives are evaluated against these criteria. The resulting scores for each alternative are then multiplied by the corresponding weights and totaled to generate a composite score for each option. This overall score allows for a direct comparison of alternatives, aiding in the selection of the most favorable choice based on the weighted evaluation of all factors considered.

The models presented in the subsection constitute effective tools that can significantly enhance the efficiency of urban policy implementation. However, their application in practice is relatively rare – these models appear much more frequently in academic research than in strategic documents of urban centers. Furthermore, their utilization may be considerably constrained by the need to select an appropriate type of model that best aligns with the intended objectives. Despite these challenges, statistical models continue to evolve, offering increasingly detailed and effective solutions. They can therefore play a crucial role in urban planning. It is essential to highlight their versatility and potential to provide valuable insights that support decision-making in the context of sustainable urban development. While these models are not always widely used in the strategic documents of cities, they represent a valuable tool for analyzing and forecasting the outcomes of implemented policies.

2. Delimitation as a tool for transport policy

2.1. Suburbanization and its significance in urban centers' transportation policy

Undeniably, the significance of urban regions is rapidly increasing along--side the progressing processes of urbanization and suburbanization. However, the phenomenon of urban sprawl gains particular importance, prompting numerous analyses of urban areas in this context. For the purposes of this monograph, a synthetic literature review was conducted to outline the main research trends associated with the suburbanization process, which significantly impacts spatial delimitation. The literature review was based on data indexed in the Scopus database.

It should be noted that the main objective of this monograph is not to conduct a comprehensive literature review related to the topic of suburbanization, but rather to identify the main areas of research. This process will facilitate later identification of the significance of delimitation in urban transportation policy. However, it is worth noting that conducting a full literature review on suburbanization currently represents one of the research gaps in the fields of economics and urban planning. Figure 10 illustrates the process of source selection.

The presented method of source selection allowed for obtaining the latest documents directly related to suburbanization processes and implemented transportation policies. Figure 11 depicts the number of indexed documents in respective years.

Figure 11. Source selection for a synthetic literature review on suburbanization

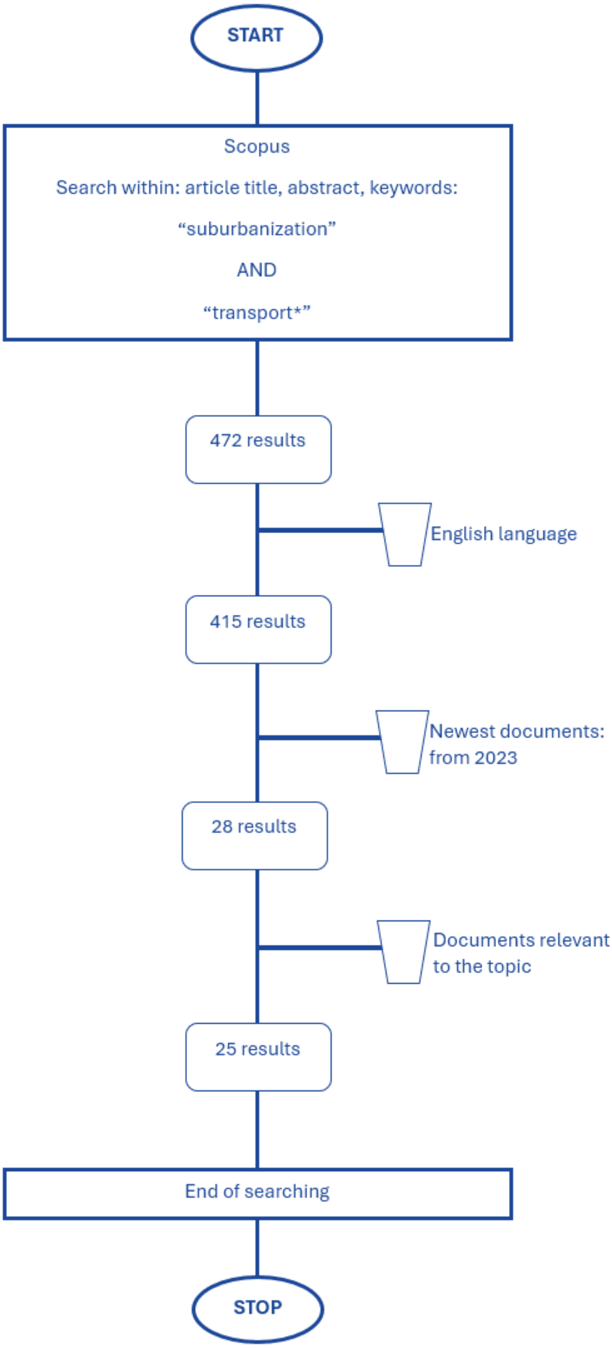
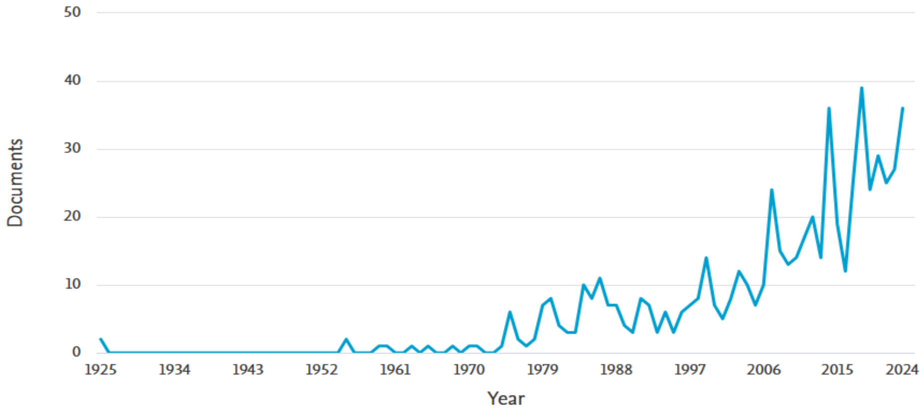


Figure 12. The increasing research interest in the topic of suburbanization in the context of transportation



Source: Scopus (2024).

There has been a dynamic increase in research interest in the topic of sub--urbanization since the second half of the 1970s. This process intensified at the beginning of the new millennium, and a continuing upward trend is still evident (with the exception of the year 2016, which saw a significant decline in interest in this topic). Table 8 presents the identified research areas discussed in scientific literature related to the suburbanization process.

Table 8. Suburbanization in contemporary scientific research – a synthetic literature review

Addressed Issues	Analysis area	Source
1	*2*	*3*
The article explores the spatial dynamics and underlying mechanisms influencing urban logistics space and activities in the Wuhan metropolitan area from 2010 to 2018. Utilizing a multinomial logit (MNL) cellular automata (CA) model, it investigates the evolution of logistics land use and facility locations. The study compares the driving forces behind the spatial changes in both land use and facilities. Key points: • **suburbanization trend** – both logistics land use and facilities demonstrate a suburbanization trend, with a non-equilibrium spread characterized by a "center-periphery" pattern. Development is higher in the west and lower in the east of the Yangtze River. Small-sized facilities exhibit a self-organizing spatial pattern aligned with residents' demand; • **spatial mismatch** – the co-location indices (CLI) between logistics land use and facilities exhibit a consistent decline over the studied period. This indicates an increasing spatial mismatch between planned land use and actual facility allocation, leading to an imbalance in logistics resource allocation and inefficiencies in logistics activities; • **concentration patterns** – large logistics facilities and land use concentrate in urban fringe areas, influenced by land prices, while small-sized facilities tend to locate in central residential areas	Wuhan metropolitan area	Zhao et al. (2024)

Table 8 cont.

1	2	3
The article delves into the complex relationship between housing and transportation costs, particularly focusing on low and low-moderate income (LMI) households in Contra Costa County, San Francisco Bay Area. Drawing on qualitative data from surveys and interviews conducted in English and Spanish. Key points: • **housing burden** – LMI households face significant housing cost burdens, prompting many to choose suburban living for various reasons such as rising rents in urban cores and a desire for homeownership and safer environments for children; however, despite moving to suburbs for lower housing costs, LMI residents still experience housing instability due to rising rents; • **transportation cost challenges** – transportation costs in suburbs are higher due to longer commutes and reliance on personal vehicles; car ownership is essential, especially for households with children, but LMI families often struggle with maintenance issues or making car payments, leading to reliance on social networks or public transit; however, existing public transit services in suburbs are inadequate, with long wait times and limited coverage, leaving LMI households vulnerable and sometimes resorting to forgoing trips altogether	San Francisco Bay Area	Pan, Deakin, and Shaheen (2023)
The article addresses the issue of healthcare accessibility in Ohio, particularly focusing on the spatial disparities in access to healthcare services by public transportation in the state's six largest cities. Key points: • **spatial disparities** – vulnerable populations in Ohio's largest cities, except Cleveland, experience lower accessibility to hospitals via public transportation; this highlights a lack of vertical equity and indicates that vulnerable census tracts have the lowest levels of accessibility; • **equity challenges** – cities such as Columbus, Cincinnati, Toledo, Akron, and Dayton demonstrate deficiencies in vertical equity and average accessibility; this suggests a need for targeted interventions to address healthcare accessibility disparities among vulnerable groups; • **suburbanization of poverty** – the study underscores the phenomenon of suburbanization of poverty in Ohio's large cities; it emphasizes the necessity of ensuring adequate public transportation infrastructure to facilitate access to hospitals located on the periphery	Six largest cities of Ohio	Alam, Tabassum and Tokey (2023)
The article discusses the potential of shared mobility services, autonomous vehicles (AVs), and electric vehicles (EVs) as solutions to various urban challenges, including suburbanization, greenhouse gas emissions, and an aging population. Specifically, it introduces a concept called the shared autonomous electric vehicle (SAEV) system, aimed at providing convenient and environmentally friendly mobility services for commuters and aging residents in suburban areas of Japan. Key points: • **introduction of SAEV System** – the SAEV system utilizes idle park-and-ride private vehicles to offer shared mobility services based on AVs; it targets two primary user groups: inbound commuters and elderly/disabled residents in suburban regions;	Japan	Zhou, Sato, and Yamamoto (2023)

Table 8 cont.

1	*2*	*3*
• **performance evaluation** – the study investigates the performance of the proposed SAEV system using agent-based simulation; results indicate that while non-EV scenarios offer better service levels due to reduced waiting times, EV scenarios (which require charging) can still provide acceptable mobility services; • **optimal fleet size and ride sharing** – maintaining a fleet size of 40 trips per vehicle or less helps keep waiting times within 5 minutes; additionally, ride-sharing can significantly reduce waiting times, especially during periods of high demand; • **emission reduction potential** – the implementation of the SAEV system is projected to lead to an average emission reduction of over 40% compared to users' previous travel modes, indicating its potential for environmental benefits		
The article addresses the issue of urban traffic-related air pollution (TRAP) exposure during daily commutes, particularly focusing on the often overlooked "first and last mile" segments where commuters tend to use active transport modes. Key points: • **current assessment methods** – previous studies mainly assess TRAP exposure based on fastest and lowest-dose routes, neglecting the "first and last mile" segments; • **study methodology** – this study utilizes a space syntax model to simulate behavior-based commuting routes in Changsha, China, and combines it with a land-use regression (LUR) model to assess TRAP exposure; • **comparison of exposure** – the study compares air pollution exposure doses of commuters across behavior-based routes with those across fastest and lowest-dose routes; results show that a significant portion of behavior-based routes does not overlap with traditional routes, leading to higher accumulated exposure doses; • **underestimation of exposure** – the findings suggest an underestimation of TRAP exposure and highlight the potential benefits of choosing cleaner routes, particularly for commuters using active transport modes; • **spatial disparities** – commuters residing in sub-central areas face relatively larger commuting time costs and higher accumulated exposure doses, indicating the need to address environmental issues in these areas; • **importance of behavioral science methods** – the study underscores the value of behavioral science methods, such as space syntax, in air pollution exposure research; these methods can inform targeted interventions to mitigate environmental problems associated with commuting	Big data analysis	Li et al. (2023)
The article explores the role of ride-hailing services in newly developed suburban areas, particularly focusing on suburban new towns in Wuhan, China. Key points: • **ride hailing usage in suburban areas** – while ride hailing services are popular worldwide, their use and value in suburban areas; residents of suburban new towns are more inclined to use ride-hailing	Wuhan	Zou et al. (2023)

Table 8 cont.

1	*2*	*3*
services compared to urban areas; ride hailing complements public transportation in suburban areas, with variations based on regional and demographic attributes; for instance, it has a greater complementary effect in high-tech industrial areas and among women and young people, especially newly developed ones, are not well understood; the study analyses usage data from 10 ride-hailing apps to examine their role in suburban new towns; • **spatial analysis** – spatial autocorrelation and geographic weighted regression (GWR) techniques are employed to investigate the relationship between ride-hailing usage and suburban characteristics; • **implications** – the study highlights the potential of integrating ride-hailing services with traditional public transportation to enhance multi-modal transportation options in newly developed suburban areas; it suggests that this integration can help address transportation challenges in areas where development is still ongoing		
The article examines the impact of rapid demographic changes, specifically aging and depopulation, on transportation behaviors and the development of public transport systems. Key points: • **demographic trends** – many countries, both developed and developing, are experiencing significant demographic shifts, including aging populations and depopulation; these changes are expected to influence various aspects of the economy, including transportation behaviors; depopulation emerges as the primary demographic force influencing the transport system in the region studied, with a projected decrease in the total number of journeys by 30% by 2050; aging has a limited impact, expected to decrease the total number of journeys by less than 4%; there is a weak impact of aging on the structure of journeys by modes of transport; • **study approach** – the study combines estimates of age-related determinants of transport behavior with demographic projections over the next 30 years to quantify the effect of ongoing demographic processes on the transport system	Silesia Province	Urbanek, Acedański, and Krawczyk (2023)
The article focuses on analyzing the accessibility impacts of logistics suburbanization, emphasizing its importance for logistics land-use planning. Key points: • **conceptualization of logistics service accessibility** – the paper conceptualizes logistics service accessibility from two perspectives: urban logistics infrastructure networks (ULINs) and logistics land use stakeholders within the network; analysis using real data from Beijing indicates significant variation in ULIN service accessibility and logistics firms' service accessibility based on different logistics facility locations; careful consideration of ULINs' service accessibility is necessary when choosing logistics facility locations to mitigate uneven service availability for logistics land use stakeholders;	Beijing	Wang et al. (2023)

Table 8 cont.

<table>
<tr><th>1</th><th>2</th><th>3</th></tr>
<tr><td>measurement approach – a quantitative approach is proposed to measure the service accessibility of ULINs and logistics land use stakeholders; this involves solving a bi-objective binary integer program to assess ULIN service accessibility and proposing cumulative-opportunity freight accessibility models for logistics land use stakeholders;
spatiotemporal impacts assessment – the method allows for the measurement of the spatiotemporal impacts of logistics suburbanization on ULIN service accessibility and the corresponding stakeholders;
implications – the study underscores the importance of freight accessibility in urban freight planning and provides effective quantitative evaluation approaches to support better practices in logistics land use and transport planning</td><td></td><td></td></tr>
<tr><td>The article addresses the anticipated impacts of autonomous vehicles (AVs) and connected-autonomous vehicles (CAVs) on transportation network performance and residential location decisions, particularly focusing on the Triangle Region in North Carolina.
Key points:
expected impact of AVs and CAVs – the high market penetration of AVs and CAVs is projected to influence transportation network performance, which is crucial for residential location decisions, especially for households commuting by personal vehicles;
study objective – the study aims to examine and compare the impacts of privately owned AVs and CAVs on residential location patterns, commute characteristics, and the spatial distribution of households within the Triangle Region;
methodology – a mixed multinomial logit model is developed using recent household survey data to capture household preferences; the Triangle Regional Model, a travel demand model for the region, is utilized to predict the network-level impacts of AV and CAV adoption; cluster analysis is conducted to explore how network performance changes vary with transportation demand and supply zone characteristics at both local and regional levels;
identified effects – extensive adoption of private CAVs is found to improve network conditions and encourage households to live farther from work, leading to an increase in suburban and rural households commuting by personal vehicles; conversely, a high market share of AVs is associated with deteriorated transportation network performance and an increase in urban households</td><td>Triangle Region in North Carolina</td><td>Hasnat, Bardaka, and Samandar (2023)</td></tr>
<tr><td>The article examines the phenomenon of retail decentralization in Sydney, Australia, as a case study illustrating broader trends during the country's postwar boom.
Key points:
historical context – during Australia's postwar boom, there was a significant shift in the form and function of retailing in Sydney, reflecting broader changes in society and the economy;</td><td>Sydney</td><td>Bailey(2023)</td></tr>
</table>

Table 8 cont.

1	*2*	*3*
• **factors driving decentralization** – several factors contributed to the process of retail decentralization, including suburban migration, the rise of car-dependent consumers, shifts in gender roles, the continued importance of public transport networks, planning policies favoring concentrated development, and the adoption of American retail formats; • **transformation of retail geographies** – as a result of these factors, the retail landscape in Sydney and other Australian capital cities underwent a transformation; retail structures shifted from highly centralized urban cores to decentralized clusters of retail outlets, featuring modern formats such as supermarkets and shopping centers; • **impact on Australian retailing** – the changes observed during the postwar boom came to define Australian retailing for the remainder of the century, shaping consumer behavior, urban development patterns, and the overall retail landscape		
The article examines the current stage of development and formation of agglomerations in Kazakhstan, which has been prioritized as a state policy. Key points: • **challenges in agglomeration development** – Kazakhstan's agglomerations face hurdles due to inherited economic structures and inadequate environmental conditions, hindering their growth; • **post-soviet era impact** – despite an increase in agglomerations' population share, administrative efforts for their formation are effective only with specific prerequisites and ongoing progress; • **disparities among agglomerations** – notably, Almaty emerges as a developed agglomeration, while others, like Shymkent and Astana, exhibit varying degrees of development, influenced by factors like transport connectivity and economic tertiarization	Kazakhstan's agglomerations	Abilov, Makhrova, and Safronov (2023)
The article examines the impact of intra-urban migration on transit accessibility for low-income residents in Toronto, Canada, amidst trends of inner-city neighborhood change, gentrification, and suburbanization of poverty. Key points: • **background** – low-income residents heavily rely on public transit, historically residing in centrally located neighborhoods with high transit accessibility; • **trends** – late 20th and early 21st-century trends show shifts in neighborhood demographics, raising concerns about low-income residents moving away from accessible transit services; • **research objective** – investigate changes in transit accessibility for low-income residents when moving within the region, comparing them to higher-income movers, and assessing changes over time; • **methodology** – historical transit accessibility data is linked to individual-level panel data from tax filers in Toronto from 1988 to 2018; descriptive statistics and regression models are employed to analyze changes in transit accessibility for over 2 million intra-urban movers; • **findings** – low-income residents experience reductions in transit accessibility when relocating within the region, indicating an increased risk of transport poverty; however, these reductions are not as significant as those experienced by higher-income movers; over time, the gap in transit accessibility changes between higher- and low-income movers is narrowing	North American cities	Allen et al. (2023)

Table 8 cont.

1	2	3
The paper examines the development of Portugal's motorway network from the early 1980s to 2011 and its impact on local population and employment growth. Key points: • **motorway development** – Portugal experienced significant growth in its motorway network, becoming the fourth highest in motorway density relative to population in the EU by 2019; motorways led to substantial increases in both population and employment in municipalities that received them; suburbanization was facilitated by motorways, with a stronger impact on population growth in suburban municipalities compared to urban areas; nonlinearity was observed in the influence of motorways on urban agglomeration dynamics, with their effect on population growth depending on the size of the local population in 1970; • **research objective** – investigate the relationship between motorway development and population and employment growth at the local level; • **addressing endogeneity** – the study addresses the potential endogeneity of motorway geography using instrumental variables based on historical maps of dirt roads from the late 18th century and main roads from a 1945 road plan	Portugal	Rocha (2023)
The paper discusses the impact of working from home (WFH) as a result of the COVID-19 pandemic on traffic congestion, public transport, and transport policy. Key points: • **unintended positive consequence** – WFH has emerged as an unintended positive consequence of the COVID-19 pandemic, potentially altering traffic congestion and public transport usage; • **policy lever** – WFH is seen as one of the most effective policy levers for managing transport network performance, offering potential solutions to congestion and crowding issues; • **data collection** – the study draws on survey data collected since March 2020 in Australia, focusing on the Greater Sydney Metropolitan Area (GSMA) and South-East Queensland (SEQ) regions; • **evidence presentation** – the paper presents evidence on the incidence of WFH from the height of restrictions to periods of relaxation and subsequent lockdowns up to December 2021; • **reception by employees and employers** – it examines how WFH has been received by both employees and employers, considering its implications for work productivity, lifestyle, and preferences for passenger modes; • **growing preference for WFH** – there is a growing preference, particularly within certain occupation classes, for WFH 1-2 days a week, with implications for transport network analysis and planning; • **impact on transport initiatives** – the study discusses the implications of WFH for transport initiatives, including the suburbanization of transport improvements, cost-effective service and infrastructure changes, and the evolving role of public transport	Greater Sydney Metropolitan Area and South-East Queensland	Hensher, Beck, and Balbontin (2023)

Table 8 cont.

1	*2*	*3*
The article addresses the importance of sustainable transportation development in modern Europe, particularly in cities, aiming to increase public transportation usage while minimizing social costs and negative environmental impacts. Key points: • **priority of sustainable transportation** – ensuring sustainable transportation development is a priority for countries, cities, and metropolitan areas in Europe; • **need for changes in public transport** – the transition of cities from industrial to service-based economies and suburbanization necessitates changes in public transport services; • **mismatch between supply and demand** – existing public transport services often do not align with passenger demand due to carriers' reluctance to change lines, stops, and schedules based on traditional passenger habits; • **importance of planning and analysis** – planning and improving public transportation systems require careful analysis to address the mismatch between supply and demand effectively; • **assessment of service quality** – the article employs the Customer Satisfaction Index (CSI) method to assess service quality, with a focus on reliability, using survey questionnaires as the main measurement tool	Metropolis GZM	Gaschi-Uciecha (2023)
The article addresses the problem of urbanization, CO2 emissions, and suburbanization, focusing on the trends and challenges associated with energy-related CO2 emissions. Key points: • **urbanization and rural-urban migration** – more than half of the world's population resides in urban areas due to the attractiveness of urban activities, leading to migrations from rural to urban areas; • **urban environmental degradation** – urban development contributes to environmental degradation, particularly through increasing CO2 emissions resulting from changes in land use and urban activities; • **urban sprawling** – the results indicate that urban expansion in Pathum Thani province exhibits characteristics of urban sprawl, with low to moderate density scattered throughout the area; • **impact on land use and lifestyle** – suburbanization influences land use changes and local lifestyle, contributing to CO2 emissions; • **factors contributing to CO2 emissions** – the study identifies several factors contributing to the increasing CO2 emissions, including building density, transportation networks, and the number of vehicle owners; • **need for mitigation strategies** – the findings underscore the importance of establishing mitigation strategies to address the adverse effects of urbanization and suburbanization, emphasizing the promotion of low-carbon initiatives and resource-efficient policies in peri-urban areas	Pathum Thani Province	Iamtrakul et al. (2023)

Table 8 cont.

<table>
<tr><th>1</th><th>2</th><th>3</th></tr>
<tr><td>The article addresses the potential conflict between private vehicle restriction policies implemented by local governments of large cities and current trends of metropolitan suburbanization.
Key elements include:
spatial reconfiguration of urban and metropolitan areas – the text reflects on the reasons behind the spatial reconfiguration of urban and metropolitan areas, including the growing share of the urban population residing in large and fragmented metropolitan peripheries;
consequences on daily mobility – changes in urban and metropolitan areas have consequences on daily mobility patterns, influencing transportation choices and behaviors;
design of mobility policies – European and local policies for transitioning to sustainable mobility are designed to address these changes, but there’s a hypothesis that they may conflict with current population and residential mobility trends;
region of Madrid – the hypothesis is tested using the region of Madrid as a case study, analyzing how population suburbanization trends have impacted daily mobility patterns, particularly in private vehicle usage despite policies promoting public transport. Results indicate that despite policies aimed at restricting private vehicle use and promoting public transport, suburbanization trends have led to an increase in private vehicle usage for daily mobility in the region of Madrid</td><td>region of Madrid</td><td>Gil-Alonso and López-Villanueva (2023)</td></tr>
<tr><td>The paper explores the security and safety implications of the polycentric function-spatial structure of cities during a pandemic. The hypothesis questions whether the fear of the epidemic will impact the planning of polycentric structures, leading to a reinforcement of local service concentrations and a resurgence of the commercial role of city streets.
Key points:
new outlook on urban security – the paper introduces a novel perspective on urban security, with a focus on the significance of local service polycentricism;
original analyses – the problem is investigated through original analyses of polycentricism, considering various levels of understanding the concept of the center and incorporating current theories and trends;
changes in perception of polycentricism – the study examines how the perception of polycentricism has evolved over time, highlighting differences in understanding and approach;
history of Cracow’s development – the author analyses factors influencing polycentricism using the history of Cracow’s development as an example. Factors such as political decisions, suburbanization, and transportation behavior patterns are explored</td><td>Cracow</td><td>Blazy and Ziobro (2023)</td></tr>
<tr><td>The article discusses the profound impact of the COVID-19 pandemic, particularly on the concept of working from home (WFH) and its acceptance in society. It outlines the evolution of WFH from being stigmatized to being widely recognized as a beneficial and potentially permanent way of work. The authors draw on research conducted since March 2020 to speculate on the significant changes expected in the land transport sector post-pandemic</td><td>Australia</td><td>Hensher, Beck, and Nelson (2023)</td></tr>
</table>

Table 8 cont.

1	2	3
Key points: • **speculation on future changes** – the article aims to anticipate the substantial changes in the land transport sector post-COVID-19, leveraging evidence gathered since the onset of the pandemic; • **structural changes** – the pandemic has triggered structural changes in society, including the growth of WFH and remote working, which are likely to have lasting effects on transportation patterns and infra-structure		
The article explores the phenomenon of urban sprawl and its relationship with suburban and regional urban growth in various spatio-temporal, socio-cultural, socio-economic, and global contexts. Key points: • **contextual analysis** – the article examines urban sprawl within different contexts, considering factors such as spatio-temporal dynamics, socio-cultural influences, socio-economic trends, and global perspectives; • **emic and etic approaches** – the analysis employs both traditional "Emic" (insiders centered) and "Etic" (cross-cultural, detached) approaches to understand the changing trends in cross-cultural suburbanization; • **synthesis of constructs** – the author correlates the two independent constructs of urban sprawl and suburban growth through an "emicetic" synthesis, integrating auto-ethnography, statistical analysis, and literature studies'; • **lessons learned** – through comparative analysis, the article reveals insights into the factors shaping urban growth in different contexts, including the influence of visionary urban planning, historical legacies, and cultural identities; • **urban policy responses** – the discussion extends to the strategies employed to address the challenges posed by urban sprawl and subur-ban growth, including urban consolidation, sustainable density man-agement, and the promotion of smart and sustainable infrastructure, particularly in transportation	Melbourne and Chandigarh	Thakur(2023)
The article investigates the phenomenon of gentrification induced by industrial development, focusing on an enclave-shaped industrial area in the Semarang Metropolitan Region (SMR). Key points: • **industrial development and suburban gentrification** – unplanned and rapid industrial development has stimulated suburbanization in the study area; following industrial development, residential and low-intensity commercial gentrification has occurred; gentrification processes in both industrial areas exhibit similarities, but areas near arterial roads show slightly higher degrees of gentrification; residents in these areas appear receptive to migrants, contrary to expectations of social segregation; • **social harmony** – despite concerns about social segregation, the study suggests that locals generally feel comfortable living alongside migrants, fostering social harmony;	Semarang Metropolitan Region	Buchori et al. (2023)

Table 8 cont.

1	*2*	*3*
• **policy implications** – the article proposes that local stakeholders can encourage and support social harmony between locals and migrants, potentially mitigating negative impacts associated with gentrification		
The COVID-19 pandemic caused significant shifts in the local economic landscapes of many U.S. cities, with uncertain long-term implications. Key points: • **business closures** – traditional urban centers and transit-concentrated areas experienced disproportionately high rates of business closures, indicating potential commercial suburbanization; middle-class and working-class Hispanic neighborhoods were particularly affected by business closures; correlation analysis and spatial regression models revealed a positive association between COVID-19 cases and business closures at both zip code and individual business levels; • **urban externalities** – while automobile accessibility and agglomeration effects are expected to remain significant post-pandemic, the benefits of proximity to public transport may diminish; • **trends** – potential increase in automobile-reliant employment subcenters and exacerbation of intraurban inequality and urban sprawl across U.S. cities	Miami-Dade County	Li and Stoler (2023)
The study investigates the challenge of retrofitting multilane arterial roadways in post-WWII suburbs to promote transit-oriented development. Key points: • **challenges of retrofitting multilane arterial roadways in suburbs** – multilane arterial roadways in post-WWII suburbs pose challenges to creating transit-oriented regions; despite the importance of retrofitting suburbs, research on the transformation potential of arterial roadways has been lacking; analysis of four suburban corridors in Toronto revealed declining walkability with the full implementation of modernist planning ideas, followed by an increase influenced by new urbanist ideas in the 1990s; however, the retrofit potential of all studied corridors declined over time, with development patterns becoming more static; • **takeaway for practice** – arterial roadway corridors offer potential for creating transit-oriented, walkable urban areas near automobile-dependent suburbs and should be a primary focus for retrofitting efforts; the study introduces a set of metrics using readily available data for evaluating retrofit potential, enabling comparison across corridors; local governments should routinely study and evaluate the potential for retrofit and intensification of all such corridors within their jurisdiction; planners should develop flexible approaches to managing corridor development to adapt to future economic, transportation, and climate changes and vulnerabilities	Toronto	Hess, Piper, and Sorensen (2023)
The research examines the challenges faced by aging populations in suburban environments. Key points: • **problematic aging environments** – the global population is aging rapidly, but local environments often lack support for older adults; Australia, known for its suburban landscape and significant baby boomer generation, exemplifies this disconnect;	Greater Melbourne	Hartt, DeVerteuil, and Potts (2023)

Table 8 cont.

1	2	3
• **challenges in addressing aging in Suburban environments** – neighborhoods lacking built environment support also lack social infrastructure; spatial disparities are most evident among older adults aged 85 years and older; analysis of policymaker interviews reveals a significant gap between challenges of suburban aging and government responses; • **implications for practice** – age-friendly planning should extend beyond basic aspects like communication and social participation; suburban areas require increased investment in transportation, housing, and outdoor spaces to support older adults; walkable suburban neighborhoods with accessible social infrastructure are crucial for promoting community connections and physical activity among older adults		

Source: Elaboration with the use of the LLM, based on the provided sources.

The majority of the presented studies focus on the microscale of the discussed issue. However, there are few publications addressing the impact of suburbanization on shaping transportation policy. Furthermore, in practically none of the analyzed documents were crucial issues related to the influence of delimitation on city evaluation indicators evaluated (thus affecting the fitting of potential econometric models as well).

In the subsection, a synthetic review of the literature on suburbanization is presented, identifying key research areas in this field. It is observed that suburbanization impacts various phenomena, such as access to logistical services, challenges related to housing and transportation costs for low-income families or access to healthcare. The studies also address issues related to urban mobility and its effects on transportation behaviors and demographic changes. Additionally, the research highlights the particular attention given to the phenomenon of urban sprawl and emphasizes the need for sustainable transport development to mitigate the negative social and environmental consequences of suburbanization.

2.2. The significance of delimitation in transport policy

The main objective of this monograph is to determine the impact of spatial delimitation on the adequacy of econometric models. Therefore, it is necessary to conduct a synthetic review of the literature on delimitation and its influence on the transport policy of a given area. The literature review was conducted using the Scopus database. The source selection process is presented in Figure 13.

Figure 13. Source selection for a synthetic literature review on delimitation in transport policy

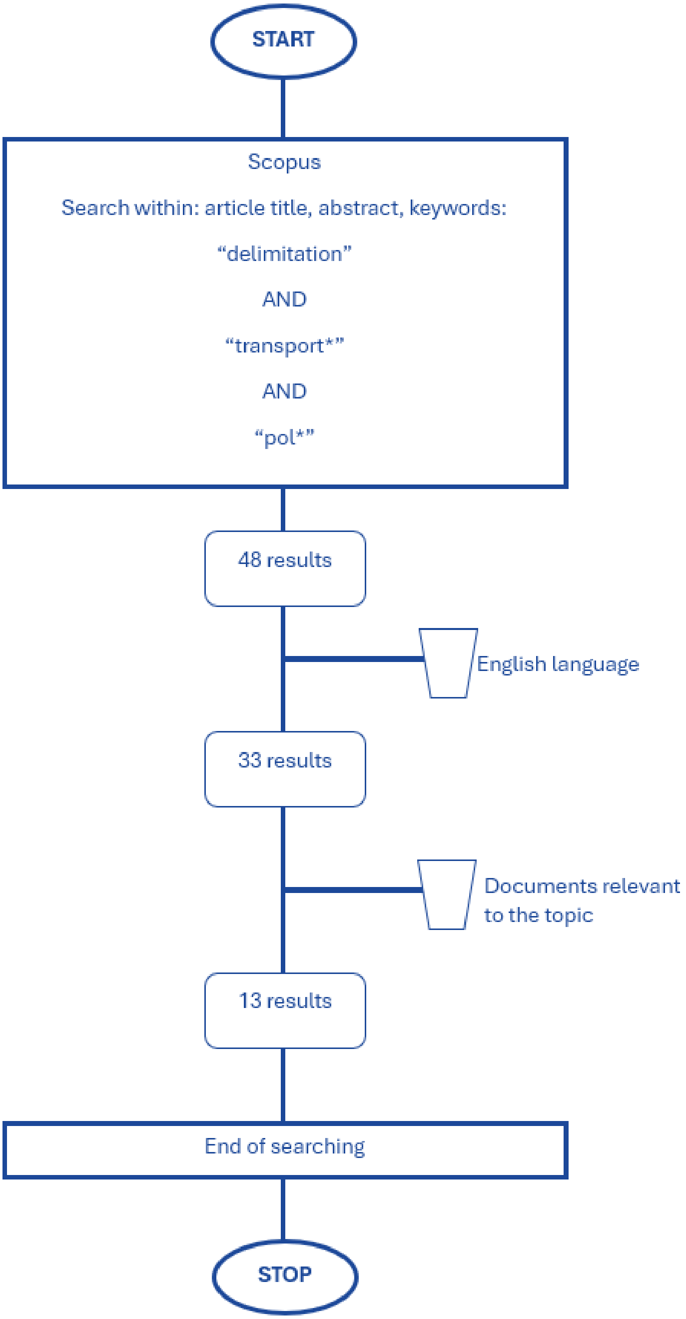


Table 9 presents the identified research areas discussed in scientific literature related to the delimitation in transport policy.

Table 9. Delimitation in transport policy in contemporary scientific research – a synthetic literature review

Addressed issues	Analysis area	Source
1	*2*	*3*
The article examines rural urbanization within China's rapid urbanization, emphasizing its significant impact on rural transformation and sustainable development, with a focus on spatial patterns and socioeconomic activities. Key points: • **urbanized rural area definition** – territories with larger population size, economic output, and built-up land area compared to other rural and urban areas are considered urbanized rural areas; • **influence factors on development** – spatial clustering, proximity to well-developed urban centers, and transportation accessibility were identified as key factors influencing the development of urbanized rural areas; • **representative socioeconomic activities** – urbanized rural areas exhibit rudimentary urban characteristics in terms of socioeconomic activities. Four representative socioeconomic activities in urbanized rural areas include an urban-like housing model, diverse non-agricultural activities, transportation improvements, and sufficient health services	Fujian Province	Guo et al. (2022)
The article explores the relationship between unfavorable access to public transport services, considered as a service of general interest, and the social exclusion of specific populations, particularly the elderly, poor, and disabled. Key points: • **transport-related social exclusion** – the article highlights the correlation between unfavorable access to public transport services and social exclusion, especially affecting the elderly, poor, and disabled populations; • **transport-disadvantaged areas** – the article addresses the issue of "transport-disadvantaged areas" linked to the spatial organization of society and the transport policies of different administrative levels; • **challenges in rural areas** – rural areas are identified as facing challenges in terms of accessibility to employment opportunities, healthcare, education, and cultural facilities in the regional center. The primary objective is to contribute to understanding the extent and geographical distribution of transport-disadvantaged areas in the specified region by identifying rural municipalities and areas where inhabitants face marginalization or exclusion from public transport services to/from the regional center; • **concept of "daily accessibility"** – the study employs the concept of "daily accessibility" as a crucial criterion for identifying negatively perceived "public transport-disadvantaged areas," focusing on territories with long distances and travel time to the regional center or insufficient organization of public transport	Banská Bystrica Region	Székely and Novotný (2022)

Table 9 cont.

<table>
<tr><th>1</th><th>2</th><th>3</th></tr>
<tr><td>The article aims to characterize remote rural Brazilian municipalities based on their socio-spatial dynamics, proposing a typology of six clusters and discussing the implications for health policies. Using territory usage as the category of analysis, the study compares clusters with socioeconomic data and distances to metropolises, regional capitals, and subregional centers.

Key points:
cluster differences – variability observed in cluster characteristics, such as population size, area, and distance from urban centers, highlighting different socio-spatial realities;
policy implications – customized health policies are essential due to variations in socio-spatial characteristics and economic logic among remote rural clusters; building health regions and offering specialized regional services are more effective in remote rural municipalities closer to urban centers, requiring alignment with health transportation policies</td><td>Brazilian rural municipalities</td><td>Bousquat et al. (2022)</td></tr>
<tr><td>The article explores the elusive nature of regional transport planning, shaped by changing institutional structures and political discourses, focusing on its essence and development in developed countries. It delves into the regional vision of transport planning, historical origins of regional problems, and the role of transport in regional policy. Key themes in regional transport planning involve delimitation, integrated planning, techniques and goals, and institutional reform, with evolving goals incorporating multiple-criteria objectives, emphasizing the importance of a holistic and inclusive approach in implementation.

Key points:
elusiveness of regional transport planning – regional transport planning is challenging due to changing institutional structures and political discourses. Transport planning goals now include multiple-criteria objectives, addressing equity and inequality issues;
four key themes in implementation:
delimitation – clearly defining the scope and boundaries of the region,
integrated transport planning – coordinating transportation plans with other aspects of regional development,
planning techniques and goals – utilizing effective planning methods and setting clear objectives,
institutional reform and governance: Implementing changes in institutional structures and governance for improved planning;
holistic and inclusive approach – emphasizes the importance of an approach encompassing effective leadership, staff competence, regional ethos development, public involvement, cooperative relationships, streamlined processes, integrated land-use planning, and accountability in regional transport planning and implementation</td><td>n/a</td><td>Chen(2021)</td></tr>
<tr><td>The article examines the role of cities worldwide as hubs for economic activity, industrial production, and innovation, emphasizing their significance in regional development. The study aims to delimit the structure of its urban agglomeration, highlighting the importance of understanding inter-city intra-agglomeration socioeconomic integrity and functional interconnectivity for efficient governance.</td><td>Rostov-on-Don</td><td>Gorochnaya and Mikhaylov (2020)</td></tr>
</table>

Table 9 cont.

1	*2*	*3*
Key points: • **cities as central hubs** – cities globally serve as central locations for economic activity, industrial production, and innovation, accumulating resources and advanced infrastructure; • **urban environment favorable for entrepreneurship** – urban environments are conducive to entrepreneurship and living, concentrating administrative, financial, and human resources, along with public infrastructure and social sector services; • **integration and coherence in regional development** – in regional development, cities' integration and coherence strengthen, functions are redefined, and specialization deepens, reinforcing the role of central cities; • **importance of consideration in governance** – understanding inter-city intra-agglomeration socioeconomic integrity and functional interconnectivity is crucial for efficient governance; • **challenges in policy formulation** – blurred boundaries of urban agglomerations hinder the development of place-specific policies for urban and regional growth; • **influence of industrial clustering and transportation** – industrial clustering and transportation networks play a significant role in determining the developmental trajectory and spatial configuration of the urban agglomeration, leading to path-dependency		
The article addresses the unsustainable increase in individual vehicle usage in medium and small-sized cities, advocating for sustainable policies through non-motorized transport, specifically focusing on designing bicycle routes on university campuses. Key points: • **unsustainable individual vehicle usage as an advocacy for sustainable policies** – the article highlights the unsustainable trend of increased individual vehicle usage in medium and small-sized cities; emphasizes the need for implementing sustainable policies, particularly through the promotion of non-motorized transport; • **bicycle and vehicle usage** – anticipates that implementing proposed bicycle infrastructure will increase the number of cyclists, subsequently reducing individual vehicle usage	Viçosa campus of the Federal University of Viçosa in Minas Gerais	Rosa Mesquita et al. (2020)
The article assesses the impacts of electric cargo bikes on city logistics, considering both public policy perspectives and urban logistics operators' interests. Focusing on the European Commission's efforts to mitigate negative traffic and environmental impacts, the study evaluates variables related to mobility, environmental impact, quality of life, costs, and efficiency. The research aims to determine if electric cargo bikes can serve as a sustainable mobility policy within specific boundaries, offering improved environmental and social impacts without compromising operational efficiency in urban logistics activities. Key points: • **traffic key performance indicators measurement** – evaluating mobility, reliability, and operational efficiency indicators, quantifying the environmental impact and analyzing different scenarios related to the introduction of electric cargo bikes;	Porto	Melo and Baptista (2017)

Table 9 cont.

1	*2*	*3*
• **replacement of conventional vans** – electric cargo bikes can effectively replace up to 10% of conventional vans in areas with maximum linear distances of about 2 km without compromising overall network efficiency. Urban logistics Well-to-Wheel CO_2 emission impacts can be reduced by up to 73%, leading to 746 kg of avoided CO_2 emissions. The introduction of electric cargo bikes has positive effects for all vehicle categories, achieving up to 25% reductions in external costs; • **sustainability in urban logistics** – cargo bikes, when implemented at an appropriate spatial scale within the city, can serve as a sustainable solution for urban logistics, contingent upon predefined conditions and an adequate implementation strategy to ensure improvements in mobility, environment, energy, running costs, and externalities		
The article addresses the challenges posed by the Paris climate goal and the need for unprecedented emission reduction, focusing on the internal inconsistencies and fragmentation in current instrumentation for climate action. It proposes a systematic approach to instrument design, categorizing instruments based on generality and bindingness, emphasizing the importance of sparseness, completeness, and non-overlap. Key points: • **instrumentation inconsistencies** – critiques the current internally inconsistent instrumentation for climate action, emphasizing its inadequacy for achieving deep emission reductions; • **fragmentation in electricity markets** – points out that national technology-specific instruments have rendered the EU cap-and-trade system unnecessary, contributing to the fragmentation of electricity markets; • **instrumentation design principles** – proposes a new categorization of instruments for systematic instrumentation design, highlights the importance of these factors in instrument design; emphasizes sparseness, completeness, and non-overlap as essential starting points for any instrumentation design; • **planning and control strategy** – recommends starting with technology-specific instruments, including subsidies and standards for reducing fossil emissions in electricity production, effective Fleet Standards for transport, and dynamic standards and permits for industry emissions; notes that subsidies create learning curves, and consistency and effectiveness may require centralization; • **institutionalism strategy** – advocates for a comprehensive upstream emission tax with proceeds at the country or state level, and an open-to--all, real-time priced electricity market to enable small-scale renewables and secondary producers on the grid. Promotes publicly provided infrastructure for a level playing field in decentral climate action; • **policy relevance** – highlights that technical instrument choices may seem neutral but are inherently policy choices; concludes that choices between governance strategies are ultimately based on preferences, and explicit instrumentation strategies are necessary for consistency, effectiveness, and legitimacy in climate action	Paris	Huppes et al. (2017)
The paper explores methodological approaches to delineating peripheral areas at the regional level, reviewing existing literature and practices. The authors introduce and test their methodology, focusing on assessing transport accessibility, socio-economic development, and economic potential.	Russian Federation subjects	Dvoryadkina, Kaibicheva, and Bausova (2017)

Table 9 cont.

1	2	3
The proposed methodology emphasizes consideration of the current municipal structure, use of publicly accessible statistical data, and descriptions of periphery based on managerial, geographical, and economic perspectives. Key points: • **factors considered** – the methodology involves evaluating the transport accessibility of territories, considers the level of socio-economic development in the delineation process and incorporates an assessment of economic potential in defining peripheral areas; • **methodological approach** – highlights attention to the current municipal structure, emphasizes the use of statistical data accessible to the general public and describes periphery from the standpoint of managerial (political), geographical, and economic approaches		
The article explores a user-centric approach to the parameterization of transport networks, shifting the focus from traditional methods employed by infrastructure administrators to the individual needs of transport network users. It discusses the use of trip planners, such as GT Planner, and other tools with bidirectional information transfer channels as a means to better understand and address the specific requirements of transport system users, ultimately aiming to contribute to the sustainable development of transport networks. Key points: • **user-centric approach** – proposes a shift towards a user-centric approach to transport network parameterization, emphasizing the importance of addressing the individual needs of transport system users; • **transport network parameterization methods** – highlights that the typical parameterization process involves defining synthetic measures for a given transport network area, dependent on its delimited manner; discusses the limitations of traditional parameterization methods, emphasizing their lack of direct linkage with statistical transport network users and their specific requirements; • **role of trip planners** – advocates for the use of trip planners, specifically mentioning GT Planner, and other tools featuring bidirectional information transfer channels in the parameterization process	n/a	Celiński (2017)
The article discusses the road safety situation in Québec, noting a decrease in road casualties despite the growing number of vehicles and drivers. The focus is on the potential of integrating transportation planning and urban planning to enhance road safety, emphasizing the crucial role of land use decisions in shaping travel patterns and safety conditions. Key points: • **integration of transportation and urban planning** – advocates for the integration of transportation planning and urban planning as a promising strategy to address road safety concerns; • **land use decisions** – emphasizes that decisions regarding land use significantly influence travel needs, modes of travel, and particularly, traffic and safety conditions; stresses the long-term impact of land use decisions on urban development and their potential efficiency in	Québec	Berthod(2016)

Table 9 cont.

1	2	3
preventing road safety issues; discusses the importance of defining general policies on land use, delimiting urbanization perimeters, and locating growth areas in shaping traffic volume and collision risks; points out that land occupation density plays a role in the frequency of accesses and intersections, impacting road safety according to various studies		
This article explores the recent surge in scientific interest in complex network analysis, a method used to characterize systems with numerous entities interconnected by relationships. While networks are generally abstract, spatial networks specifically involve nodes and edges with spatial references. The focus has shifted to methods for defining and investigating communities within networks, where the spatial factor can arise from the topological community structure mapping onto geography or spatial clusterization of nodes. The paper provides a state-of-the-art summary of advances in network community detection methodologies, particularly in spatial networks. Key points: • **complex network analysis** – highlights the versatility of complex network analysis by applying it to various systems, including biological (predator-prey), information (internet), social (actors in the same movie), and transportation (railway and road networks); emphasizes the unique nature of spatial networks within the broader category of networks, where nodes and edges have explicit spatial references; • **focus on community detection** – shifts the scientific focus to methods for defining and investigating communities within networks; discusses how the spatial factor can emerge either from the topological community structure mapping onto geography or through spatial clusterization of nodes embedded in space; • **policy and planning implications** – highlights the relevance of the study for policymakers and planners, particularly in addressing issues related to the delimitation of sub-regional domains based on specific territorial features	Island of Sardinia	Montis, Caschili, and Chessa (2013)
The article addresses the challenge of containing urban sprawl in land-use planning by implementing regulations that limit construction outside urban perimeters. The focus is on establishing the limits of consolidated urban areas, and the paper introduces a methodology for this purpose. Utilizing a Geographical Information System (GIS) to identify existing buildings, along with an analysis of road networks, social facilities, and physiographic constraints, the methodology defines criteria for delimiting urban settlements. Key points: • **containment of urban sprawl** – addresses the challenge of containing urban sprawl in land-use planning through the integration of regulations limiting construction outside urban perimeters; • **delimitation of urban settlements** – focuses on establishing the limits of consolidated urban areas within settlements. Introduces a methodology for delimiting urban settlements, utilizing a Geographical Information System (GIS) to identify existing buildings and analyzing road networks, social facilities, and physiographic constraints; defines criteria for delimiting urban settlements based on the identification of effectively consolidated urban areas; achieves an accurate delimitation of current settlements that aligns with rational land-use objectives	Tomar	Ferreira et al. (2010)

Source: Elaboration with the use of the LLM, based on the provided sources.

Within the conducted literature review, other thematic areas related to spatial delimitation were also identified, although they are not relevant from the perspective of the monograph's theme (transport policy). Among other topics discussed in the literature on delimitation are articles addressing issues such as:

- delimitation of maritime areas (Crickard, 1995; Franckx, 2011; Shaffer, 2011; Bezrukov, 2015; Bellefontaine et al., 2016; Pritchin, 2020; Egorov et al., 2021; Janusz-Pawletta, 2021; Xia et al., 2023),
- relocation of container terminals (Santos, Martins, and Soares, 2021),
- one belt one road initiative (Panibratov et al., 2022),
- flood mapping (Cunha et al., 2017),
- space flights (Nugraha, 2016; Oduntan, 2011),
- global crisis (Mugarura, 2016),
- arctic policy (Bezrukov, 2015; Pieper et al., 2011),
- environmental policies for eco-friendly products (Weidema, Suh, and Notten, 2006),
- mapping areas based on the occurrence of a specific soil type (Němeček and Kozák, 2003),
- unstable border areas (Stanley, 2002),
- pipeline transportation (Sinuraya, 2001).

This subchapter provides an analysis of issues related to spatial delimitation and its impact on the adequacy of econometric models, with a primary focus on transportation policy. A synthetic literature review was conducted to identify how spatial delimitation affects various aspects of transportation planning, particularly its impact on transport accessibility and social exclusion in different regions.

The literature review identified key research areas, such as rural area urbanization, transport exclusion in the context of access to public services, and socio-spatial dynamics in remote rural areas. These studies indicate that spatial delimitation has a direct influence on mobility, socio-economic integration, and the effectiveness of public policies. The research also highlights challenges associated with regional transportation planning, resulting from evolving institutional structures and political discourses. Additionally, it includes analyses of issues related to uncontrolled urban sprawl and proposes methodological approaches to mitigating this phenomenon through improved spatial planning. The reviewed documents also discuss the variation in approaches to defining peripheral areas and the importance of integrating transportation planning with urban policy, which is crucial for enhancing road safety and promoting sustainable urban development.

The vast majority of identified publications do not directly address the delimitation topic but rather make references to this process. Delimitation is primarily present in the context of maritime transport or airspace. It is worth noting that several of the identified articles discuss the issue of delimitation in urban areas and its impact on the transport policy of a given area. However, none of the analyzed articles addressed the impact of delimitation on the fitting of econometric models, confirming the existence of a research gap.

2.3. Area delimitation in transport plans of the largest Polish urban areas

For analysis, the 10 largest cities in Poland were selected based on population size, along with the largest metropolitan area in Poland, namely the Metropolis GZM (Upper Silesian and Zagłębie Metropolis). Table 10 presents the urban areas on which the analysis was conducted.

Table 10. Areas designated for the analysis of transport plans

Urban area	Population (rounded to the nearest thousand)
Metropolis GZM	≈ 2 100 000
Warszawa	≈ 1 862 000
Kraków	≈ 803 000
Wrocław	≈ 674 000
Łódź	≈ 658 000
Poznań	≈ 541 000
Gdańsk	≈ 486 000
Szczecin	≈ 392 000
Bydgoszcz	≈ 339 000
Lublin	≈ 336 000
Białystok	≈ 293 000

Source: Elaboration based on: Polska w liczbach (2024); Metropolis GZM (2024).

The main directions of area delimitation were identified in the areas defined in Table 10. The analysis focuses on the latest plans for sustainable development of public mass transit in respective urban areas. The results of the conducted analysis are presented in Table 11.

Table 11. Analysis of the delimitation process applied in transportation plans

Urban area	Delimitation	Source
1	*2*	*3*
Metropolis GZM	Delimitation of the area according to administrative criteria: • municipalities constituting the GZM, • municipalities having an agreement with GZM regarding the delegation of GZM to perform the functions of public mass transit organizer, • municipality belonging to GZM, in which public mass transit is not organized. Municipalities constituting the Metropolis are divided into: • core GZM municipalities (with the highest concentration of social and economic functions), • municipalities not part of the core GZM. The Metropolis is also divided according to spatial development directions: • areas of multifunctional development with multi-family housing, • low-intensity residential areas, • service areas, • production areas, warehouses, logistics, • communication areas, • technical infrastructure areas, • agricultural areas, • green areas, • forest areas, • closed areas	GZM Plan (2021)
Warszawa	Delimitation of the area according to administrative criteria – boundaries of the city of Warsaw (including districts, referred to in the plan as “transportation zones”), as well as boundaries of other municipalities. The plan also includes division into urban areas, urban-rural areas, rural-urban areas, and rural areas	Warszawa Plan (2015)
Kraków	Delimitation of the area according to administrative criteria – boundaries of Krakow including individual districts. The plan also includes division according to spatial development criteria: • historic heritage area of the city center and surrounding urban development, • area of the “old” Nowa Huta, • complexes of multi-family residential neighborhoods, • complexes of single-family housing, • areas of industrial concentration, • green and open spaces, • areas of the city’s transportation and transport system. There is also a division into communication axes: • north-south axis, • east-west axis, • southwest-northeast axis. Additionally, areas are marked according to noise intensity (acoustic map)	Kraków Plan (2013)

Table 11 cont.

<table>
<tr><th>1</th><th>2</th><th>3</th></tr>
<tr><td>Wrocław</td><td>Delimitation of the area into:
• municipalities surrounding Wrocław,
• other neighboring municipalities of Wrocław,
• downtown area of Wrocław,
• Wroclaw's metropolitan center,
• area of compact urban development in Wrocław,
• area of dispersed urban development in Wrocław</td><td>Wrocław Plan (2016)</td></tr>
<tr><td>Łódź</td><td>Delimitation of the area according to administrative criteria – boundaries of Łódź including individual districts</td><td>Łódź Plan (2018)</td></tr>
<tr><td>Poznań</td><td>Delimitation of the area according to administrative criteria – boundaries of Poznań including individual districts (as well as auxiliary units of the city of Poznań) and neighboring municipalities (Poznań Agglomeration).

Specification of the so-called "urban functional area":
• centers of administration and business environment institutions,
• fair and commercial-service centers,
• academic, scientific, and cultural centers,
• residential areas,
• industrial areas,
• open green areas</td><td>Poznań Plan (2019)</td></tr>
<tr><td>Gdańsk</td><td>Delimitation of the area according to administrative criteria – boundaries of Gdańsk including individual urban districts and auxiliary units of the city, as well as neighboring municipalities, divided into:
• urban municipalities,
• urban-rural municipalities,
• rural municipalities.

Additionally, delimitation of the area based on the accessibility of public transportation stops (buses and trams) within a radius of 500 meters</td><td>Gdańsk Plan (2021)</td></tr>
<tr><td>Szczecin</td><td>Delimitation of the area according to administrative criteria – boundaries of Szczecin including individual districts and neighborhoods. Also, the counties in the West Pomeranian Voivodeship are included.

Zones divided according to their characteristics:
• agricultural land;
• forests;
• waters;
• urbanized areas, including:
  ○ residential areas,
  ○ industrial areas,
  ○ built-up areas,
  ○ unbuilt urbanized areas;
• recreational areas;
• communication areas;
• mining areas;
• ecological areas;
• unused lands;
• miscellaneous</td><td>Szczecin Plan (2014)</td></tr>
</table>

Table 11 cont.

1	2	3
Bydgoszcz	Delimitation of the area according to administrative criteria – boundaries of Bydgoszcz including individual urban units. Also, the real estate parcels are divided into: • residential areas: built-up, unbuilt, and green spaces, • forests and woodland, • agricultural land, • communication areas, • miscellaneous areas, • land under water bodies, • unused lands, • mining areas. Additionally, isochrones of access to bus stops are presented (up to 300m, up to 400m, and up to 500m)	Lublin Plan (2013)
Lublin	Delimitation of the area according to administrative criteria – boundaries of Lublin including individual districts and neighboring municipalities (with which agreements have been concluded regarding the organization of public mass transit and which have preliminarily expressed their accession to the agreement). Additionally, division into urban structure: • multifunctional city center district, • residential districts around the city center district, • industrial-storage clusters, • open space areas	Białystok Plan (2015)
Białystok	Delimitation of the area according to administrative criteria – boundaries of Białystok including individual neighborhoods (auxiliary units of the municipality) and neighboring municipalities (with specification of municipalities that have signed agreements with the city regarding the delegation of public mass transit organization). Additionally, identified structural zones in the city's spatial policy and coverage of the city by spatial development plans are presented. The influence of spatial development on residents' travel behaviors (such as travel distance, frequency of travel, and choice of transportation mode) has been established, considering the following factors: • population density, • employment density, • spatial development density, • location, • city size. Furthermore, division into zones with different transport policies is made: • central core zone, • downtown zone, • zone of concentration of residential neighborhoods and single-family housing, • zone of extensive development	Bydgoszcz Plan (2013)

Source: Elaboration based on the provided sources.

Delimitation methods used in Polish cities vary significantly in terms of complexity and precision, which affects the effectiveness of spatial planning. Cities like Kraków and Poznań employ multifaceted criteria, taking into account both spatial functions and specifics such as transportation and acoustic characteristics, which allows for more sophisticated and needs-based planning. In contrast, cities like Łódź use simplified methods primarily based on administrative boundaries, which may limit their ability to accurately reflect dynamic urban and functional changes. Additionally, the introduction of elements such as isochrones for public transportation access, as seen in Bydgoszcz and Gdańsk, is a positive step but may be insufficient if not supported by a more complex approach to spatial divisions. The analysis clearly shows that the most commonly chosen criterion for delimitation is the division of urban areas based on administrative criteria – such an approach was present in each of the analyzed documents. This phenomenon is perfectly understandable, as statistical data are most often aggregated precisely in terms of administrative units, and the competencies of various governing bodies end with the borders of individual cities and municipalities. However, there are clear attempts to perform delimitations taking into account other characteristics, such as the functional layout of a given urban area or division according to the type of land or properties. However, these are usually approaches that supplement a given analysis and do not form the basis for creating the transport policy of the area.

Delimitation methods used in various cities exhibit different approaches to managing urban space. Some areas employ more complex criteria that may better address detailed needs in spatial planning. These methods incorporate both administrative and functional aspects, allowing for more nuanced urban management. However, this complexity can lead to difficulties in coordinating actions across different zones and potential challenges in practical implementation. Nevertheless, some cities use more simplified methods, which may limit flexibility and precision in planning. Additionally, the absence of more sophisticated spatial divisions can restrict the usefulness of plans for managing development and spatial function diversity. For example, while a division into transportation zones is useful for transport planning, a general division based on rigid criteria (e.g., urban vs. rural) may be overly simplistic and fail to capture the full spatial diversity or fully account for dynamic changes in urban development.

In summary, two main approaches to the issue of delimitation can be distinguished: the more complex approach, which takes into account multiple factors, and the simpler approach, which primarily focuses on a single factor (usually administrative criteria). The relative simplicity of delimitation according to administrative criteria means that, in the future, the majority of analyses will likely be conducted in this manner. This approach is not erroneous, but it does not exhaust the issue under analysis.

A potential area for future research could be the creation of a delineation algorithm that does not focus on administrative criteria. However, it must be acknowledged that developing such a model will prove to be extremely difficult, if not impossible – every urban area has its own unique characteristics, and it is these that should determine the delineation process. Nevertheless, research addressing the thematic scope discussed in this subsection appears to be necessary.

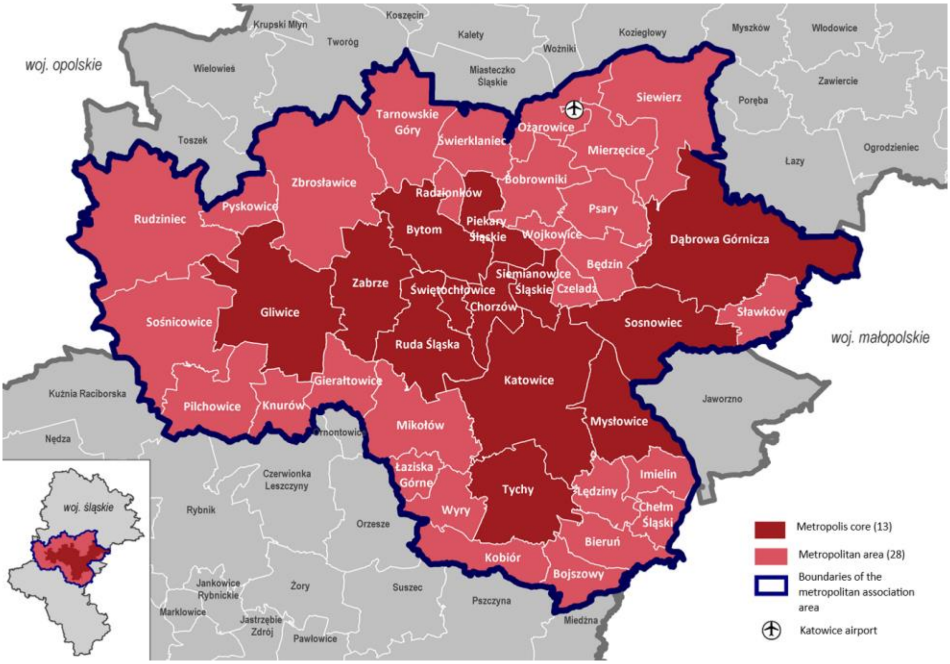
3. Area delimitation as a determinant of statistical models compatibility in polycentric-dispersed agglomerations: A study of public collective transport in Metropolis GZM

3.1. Methodology and data

The delimitation of the area is not a simple task. Administrative boundaries of cities rarely correspond to their functional borders, which causes problems with the correct interpretation and analysis of the studied phenomena (Borruso, 2003). It should be noted, however, that delimitation of the area according to its administrative structure is often the only option available, as the available data is aggregated precisely according to the administrative criterion. It is also worth mentioning that increasingly observed processes in which intermediate space gradually gain centrality, thus blurring the difference between the city and the suburbs (Phelps et al., 2006; Keil, 2013). This situation makes an analysis based on administrative boundaries, where individual cities are analytical nodes of the agglomeration network, justifiable (van Meeteren, Neal, and Derudder 2016).

The monography aims to present the problems that may arise during the creation of an econometric model for the issues of public collective transport in a polycentric agglomeration. The following research hypothesis has been proposed – in polycentric metropolitan areas there are economic models that, when using the same set of input data, may only be well-suited for certain areas of the entire urban complex. The largest Polish agglomeration, i.e. Metropolis GZM, consisting of 41 communes and cities of the Silesian Voivodeship, was selected as the research area. It should also be emphasized that there are significant differences between the municipalities belonging to the GZM, both in terms of income and the level of development (Musioł-Urbańczyk and Sorychta-Wojsczyk, 2019). The Metropolis GZM consists of a core (13 cities) and other members not included in the core (28 municipalities). Figure 14 presents the map of the Metropolis GZM with the core highlighted.

Figure 14. Metropolis GZM



Source: Translation based on: InfoGZM (2024).

The characteristics of the Metropolis GZM makes this area a very good testing ground for the issue analyzed in the article. Therefore, Metropolis GZM is an good example of a polycentric-dispersed agglomeration.

In the monography, an analysis was conducted of the impact of various factors on modal split, specifically on the choice of public transport for home-work-home commutes. It should also be noted that the analysis covered public collective transport provided by the Metropolitan Transport Authority (ZTM), which means that the presented model covers a maximum of 40 municipalities, as one of the GZM municipalities does not have public collective transport provided by the ZTM (Rudziniec). The data used in the analysis can be found in Annex to the work – data was collected from Polish Central Statistical Office (Główny Urząd Statystyczny, 2022), the Metropolis GZM Transport Plan (GZM Plan, 2021) and the Metropolitan Railway Construction Plan (*Koncepcja Kolei Metropolitalnej*…, 2018). In the analysis, the following variables were utilized:

- Y – modal split – public transport in motivations home – work – home [%],
- X_1 – motorization indicator [passenger cars / 1,000 inhabitants],
- X_2 – length of communication lines per square kilometer of the area of potential transport service [km],

- X_3 – length of communication routes per square kilometer of the area of potential transport service [km],
- X_4 – number of vehicle kilometers travelled operated by the ZTM on a statistical working day per 1 inhabitant [VKT[15]],
- X_5 – average radius of access to the public transport stop for the area of the potential transport service [m],
- X_6 – price of a standard monthly ticket for the whole network to the average gross salary in the enterprise sector ratio [%],
- X_7 – average number of communication lines per public transport stop.

The methodological approach used in the article is based on the multiple regression analysis. The least squares method was used – the final solution minimizes the sum of squared errors when solving each equation (Scarianio and Calzada, 2004). All data can also be presented in a matrix form, so the model used in the has the following form (Brown, 2009):

$$Y_v = \beta X + \varepsilon$$

where:

$$Y_v = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_{n_v} \end{bmatrix}$$

$$X = \begin{bmatrix} 1 & x_{11} & x_{21} & \cdots & x_{k_{ex}1} \\ 1 & x_{12} & x_{22} & \cdots & x_{k_{ex}2} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 1 & x_{1n_v} & x_{2n_v} & \cdots & x_{k_{ex}n_v} \end{bmatrix}$$

$$\beta = \begin{bmatrix} \beta_0 \\ \beta_1 \\ \beta_2 \\ \vdots \\ \beta_{k_{ex}} \end{bmatrix}$$

$$\forall E(\varepsilon) = 0$$

symbols meaning:

- Y_v – dependent variable,
- X – independent variables,
- β – scalar,
- E(ε) – expected value of error terms.

[15] Vehicle-kilometer.

The number of elements in each matrix depends on the number of identified factors that qualified for use in the models and the number of observations. It is worth noting that the article concerns polycentric-dispersed agglomerations, so the entire analysis was carried out several times, taking into account different variants (area delimitation – the entire Metropolis, the core of the Metropolis and other cities of the Metropolis):

$$Nv = \begin{bmatrix} N_1 \\ N_2 \\ N_3 \end{bmatrix}$$

where:

$$N_1 = c_{mt} - c_{mn} \vee N_2 = c_{ct} - c_{cn} \vee N_3 = c_{rt} - c_{rn}$$
$$c_{mt} = c_{ct} + c_{rt}$$
$$c_{mn} = c_{cn} + c_{rn}$$

symbols meaning:

- Nv – analyzed variant (delimitation),
- c_{mt} – all cities of the agglomeration,
- c_{mn} – all cities of the agglomeration without public transport,
- c_{ct} – all cities of the agglomeration core,
- c_{cn} – all cities of the agglomeration core without public transport,
- c_{rt} – the remaining city of the agglomeration,
- c_{rn} – the remaining city of the agglomeration without public transport.

The variables used in the model were also selected. Firstly, the spatial auto-correlation (Global Moran's I) was calculated (Miśkiewicz-Nawrocka and Zeug--Żebro, 2017):

$$I = \frac{n}{S_0} \times \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{i,j} z_i z_j}{\sum_{i=1}^{n} z_i^2}$$

where:

$$S_0 = \sum_{i=1}^{n} \sum_{j=1}^{n} w_{i,j}$$

$$z_i = \frac{I - E[I]}{\sqrt{V[I]}}$$

$$E[I] = \frac{-1}{(n-1)}$$

$$V[I] = E[I^2] - E[I]^2$$

symbols meaning:

- z_i / z_j – deviation of an attribute for given feature,
- $w_{i,j}$ – spatial weight between given features (1 – have a bordered, 0 – does not have a border),
- n – total number of features,
- S_0 – aggregate of spatial weights.

In cases where the Global Moran's I statistic takes on values:

- I = 0 – no spatial correlation (randomly dispersed),
- I = 1 – positive spatial correlation (perfectly clustered),
- I = –1 – negative spatial correlation (perfectly dispersed).

In accordance with the interpretation of extreme values presented in the literature, the following ranges and their corresponding meanings have been adopted for the global indicator (table 12).

Table 12. Global Moran's I interpretation

Global Moran's I value	Interpretation
I ∈ (0,5; 1>	strong positive spatial autocorrelation
I ∈ (0,3; 0,5>	moderate positive spatial autocorrelation
I ∈ (0,1; 0,3>	weak positive spatial autocorrelation
I ∈ (0,05; 0,1>	really weak positive spatial autocorrelation
I ∈ <–0,05; 0,05>	no spatial autocorrelation
I ∈ <–0,1; –0,05)	really weak negative spatial autocorrelation
I ∈ <–0,3; –0,1)	weak negative spatial autocorrelation
I ∈ <–0,5; –0,3)	moderate negative spatial autocorrelation
I ∈ <–1; –0, 5)	strong negative spatial autocorrelation

Also, the absolute mean of Global Moran's I indicator was calculated. If the strong spatial autocorrelation appears, spatial regression models should be used.

It was also assumed that the variables cannot be correlated with each other (Pośpiech and Mastalerz-Kodzis, 2016) and must have an appropriate level of variability (Bedeian and Mossholder, 2000). This approach allowed to transform the set of input variables into a set of output variables:

$$ken = \begin{bmatrix} x_{k_1} & x_{k_2} & \cdots & x_{k_{en}} \end{bmatrix}$$

$$kVc = \begin{bmatrix} x_{k_1} & x_{k_2} & \cdots & x_{k_{Vc}} \end{bmatrix}$$

$$kR^{-1} = \begin{bmatrix} x_{k_1} & x_{k_2} & \cdots & x_{k_{R^{-1}}} \end{bmatrix}$$

$$kex = \begin{bmatrix} x_{k_1} & x_{k_2} & \cdots & x_{k_{ex}} \end{bmatrix}$$

where:

$$\forall kVc: V_x = \frac{\sqrt{\frac{\sum_{i=1}^{n}(x_{ij_{ken}} - \overline{x_{ij_{ken}}})}{n_v}}}{\overline{x_{ij_{ken}}}} < \sigma \wedge \sigma = 0{,}05\mu$$

$$\forall kR^{-1}: R^{-1} = (R^D)^T{}_{ken} \times \frac{1}{\det(R)_{ken}} \wedge dR^{-1} > \tau \wedge \tau = 10\omega$$

$$kex \in (kVc \cap kR^{-1})$$

$$\mu = 0{,}9$$

$$\omega = 1{,}1$$

symbols meaning:

- ken – set of input variables,
- kex – set of output variables,
- kVc – set of variables with variability condition,
- kR^{-1} – set of variables with correlation condition,
- k_{en} / k_{ex} / k_{Vc} / k_R^{-1} – elements of individual sets,
- x_{ij} – value of the i-th variable for the j-th case,
- n_v – population size of the analyzed variant,
- R – correlation matrix,
- $(R^D)^T$ – transpose matrix of algebraic complements of a correlation matrix,
- det(R) – correlation matrix determinant,
- dR^{-1} – main diagonal of the inverse correlation matrix,
- μ / ω – margin correction factor.

To avoid introducing a rigid framework of limit values into the model, the margin correction factors were used. Their main task is to introduce a margin of error for the adopted ranges (+/–10%).

The entire procedure allowed for the creation of three multiple regression models, the general notation of which is as follows (Uyanik and Güler, 2013):

$$Y_v = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_{k_{ex}} x_{k_{ex}}$$

where:

$$Y_v = \begin{bmatrix} Y_1 \\ Y_2 \\ Y_3 \end{bmatrix}$$

Next, individual variants of the model were analyzed. Their null hypothesis of homoscedasticity according to White Test (Ando and Hodoshima, 2007), the significance of individual variables, the significance of the entire model, the standard deviation of the residual component (in relation to the mean value of Y and the context of the identification of extreme observations) as well as the general and specific fit of the model (Akossou and Palm, 2013) were checked. Therefore, the analysis procedure was as follows:

$$S_u = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \hat{y}_t)^2}{n_v - 2}}$$

$$Y_v < (3S_u)\omega$$

$$S_e = \left[\frac{S_u}{\sum_{i=1}^{n} Y_v} \times\right] 100\% < \varphi\omega \wedge \varphi = 20\%$$

$$P_1 \to p_v \in (0; 0{,}05\omega) \wedge P_2 \to p_v \in \langle 0{,}05\omega; 0{,}1\omega) \wedge P_3 \to p_v \in \langle 0{,}1\omega; 1\rangle$$

$$R^2 = \left[\frac{\sum_{t=1}^{n}(\hat{y}_t - \bar{y})^2}{\sum_{t=1}^{n}(y_t - \bar{y})^2}\right] \times 100\%$$

$$R^2{}_1 \to R^2 \in \langle 100; 80\mu) \wedge R^2{}_2 \to R^2 \in \langle 80\mu; 60\mu) \wedge R^2{}_3 \to R^2 \in \langle 60\mu; 0)$$

$$R^2{}_{adj} = \left[1 - \left(1 - \frac{\sum_{t=1}^{n}(\hat{y}_t - \bar{y})^2}{\sum_{t=1}^{n}(y_t - \bar{y})^2}\right)\frac{n-1}{n_v - p - 1}\right] \times 100\%$$

$$R^2{}_{adj1} \to R^2{}_{adj} \in \langle 100; 60\mu) \wedge R^2{}_{adj2} \to R^2{}_{adj} \in \langle 60\mu; 50\mu) \wedge R^2{}_{adj3} \to R^2{}_{adj} \in \langle 50\mu; 0)$$

symbols meaning:

- $P_1/P_2/P_3$ – significance group (significant/marginally significant/non-significant),
- $R^2{}_1/R^2{}_2/R^2{}_3$ – model compatibility group (good/sufficient/bad),
- p – total number of explanatory variables in the model (not including the constant term),
- $R^2{}_{adj1}/R^2{}_{adj2}/R^2{}_{adj3}$ – variables compatibility group (good/sufficient/bad).

The analysis carried out in this way made it possible to compare individual variants of the analysis and to achieve the aim of the article, i.e. to present potential problems that may occur when creating a multiple regression model (other econometric models) for polycentric agglomerations.

3.2. Results

Firstly, it must be noted that no significant spatial autocorrelation was observed. Table 13 presents values of Global Moran's I indicator for each variable.

The main result of conducted analysis showed that using the same input data for different areas of a polycentric-dispersed agglomeration (in this case Metropolis GZM) results in different degrees of model fit. Variables that explain the phenomenon in a satisfactory way in one area of the metropolis may not be suitable for other areas (e.g., the entire agglomeration, its core and suburbs).

While this situation has practically no significance for monocentric agglomerations, for polycentric ones, which are subject to a single, common development strategy, this problem may have serious implications, which will be discussed further in the chapter. Table 14 presents the obtained results of a multiple regression model for three different areas of Metropolis GZM (the entire metropolis, the core and the cities outside the core).

Table 13. Global Moran's I indicator results

Variable	Global Moran's I	Interpretation	Comment on the result
X_1	0,316	moderate positive spatial autocorrelation	The result is influenced by the estimation of values from counties to municipalities
X_2	0,160	weak positive spatial autocorrelation	–
X_3	0,145	weak positive spatial autocorrelation	–
X_4	0,249	weak positive spatial autocorrelation	–
X_5	0,066	weak positive spatial autocorrelation	–
X_6	–0,129	weak negative spatial autocorrelation	–
X_7	0,321	moderate positive spatial autocorrelation	Central cities (metropolis core, i.e., the cluster) provide more public mass transit lines on each stop
Absolut mean	**0,198**	**weak spatial autocorrelation**	**Spatial regression models are unnecessary**
p-value = 0,008			

Table 14. Model results

	Y1 (N1)		Y2 (N2)		Y3 (N3)	
	estimator	**p-value**	**estimator**	**p-value**	**estimator**	**p-value**
β_0 (intercept term)	90,05	0,002 (P_1)	50,70	0,002 (P_1)	not applicable	0,796 (P_3)
β_1	–0,04	0,107 (P_2)	not applicable	0,764 (P_3)	not applicable	0,839 (P_3)
β_2	–1,49	0,005 (P_1)	3,06	0,004 (P_1)	not applicable	0,484 (P_3)
β_3	not applicable	0,107 (P_3)	–11,22	0,003 (P_1)	not applicable	0,165 (P_3)
β_4	not applicable	0,745 (P_3)	–106,58	0,109 (P_2)	not applicable	0,466 (P_3)
β_5	not applicable	0,920 (P_3)	not applicable	0,109 (P_3)	not applicable	0,277 (P_3)
β_6	–18,99	0,004 (P_1)	not applicable	0,759 (P_3)	not applicable	0,174 (P_3)
B_7	not applicable	0,906 (P_3)	–87,23	0,021 (P_1)	58,52	1,92E–08 (P_1)

Note: Colors meaning:
red – insufficient result,
yellow – marginally sufficient result,
green – sufficient result.

In addition to the coefficient values for individual variables, basic information about the model fit was also obtained, as presented in table 15.

Table 15. Model fit

	Y1 (N1)	Y2 (N2)	Y3 (N3)
model significance	5,02E-05	0,01	2,55E-08
model significance group	significant	significant	significant
White' test result	0,31	0,24	0,06
White' test H_o rejected?	no	no	marginally no
$Y_v < (3S_u)\omega$	yes	yes	yes
S_e	55,65%	21,82%	72,38%
$S_e < \varphi\omega$	no	yes	no
R^2	50,12%	76,33%	70,92%
R^2 group	bad	good	sufficient
R^2_{adj}	44,44%	64,50%	67,08%
R^2_{adj} group	bad	good	good
Is the model acceptable?	**no**	**yes**	**no**

Note: Colors meaning:
red – insufficient result,
yellow – marginally sufficient result,
green – sufficient result.

For the Metropolis GZM and the selected set of variables (appendix 1), the multiple regression model was only well-fitted in one case (core cities of the metropolis). In the case of analyzing the entire area, the model was characterized by a very large standard error and low R^2 and R^2_{adj} coefficients. For the suburban cities, the model met all the fitting conditions except for the high coefficient of error.

The final form of the model is as follows:

$$Y_1\ (N_1) \rightarrow not\ applicable$$

$$Y_2\ (N_2) = 3{,}06x_2 - 11{,}22x_3 - 106{,}58x_4 - 87{,}23_{x7} + 50{,}70$$

$$Y_3\ (N_3) \rightarrow not\ applicable$$

On Figure 15, the distribution of residuals is presented. On Figure 16, the distribution of the fitted line is presented.

Figure 15. The distribution of residuals

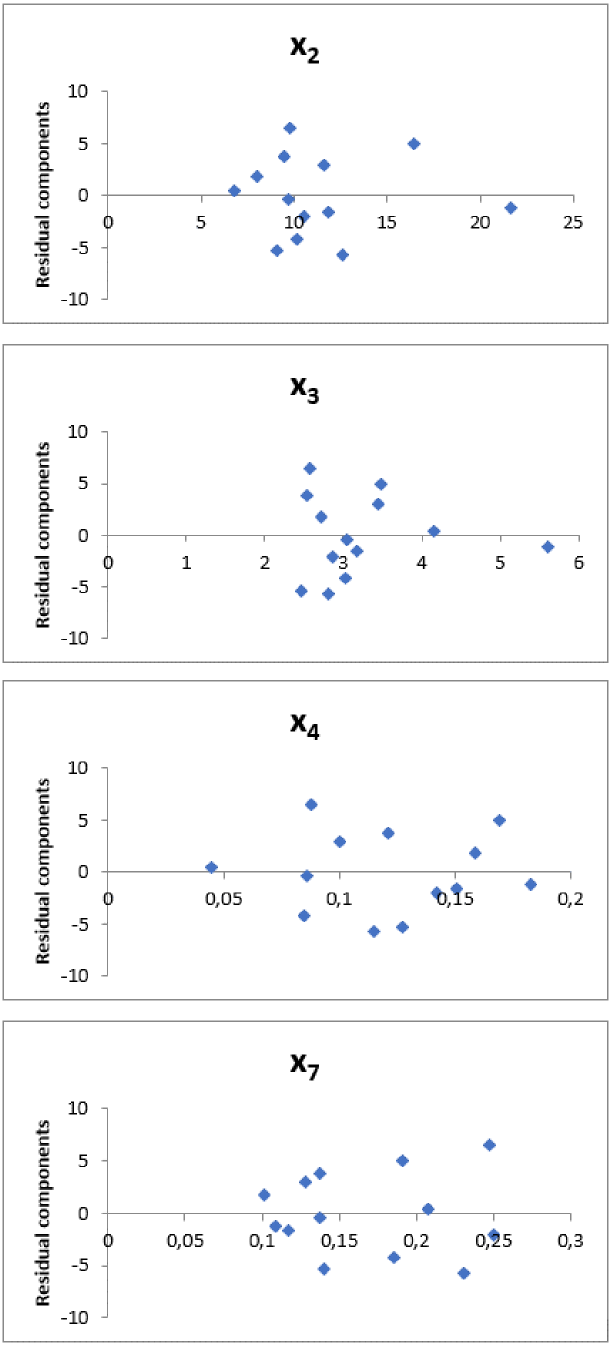
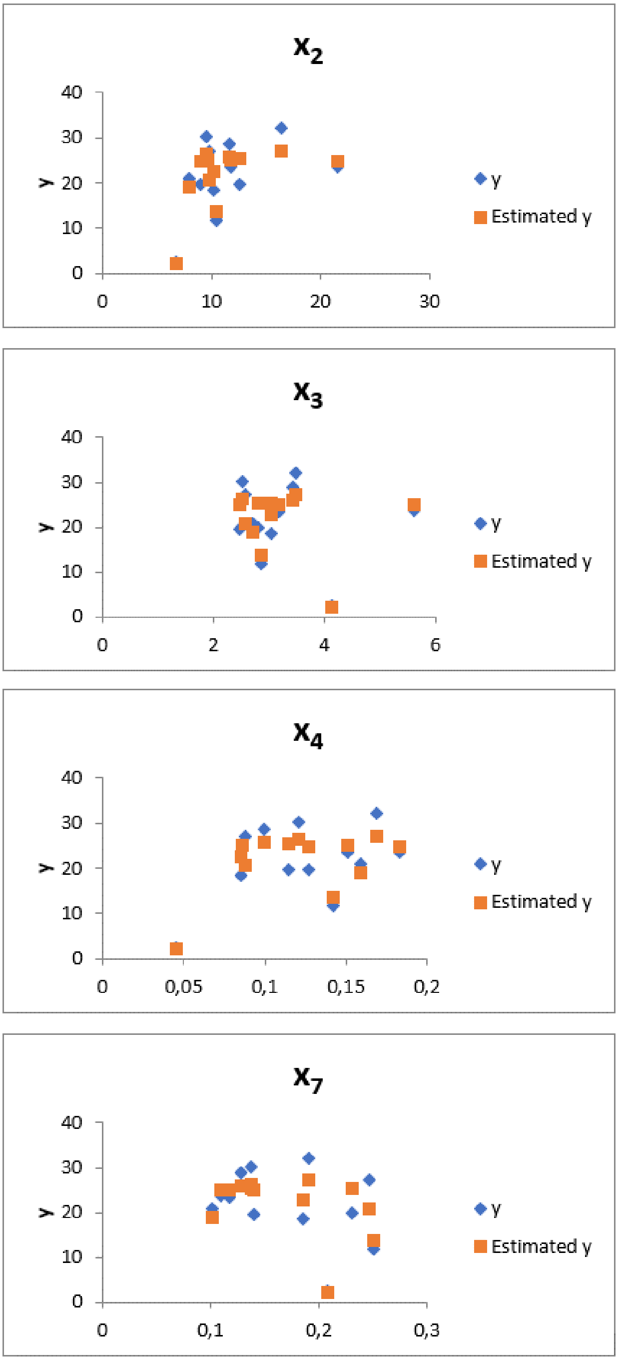


Figure 16. The distribution of the fitted line



The presented situation confirms the research hypothesis that a phenomenon that has been explained using a certain set of variables in one area may not be explained for the entire polycentric metropolis or other smaller areas. It has significant implications for urban planning in heterogeneous urban clusters. The person responsible for urban planning (both in terms of public transport and areas such as urban planning, social, cultural, sports policy, etc.) must take into account the fact that certain factors that greatly affect people living in one area of the metropolis may have a decidedly worse (or no) effect on people living in other areas. This situation means that all plans for the development of the entire metropolis that do not take into account the specific characteristics of the constituent entities, and rely on general data, may prove to be incorrect. This problem will be even more significant, the greater the diversity of a given area (as is the case in the Metropolis GZM) – if a given polycentric agglomeration consists of many entities with different levels of urbanization, education, earnings, etc., general development plans for the entire area may not be suitable for individual constituent parts. The use of the same input data across different areas of an agglomeration leads to varying model fits, which can have significant implications for urban planning. It has been observed that variables that effectively explain phenomena in central city areas may be insufficient or entirely inappropriate for other parts, such as suburbs. This variation suggests that general development plans that do not account for the specifics of individual areas may result in erroneous decisions.

In the case of polycentric agglomerations, a coherent urban system should be created – therefore, a holistic approach to a given urban center is necessary. However, the holistic view should only apply to the main directions of development – individual actions should be considered individually, taking into account the diverse character of individual components of the agglomeration. Otherwise, the effects of implementing a given policy may be completely different from those planned.

A good example of the described error can be a hypothetical situation where a new transport policy is planned in a polycentric-dispersed agglomeration. The model created for the entire agglomeration is well adjusted. However, this does not mean that the policy will work in the same way in all areas – it may turn out that what works very well for the residents of central cities will not work at all for the residents of suburbs (the opposite relationship may also occur). The situation is similar when creating a model whose main goal is to explain human behavior – a high fit of the model in certain parts of the agglomeration may neutralize the weak fit in other parts of the urban complex.

3.3. Praxeology as an alternative to quantitative models

Mainstream economics largely emphasizes quantitative research. However, the question remains whether accurate quantitative models can be created based on incomplete data (which is always the case in macro-scale research). It should also be noted that all quantitative data is strictly related to a given period of time and therefore to the specific conditions that existed during that period. Furthermore, the assessment of the significance of individual factors is directly in the hands of the researcher (Mises, 2007). This raises the question of whether it is possible to predict the future based on incomplete historical data. The answer to this question has been a topic of discussion in the economic community for years (Machaj, red., 2011).

Economics is a social science, which means that it cannot rely on epistemological assumptions derived from natural sciences. In economics, it is not possible to conduct experiments, describe it only in a quantitative way, or conduct induction. Economics must be supported by qualitative research and aprioristic statements, making it a deductive science by definition. Furthermore, all human actions are related to the subjective feelings of individual people, and it is precisely these individual people who should be at the core of economic considerations. Economics is objective precisely because it looks at the subjective approaches of individual people – this is a praxeological approach. Praxeology is an aprioristic science (similarly to mathematics or logic). When a person pursues a chosen goal, they undertake specific actions. They use various means to achieve their goals. It should be noted that everything in the physical world is an object, but it is only when a person takes action and uses a given object that it becomes a means. Objects are studied by natural sciences, while means (i.e., objects used by people to achieve their goals) are the domain of praxeology. However, it should be noted that from the perspective of praxeology, the value judgments made by individual people are not significant – only their actions and their effectiveness matter (Mises, 1998). Therefore, praxeological analysis can be directly translated into issues of urban logistics, where the focus is not only on the goals being pursued but also on the means chosen to achieve them.

All decisions related to the organization of polycentric agglomerations in general, and in particular, the organization of public transport should, according to praxeology, refer to the effectiveness of human action. These models should therefore use deduction to arrive at aprioristic statements, based on which detailed concepts of the functioning of polycentric agglomerations are created (this assumption, mutatis mutandis, also applies to monocentric agglomerations, as aprioristic statements will be the same).

Human action will of course be determined by institutional conditions. In the case of urban transport policy, it will be important whether individual components are subject to free market principles or operate within an interventionist or socialist economy. The ownership of individual entities and their main goal will also be important. State-owned companies focused on achieving predetermined tasks will be managed differently than private companies focused on profit (Mises, 1944). The choice of a particular model will determine the final shape of a given urban center, for example, whether by increasing the cost of public transportation, which would not be acceptable in a free market, we are able to eliminate the problem of mobility exclusion in certain areas or groups of residents.

The main research challenge in applying praxeology to urban studies will be the identification of a fundamental axiom and its development into a praxeological theory of urban areas. This challenge is particularly significant because basing a multidimensional theory of urban areas (Chapter 1.1) on a single foundational statement and then logically expanding the theory from it may prove to be a very difficult task. It should also be noted that such an approach is likely to be considered alternative to the mainstream economic perspective, which may result in it not gaining acceptance among many researchers. Additionally, it is important to highlight that praxeology is a fully qualitative approach – however, the modern world often demands that researchers quantify the phenomena they describe. As a result, it may become necessary to create a praxeological-quantitative methodological hybrid.

Practical research on logistical issues is a practically untouched scientific topic. Logistics, considered as a social science, also falls under the basic, unchanging praxeological laws. Through the use of deduction, it is possible to create a coherent model for assessing the selection of means to achieve the intended goal (as is the case, for example, in the praxeological analysis of the impact of partial reserve on business cycles (Huerta de Soto, 2020) or monetary and credit issues (Mises, 2009). Praxeology seems to be an interesting alternative to established quantitative models in the field. This monography may contribute to the creation of a praxeological model for the functioning of polycentric agglomerations in general, and issues related to urban logistics in particular.

Conclusions

Area delimitation is an extremely crucial component of the implemented transport policy. It is the chosen method and scope of delimitation that largely determines the course of urban area studies and the results obtained in their course. This monograph presents the main directions of addressing area delimitation in the transport policy of large urban areas. The conducted literature review provides a good outline of the identified research gap, and the conducted studies clearly confirm how essential delimitation is for the development of urban areas. One of the conclusions, which unequivocally suggests that the delimitation of urban areas is often a process that is overlooked or, at best, a peripheral element of strategic documents in the field of transport policy, may be concerning.

The literature and empirical research conducted for the purposes of this monograph confirmed the research hypothesis set for the work – that area delimitation significantly influences the fit of econometric models in polycentric-dispersed agglomerations. Both objectives set for the work have also been achieved. The theoretical objective was accomplished through a thorough literature review (chapters 1 and 2). The research objective was realized in the practical chapter of the monograph (chapter 3), where a multiple regression model for the Metropolis GZM area was created, in which different model variants resulted from the chosen method of area delimitation (in the analyzed case, this was delimitation according to the administrative criterion, replicating the most common method of dividing Metropolis GZM in strategic documents). The analysis of three delimited areas showed that the same input data, but for a different research area (depending on the chosen method of delimitation), would yield different results and a different degree of model fit. This situation highlights the fact that delimitation is a very important element of urban area studies, and its omission can lead to incorrect research results.

It should also be noted that the analyses conducted in this work are not free from research limitations, which could have influenced the results obtained to some extent. Part of the data used in the model was aggregated into larger administrative units, necessitating their estimation for smaller areas. Similarly, the selection of input data will affect the results obtained – a different selection of diagnostic variables will generate various outcomes of the multiple regression model and levels of fit. Another research limitation is the chosen method of delimitation itself – as mentioned several times in the work, delimitation according to the administrative criterion is not the best method of dividing urban areas. Nevertheless, there is a lack of reliable data sources for urban areas that aggregate data for categories other than the administrative division of the area. It is also worth noting that the aim of the work was not the analysis of data obtained from the multiple regression model, but the degree of fit of these models – thus, some of the results obtained (e.g., the direction or strength of identified relationships) may raise certain doubts. However, this flaw does not affect the way of assessing the degree of fit of the models, and it is precisely the level of their fit that was the main research area of the monograph.

It's also valuable to identify potential future research areas that would deepen the topics discussed in the monograph. This work serves merely as an introduction to further research and can be seen as an impetus to initiate an academic debate in this field and subsequent studies. Thus, the monograph is merely the proverbial "tip of the iceberg." Future research could focus on conducting a full, systematic literature review in the field of area delimitation, as well as a more comprehensive review of strategic documents in terms of the delimitation models they use. It is also desirable to create a conceptual map of delimitation methods and, most importantly, propose a single, coherent method of conducting the delimitation process in urban areas. Future studies could also explore other urban areas (not just polycentric-dispersed agglomerations). Within these studies, other econometric models could be evaluated as well.

This work is aimed at urban planners, individuals, and institutions responsible for the transport policy of urbanized areas, as well as researchers and other parties interested in the theme of urban transportation and delimitation processes.

The research and its results presented in this work may encourage urban planning decision-makers to pay more attention to the process of delimitation and to consider it a crucial element in shaping transportation policy. The analysis of transportation plans conducted in this study could, in turn, serve as a sort of compass for authors of future documents in this field. Furthermore, the very proposal of using econometric modelling in the context of urban planning could serve as an impetus to place greater emphasis on it in transportation plans. This seems particularly important given the absence of such methods in most of the analyzed documents. The proposed two-dimensional model of urban areas presented in this work may also prove significant, as it can be utilized by urban planners, particularly in metropolitan areas. Nevertheless, it should be noted that this model should be subjected to regular audits to ensure its suitability for the specific characteristics of the urban area in question. There may be a need to add additional dimensions or make complete modifications to the model as necessary. It should also be noted that the chapters providing a synthetic literature review on the phenomena of suburbanization and delimitation will be particularly useful. These chapters will be valuable for researchers seeking a foundation for their studies in this field. Additionally, the review can benefit those responsible for shaping transportation policy in urban areas by offering a better understanding of the main trends in current scientific research. It is also important to highlight the praxeological approach to urban issues proposed in this work. This is an alternative approach to the mainstream research, potentially serving as an ideal complement. However, it should be noted that the use of praxeology in urban studies is an area that has been largely unexplored scientifically, making it a promising direction for future research. Nonetheless, the novelty of this issue may present a significant challenge for conducting studies in this field, as there will be a lack of existing research results upon which further investigations could build.

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Annex – input data

	Y	X_1	X_2	X_3	X_4	X_5	X_6	X_7
Będzin	11,335	590,3 (e)	21,657	4,896	0,177	219	3,073 (e)	0,236
Bieruń	11,77	584 (e)	8,594	7,811	0,105	309	2,948 (e)	0,268
Bobrowniki	12,745	590,3 (e)	19,206	5,901	0,234	238	3,073 (e)	0,26
Bojszowy	6,495	584 (e)	11,5	11,5	0,102	226	2,948 (e)	0,08
Bytom	18,43	476,5	10,177	3,032	0,085	299	2,809	0,185
Chełm Śląski	7,895	584 (e)	9,183	4,093	0,173	244	2,948 (e)	0,094
Chorzów	27,175	449,2	9,745	2,577	0,088	304	2,878	0,247
Czeladź	24,21	590,3 (e)	12,799	3,48	0,116	293	3,073 (e)	0,268
Dąbrowa Górnicza	20,845	598,1	8,006	2,71	0,159	324	2,379	0,101
Gierałtowice	9,465	593,1 (e)	8,443	6,186	0,148	277	3,023 (e)	0,123
Gliwice	19,615	667,7	9,048	2,466	0,127	309	2,275	0,14
Imielin	3,245	584 (e)	2,51	1,646	0,059	306	2,948 (e)	0,118
Katowice	32,095	734,6	16,42	3,49	0,169	259	2,17	0,191
Knurów	12,49	593,1 (e)	7,377	1,975	0,083	424	3,023 (e)	0,25
Kobiór	1,2	606,8 (e)	3,75	3,75	0,044	461	3,027(e)	0,167
Lędziny	5,26	584 (e)	12,236	11,076	0,107	225	2,948 (e)	0,106
Łaziska Górne	5,88	596 (e)	5,963	5,788	0,09	307	2,906 (e)	0,111
Mierzęcice	0,71	590,3 (e)	18,2	14,6	0,2	178	3,073 (e)	0,109
Mikołów	13,83	596	16,042 (e)	3,975	0,151	204	2,906 (e)	0,143
Mysłowice	23,455	574,6	11,816	3,167	0,151	259	2,895	0,117
Ożarowice	26,385	547,3 (e)	13,788	5,925	0,258	238	2,876 (e)	0,16
Piekary Śląskie	11,745	503,9	10,518	2,866	0,142	329	2,582	0,25
Pilchowice	0	593,1 (e)	8,67	7,034	0,077	247	3,023 (e)	0,083
Psary	0	590,3 (e)	17,525	8,537	0,183	183	3,073 (e)	0,119
Pyskowice	7,64	593,1 (e)	7,719	2,39	0,065	302	3,023 (e)	0,2
Radzionków	26,28	547,3 (e)	5,375	2,295	0,082	346	2,876 (e)	0,222
Ruda Śląska	30,255	503,9	9,474	2,532	0,121	319	3,03	0,137
~~Rudziniec~~	~~n/a~~	~~n/a~~	~~n/a~~	~~n/a~~	~~n/a~~	~~n/a~~	~~n/a~~	~~n/a~~
Siemianowice Śląskie	19,715	501,3	12,6	2,801	0,115	265	2,868	0,231
Siewierz	0,135	590,3 (e)	10,014	6,568	0,304	208	3,073 (e)	0,069
Sławków	0,245	590,3 (e)	3,11	2,217	0,111	337	3,073 (e)	0,083
Sosnowiec	28,795	551,5	11,619	3,44	0,1	282	2,818	0,128
Sośnicowice	5,83	593,1 (e)	2,558	2,558	0,177	335	3,023 (e)	0,071
Świerklaniec	2,34	547,3 (e)	12,35	3,643	0,182	318	2,876 (e)	0,256
Świętochłowice	2,555	472,9	6,82	4,148	0,045	259	3,104	0,208
Tarnowskie Góry	12,725	547,3 (e)	13,533	3,274	0,137	299	2,876 (e)	0,265
Tychy	23,69	602,8	21,605	5,611	0,183	203	2,725	0,109
Wojkowice	22,235	590,3 (e)	11,39	3,736	0,181	223	3,073 (e)	0,216
Wyry	5,51	596 (e)	7,967	7,967	0,076	252	2,906 (e)	0,1
Zabrze	24,885	497,2	9,727	3,038	0,086	304	2,691	0,137
Zbrosławice	11,92	547,3 (e)	16,377	8,015	0,269	219	2,876 (e)	0,12

Note:
Y – modal split – public transport in motivations home – work – home [%],
$\mathbf{X_1}$ – motorization indicator [passenger cars / 1,000 inhabitants],
$\mathbf{X_2}$ – length of communication lines per square kilometer of the area of potential transport service [km],
$\mathbf{X_3}$ – length of communication routes per square kilometer of the area of potential transport service [km],
$\mathbf{X_4}$ – number of vehicle kilometers travelled operated by the ZTM on a statistical working day per 1 inhabitant [VKT],
$\mathbf{X_5}$ – average radius of access to the public transport stop for the area of the potential transport service [m],
$\mathbf{X_6}$ – price of a standard monthly ticket for the whole network to the average gross salary in the enterprise sector ratio [%],
$\mathbf{X_7}$ – average number of communication lines per public transport stop,
e – estimated value (ceteris paribus).

This book explores the critical role of urban area delimitation in shaping transportation policy, focusing on its impact on the accuracy of econometric models in polycentric regions. As cities face increasing challenges like suburbanization and spatial complexity, this research sheds light on the often-overlooked process of delimitation. Using the Metropolis GZM as a case study, it offers insights for urban planners, policymakers, and transportation specialists, blending interdisciplinary research with practical findings to highlight how delimitation can influence the future of urban development and transportation strategies.

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