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Original article

A spatial analysis of one of the regional logistics clusters in central Poland using GIS

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ABSTRACT

Logistics services are a consequence of increasingly rapid economic development and globalisation. More and more facilities with adequate transport accessibility are being created for the storage of goods, which form logistics clusters. They emerged later in Central and Eastern Europe than in the United States and Western Europe. Investment in Poland's first logistics parks can be linked to the political and economic transformation in 1989, Poland's accession to the European Union in 2004, the development of motorways, and Poland's integration into the global economy. In the second decade of the 21st century, there are more than a dozen places in Poland that can be called logistics clusters. The purpose of this research was to geographically analyse a selected regional cluster located in Lodz voivodeship, as well as its links to the transport network of Poland and Europe. Geostatistical and GIS methods were used for spatial analysis. It was shown that its spatial distribution is strongly related to the A1 highway, the intersection of the A1 and A2 highways and the voivodeship city of Lodz. The characteristics of the geographic environment give reason to suggest that it has great development potential and is worthy of further observation and comparative studies.

KEY WORDS: logistics parks, geostatistics, Lodz voivodeship, Geographical Information Systems

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1. Introduction

Supra-regional trade is possible when there is an adequate settlement and transport network equipped with logistics services such as transport and storage capacity for goods. Such services have been offered for centuries by coastal port cities such as Amsterdam and Rotterdam, and river port cities such as Lyon and Memphis. Seaports located at the mouths of major rivers have for centuries both stored a variety of goods, trans-shipped and forwarded them onward (SHEFFI, 2012). In James Vance's mercantile model of the development of the North American settlement system (VANCE, 1970), in its fourth and fifth stages, he identified cities with an important role as commercial centres in connection with the hydrographic network (e.g. New Orleans, St. Luis, Buffalo, Cleveland, Detroit, Chicago and Milwaukee). Over time, the road, rail and air transport network began to play an increasingly important role in its development (TAAFFE ET AL., 1963; SCHMITT & GOLLNICK, 2012). Logistics services were a consequence of increasingly rapid economic development and globalisation. More and more facilities with adequate transport accessibility for the storage of goods were created, and logistics clusters were formed. The role of the geographical environment in their location has been emphasised, as well as their distribution in geographical space (SHEFFI, 2012).

The emergence of the first major *logistics clusters* in Poland can be linked to the political and economic

transformation of 1989 (Poland was behind the "Iron Curtain" and had most of its economic ties with the countries of the Council for Mutual Economic Assistance (PELZMAN, 1977)), and the accession of Poland to the European Union in 2004 (JUDGE ET AL., 2004), which allocated considerable funds to support the spatial cohesion of the member states. The Trans-European Transport Network (TEN-T) initiative was launched to strengthen the transnational coordination of transport infrastructure investments. The European Union coordinates and co-finances transnational investments in road, rail, airport and port infrastructure (WIŚNIEWSKI, 2015). The new member states, including Poland, have benefitted and continue to benefit from substantial investment in transport infrastructure. This was the impetus for the development of the economy and, within it, the emergence of logistics services in the country.

In the second decade of the 21st century, there were several places in Poland that could be called logistics clusters. The aim of this study was to analyse one of them, which has been in the making for more than a dozen years and is growing in size each year. The analysis covered the geographical characteristics of the cluster and its links to the transport network of Poland and Europe. The analytical capabilities of GIS were used to bring the data together in a single geodatabase, as well as geovisualisation of the results and statistical analyses.

2. Literature review

The topic of defining logistics centres, as well as a review of the literature on the subject, can be found by many authors (MEIDUTĖ, 2005; RIMIENĖ & GRUNDEY, 2007; KUKOVIC ET AL., 2014; IZDEBSKI ET AL., 2017; UYANIK ET AL., 2018; ISLAM ET AL., 2021). Several authors discussed cases of logistics centres located in metropolitan area, these were: the Paris region, (RAIMBAULT ET AL., 2012; HEITZ & BEZIAT, 2016), the Gothenburg metropolitan area (HEITZ ET AL., 2020), the Tokyo Metropolitan Area (SAKAI ET AL., 2016), the Greater Toronto Area (WOUDSMA ET AL., 2016), the Piedmont Atlantic Megaregion (PAM) and Atlanta (DABLANC & ROSS, 2012), the Wuhan, the largest metropolis in the Central China (YUAN & ZHU, 2019), São Paulo Metropolitan Region (GUERIN ET AL., 2021). Yet others focused on finding potential locations for such centres (BOILE ET AL., 2011; ÖZCEYLAN ET AL., 2016), their concentration and deconcentration (CIDELL, 2010), as well as logistics sprawl (ALJOHANI & THOMPSON, 2016; WOUDSMA ET AL., 2016; HEITZ ET AL., 2017; DABLANC & BROWNE, 2020).

An extensive literature review (based on 2009–2018 data from Scopus and Web of Science databases) on environmental concerns in logistics was found (ISLAM ET AL., 2021). These authors noticed that environmental concerns in logistics are linked to many subject areas, including business management, engineering, environmental sciences, computer science and mathematics. They calculated that the main topic area was business management and accounting (21% of articles), with the second largest topic area being engineering (20%). Environmental sciences *ex aequo* with computer science (4th) (11% of articles). (UYANIK ET AL., 2018) suggested providing guidance to researchers or decision-makers who are looking for answers to the question of what is the best location for a planned logistics centres. For this they searched the ResearchGate database, ScienceDirect, and a database with Turkish diploma theses (1999–2016). As a result of the analyses, the authors presented the most important decision-making criteria they encountered in the literature they had surveyed. These were: Cost (land, labour, investment, facility, operation, transportation, information) – 33%, Natural Resources (water, power and electric supply, weather, landform, geographic, topological, and hydrological condition) – 31%, Proximity to Railroad System 21%, Proximity to Highway System – 19%, Proximity to Airport – 15% Proximity to Harbour – 14%, Size – 14%, Suitability to Enlargement (Land) – 12%, Proximity to Industrial Zone – 12%, Macro-economic Benefit/ Performance – 12%, Environmental Impacts – 11%, Freight Transport – 10%, Suitability to Construction (Topography, Geography, Ground Structure) – 9% and others.

This research analysed the location of a logistics cluster from a geographical perspective. Thus it is necessary to clarify the concept. Discussion of it can be seen in a number of works discussed by SHEFFI (2012). The authors use various terms such as clusters, hubs, or centres. Depending on the country in which the cluster operates, it may have different names, such *logistics parks* in the United States and China, *transport centres* in Denmark, *logistics platforms* in Spain, *freight villages* in Germany, *distriparks* in India, and *logistics centres* in other places. (SHEFFI, 2012. p. 79) defines a cluster as a region with a very high concentration of logistics activities relative to the local population or economy. He distinguishes between the terms *logistics clusters*, *logistics parks*, and *logistics campuses.* Logistics clusters do not,

according to him, have a central management, they are a collection of logistics companies and facilities operating in a certain space with fuzzy boundaries. In contrast, *logistics parks* have a defined owner and geographical boundaries. They can be created by agencies such as ProLogis, private companies such as Hillwood, port or airport managements, as well as government agencies. A special type of *logistics park* is a *logistics campus*, where a business entity operates both the property and the entire logistics operation (such as the logistics campus of United Parcel Service Inc. (UPS) in Louisville, Kentucky). SHEFFI (2012) also notes that logistics clusters can vary in their impact and size. In addition to huge logistics complexes in Rotterdam, Singapore and Shanghai, for example, smaller national or regional centres have been located around the world. Together with the transport infrastructure, they form a dense network with a different spatial extent and economic significance. This analysis uses the concept of a *logistics cluster*, which is a collection of *logistics parks* operating in a certain geographical space.

The question "What is a transport & logistics centre?" is answered by the Europlatforms EEIG, the European Association of Logistics Platforms, which was established in 1991. The platform brings together nine European countries: Portugal, Italy, Germany, Denmark, Greece, Hungary, Poland, Finland and Spain. According to the definition it is a "Centre in a defined area within which all activities relating to the transport, logistics and distribution of goods, both for national and international transit, are carried out by various operators on a commercial basis."[1] It can be noted that the definition of SHEFFI (2012) which is a logistic park has the same characteristics as a logistic centre according to Europlatforms EEIG. The authors of this article assumed that they were studying logistics parks that composed a cluster located in central Poland.

Geographic Information Systems are very well adapted for the spatial analysis of logistics clusters. They are used, among other things, to analyse the potential location of logistics facilities (BOILE ET AL., 2011; RUDA, 2014; SHAHPARVARI ET AL., 2020). In the first stage of the search for an optimal location, GIS is applied to identify suitable areas based on environmental, social, and economic characteristics. For this purpose, GIS collects spatial data such as, for example, terrain topography, hydrography, protected areas, communication links, ownership structure, economic and demographic situations, etc. This is followed by spatial analysis and the creation of maps for further analysis. A multi-criteria decision-making method (MCDM) or selected mathematical models are used to indicate the best location (RIKALOVIĆ ET AL., 2018; ÇAKMAK ET AL., 2021; ÖNDEN ET AL., 2023).

This article addresses selected issues discussed in the literature. Firstly, it presents a regional cluster in central Poland in the Lodz Voivodeship, which was established relatively recently (after the political transformation in 1989) and is still developing. Secondly, it addresses aspects of localization, its relationship with the environment and an analysis using spatial statistics with GIS. Thirdly, the Geographic Information System used and the spatial analysis methods confirm their usefulness in this and other studies.

3. Materials and methods

The research procedure involved several steps (Fig. 1). The main objective of the work included not only the geographical analysis of the selected cluster, but also Table 2 the acquisition of a variety of spatial data and its implementation in a Geographical Information System.

Firstly, the study required the collection of data on logistics centres operating in 2018 in the Lodz voivodeship. It turned out that not a single up-to-date database containing information on all locations was available. For this reason, several databases were used: from the State Emergency Medical Service database for the Lodz voivodeship, the list of logistics centres in the Lodz voivodeship compiled by the Office of Spatial Planning of the Lodz voivodeship, and also from Cushman & Wakefield (Commercial Real Estate Services), which has a commercial database of logistics facilities. Each of these was incomplete but their common part allowed the creation of the base used in the research. In order to check the reliability and validity of the collected data, a field survey was carried out.

The addresses of the logistics park were obtained thanks to geolocation capabilities of the GIS, a vector point layer was created (format shapefile).

[1] https://www.europlatforms.eu/definition/ [27.04.2024}

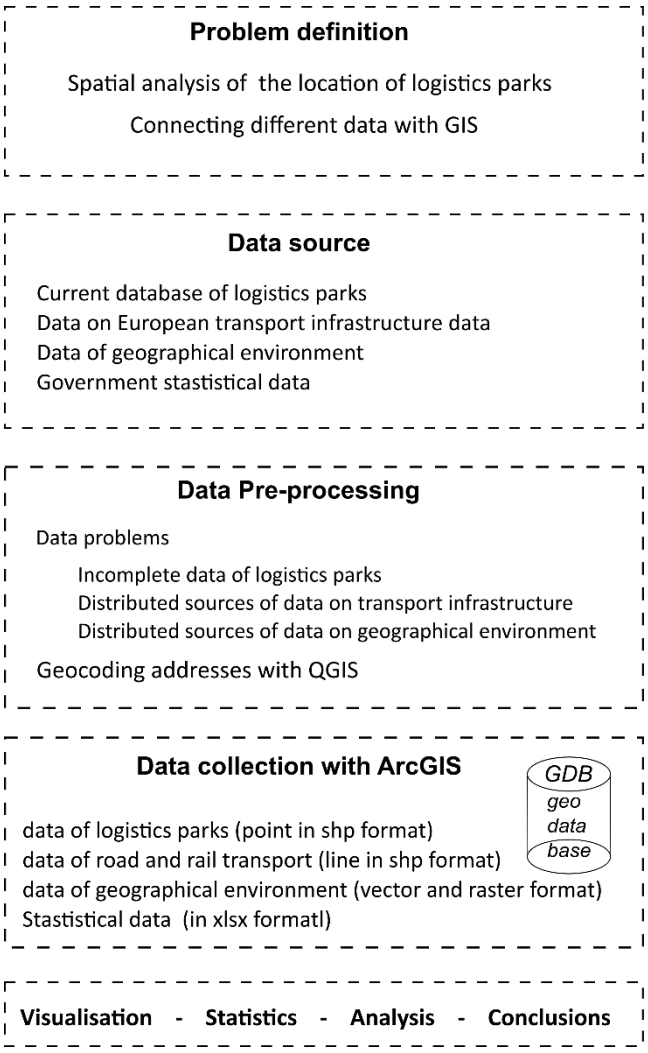

Fig. 1. Methodology for the geographical study of regional logistics parks

Secondly, data on the European transport infrastructure was needed, which was obtained from studies by the European Commission[2] and the Polish Office of Rail Transport[3]. Thirdly, data and studies relevant to the research objective were sought for the geographical analysis. They had different formats, which had to be processed accordingly and combined in a geobase in a single coordinate system. Vector data with the course of major roads, railways, railway terminals, airports, and land cover were obtained from the Polish Head Office of Geodesy and Cartography.

From an analysis point of view, the data on logistics parks, intermodal terminals, airports and motorway junctions were in the geometric form of a point with an associated table of attributes. These were used for spatial statistical analysis. The collected data were prepared accordingly and implemented into GIS software (ArcMap 10.4.1).

Of the various statistical methods also used by other researchers, a few were chosen to be used in this research and these were: average nearest neighbour, centrographic measures, kernel function. The first allowed us to determine the degree of dispersion of points and whether they form a clustered, random or regular distribution in space (MYINT, 2008). The second was meant to identify the geometric centre of the cluster and the directions of dispersal of objects (JAŻDŻEWSKA, 2018), as well as to calculate the statistics for the location of the centroid in relation to the nearest railway terminal, airport, port, motorway junction. The third identified sites with a high density of objects in the geographical space (JAŻDŻEWSKA, 2017) and provided an opportunity to identify factors influencing this density. The whole was used to realise the main objective, i.e. the spatial characterisation of a regional logistics cluster in central Poland. The methodology used, utilising GIS methods and tools, can be used for comparative analyses with other logistics clusters in Europe.

4. Regional logistics centre in the context of the transport network

The study area is located in the centre of Poland, through which the pan-European transport corridors pass[4][5]. These are two parallel corridors II, III, the meridional corridor VI, and the branches of corridor I. Pan-European Corridor II connects Western Europe with Russia, and Corridor III with the Ukraine. Corridor VI starts in the port city of Gdańsk and runs south to the Czech Republic and Slovakia. It has several branches connecting to Corridors I, II, III, IV and V, thus linking the port cities of the Baltic, Mediterranean and Black Sea. In addition, five rail freight lines included in the Trans-European Transport Network (TEN-T) run through Poland (BARTOSIEWICZ & SZTERLIK, 2019; WIŚNIEWSKI, 2017b).

[2]https://ec.europa.eu/transport/infrastructure/tentec/tentec-portal/map/maps.html#&ui-state=dialog
[3]https://dane.utk.gov.pl/sts/transport-intermodalny/mapa-terminali/18573,Dane-o-terminalach-intermodalnych.html#Mapa
[4]https://ec.europa.eu/transport/infrastructure/tentec/tentec-portal/site/maps_upload/corridors_png/Europe_Corridors_ALL_web19_05_2017.png
[5]https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX%3A32017R0849 Annex I

The studied logistics cluster is located in the centre of Poland in the Lodz voivodeship, whose capital is Lodz (Table 1, Fig. 2). The city and the adjacent 30 boroughs have formed the Lodz Metropolitan Area Association linked to the regional rail and bus networks, as well as to the transport network of Poland and European Union countries (NAPIERAŁA ET AL., 2013). In the future, the planned high-speed rail line running through the city[6] (Fig. 2) will play an important role. It is worth stressing the very high transport potential of Lodz both on a regional and national scale (WIŚNIEWSKI, 2017a). It was decided that the location of the cluster would be referred to the administrative boundaries of the Lodz voivodship.

From the 19th century until the 1990s, Lodz was Poland's largest centre of the textile industry (LISZEWSKI, 1997). The city is one of the largest in Poland. Lodz's current industrial zone includes companies representing various industries. More than 40 companies operate here in the domestic appliance sector, among them: B/S/H, Indesit, Coco, Drahtzug Stein, Míele, Whirpool, WITHWEIN. Mecalit, Ciat; there are also pharmaceutical and cosmetic companies: Gillette, Procter & Gamble, mabian, Aflofarm, Dela Cosmetics; companies manufacturing automotive components: Haring, Wielton. ABB, Drahtzug Stein; IT companies: Ericpol, Fujitsu Services, AMG.net, Tom-Tom, Hexagongeospatial, BPO companies: Infosys, BSS, Deloitte Digital. Some 40 garment and textile companies are still in operation.

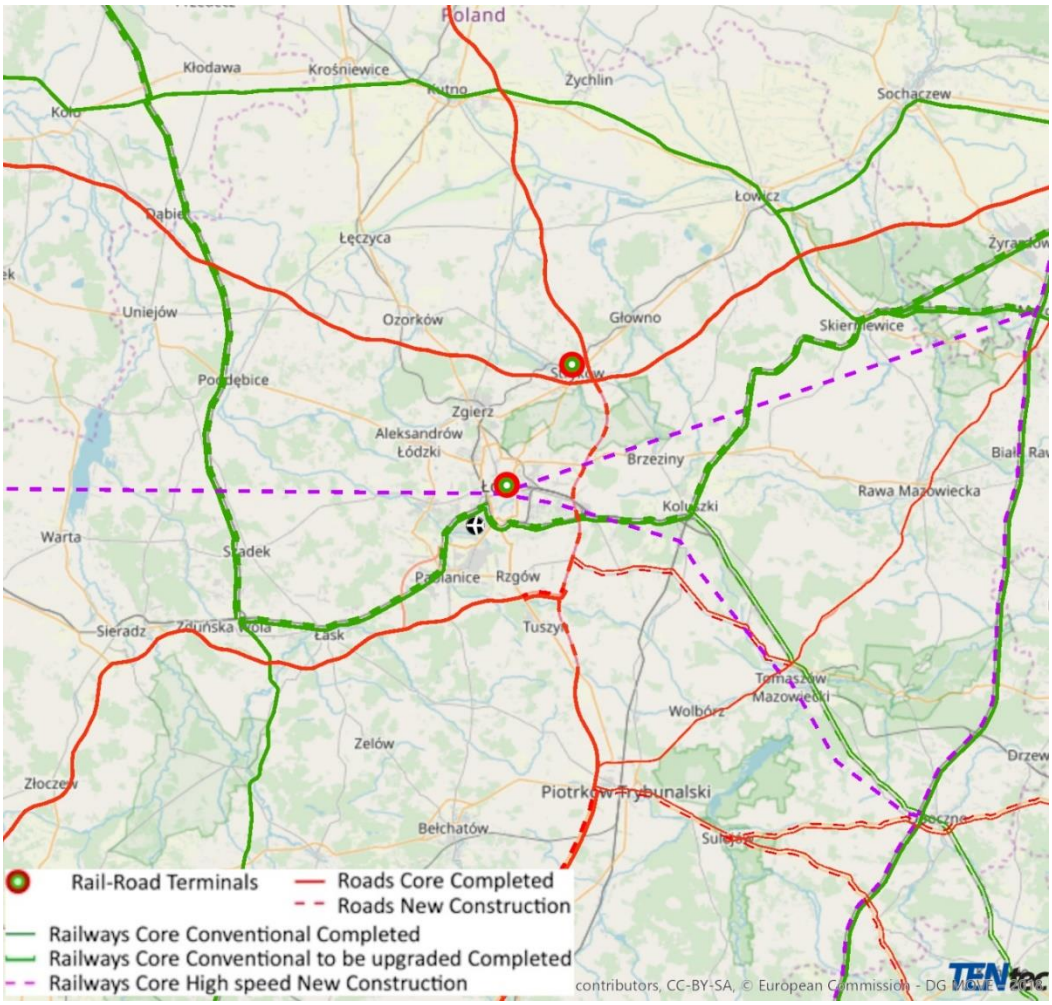

Fig. 2 Comprehensive transport network in the Lodz region
(Source: https://ec.europa.eu/transport/infrastructure/tentec/tentec-portal/map/maps.html#&ui-state=dialog)

[6]https://ec.europa.eu/transport/infrastructure/tentec/tentec-portal/map/maps.html

Table 1. Selected attributes of the study area in 2020 (Source: Own elaboration and https://stat.gov.pl/)

Attributes	City Łódź	Łódzkie voivodship
Total area [km^2]	293	182019
Population [thousands]	678 104	2 415 816
Population per 1 km^2	2 295	133
Transport and storage [employed in total]	nd	34 013
Number of rail intermodal terminals	2	6
Exploited railway lines [km]	70	1080
Railway lines in 100 km^2	23	5,9
Expressways and motorways [km]	25	449

Two pan-European corridors intersect in the vicinity of Lodz: No. I is the A1 motorway (Gdańsk – Gorzyczki border with the Czech Republic) and No. II is the A2 motorway (Świecko border with Germany – Kukuryki border with Belarus). In addition, two S8 expressways are in operation (Wrocław–Warsaw–Białystok), the S12 expressway (Piotrków Trybunalski – Dorohusk border with Ukraine) is under construction and the S14 western bypass of Lodz will connect the A2 motorway with the S8 expressway. Not all roads listed are 100% complete but construction work is ongoing (Fig. 4). The intersection of the two motorways A1 and A2 provides an opportunity to connect the cluster with European ports (Table 2). Lodz is located closest to the Baltic ports and the North Sea, reachable within a few hours, only the ports on the other side of the Baltic (Swedish Malmö and Russian Primorsk) are 11 to 17 hours away (not counting the time to cross the border with Russia). It takes 13–15 hours to reach the English Channel (Dunkerque, Le Havre) and about a day to reach the Black Sea and Mediterranean ports. The Spanish and Portuguese Atlantic ports of Algeciras and Lisbon are located the farthest (over 31 hours).

There are also important railway routes running through the centre of Poland (C-E20 RFC8 North Sea-Baltic Sea (east-west), C-E65/1 RFC5 Baltic Sea-Adriatic Sea (north-south) and there are six intermodal terminals with a total capacity of 534 thousand [TEU][7] (Eurotrans in Stryków, Spedcont and Centrostal in Lodz, Loconi Intermodal Radomsko, Erontrans Container Terminal in Radomsko, PCC Intermodal Kutno), which enable the transshipment of goods and serve as important logistics elements. There are plans for a high speed railway that will run through the city (partly underground) and connect Warsaw – Lodz – Poznań – Berlin and Warsaw – Lodz – Wrocław – Prague. 25% of containerised goods by intermodal road transport in 2021 (based on the number of tonnes) are transported through the Lodz Voivodeship (the transport of containerized goods by intermodal road transport in 2021 (based on the number of tonnes) (Fig. 3).

Table 2. Distance and travel time from the junction of the A1 and A2 motorways in Poland to European ports (Source: Own elaboration based on Google Maps)

Baltic Sea			North Sea			Mediterranean Sea			Black Sea		
Port city	Distance [km]	Time [h]	Port city	Distance [km]	Time [h]	Port city	Distance [km]	Time [h]	Port city	Distance [km]	Time [h]
Gdańsk	365	3:10	Hamburg	802	7:24	Triest	11102	110:51	Odessa	11335	116:00
Riga	779	9:14	Bremerhaven	923	8:10	Genua	11599	115:31	Constanta	11842	118:40
Malmo	934	11:00	Rotterdam	1175	11:00	Marsylia	11964	118:20	Varna	11849	119:40
Petersburg	1414	17:16	Antwerpia	1200	11:02	Barcelona	21251	221:30	Novorossiysk	11975	225:00

[7]https://dane.utk.gov.pl/sts/transport-intermodalny/mapa-terminali/16784,Dane-o-terminalach-intermodalnych.html

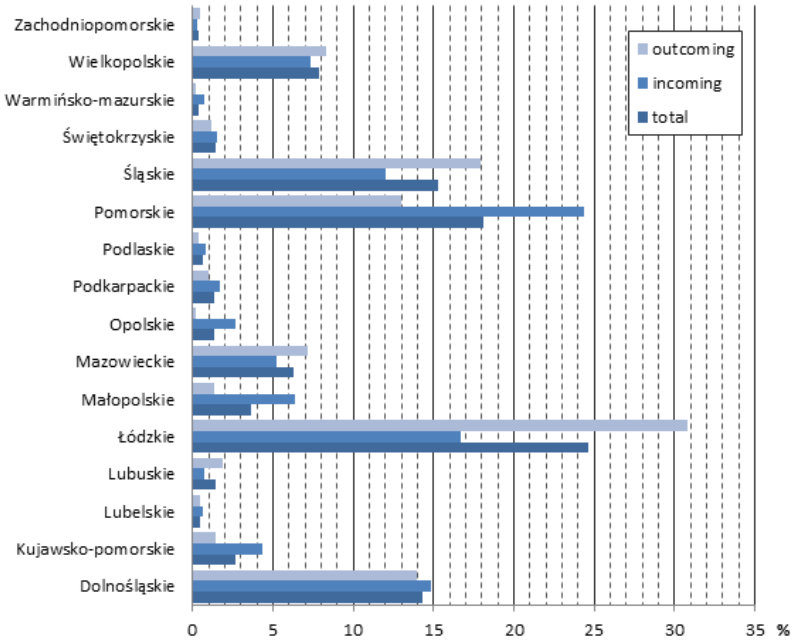

Fig. 3. The share of voivodships in the transport of containerised goods by intermodal road transport in 2021 (based on the number of tonnes)[ab] (Source: Intermodal Transport in Poland in 2021, 2022; redrawn Fig. 5 p. 4)
[a]The data include transport to / from intermodal terminals located in Poland. [b]Estimated data

5. Spatial analysis

In 2018, there were 49 logistics parks in the study area (2018). Among others, the following companies had their facilities here: CBRE, Goodman, Hillwood, Jones Lang LaSalle, Logicor, MountPark, Prologis, Park Panattoni Development Company Raben Group, Segro, White Star Real Estate, as well as: Auchan, Dino, Ikea, Unilever, Kaufland. The vast majority of these are international companies. A preliminary assessment of their location in the Lodz Voivodeship allows one to conclude that their spatial distribution has a certain specificity (Fig. 4). Links to the settlement and transport networks are evident.

At the beginning, it was assumed that the study sites form a spatial cluster in statistical terms. This hypothesis was verified by using the Average Nearest Neighbour (ANN) analysis (Fig. 5). The ANN method assesses the extent to which a spatial point pattern deviates from a random one in the direction of clustering or regularity (PHILO & PHILO, 2022). The Average Nearest Neighbour (ANN) tool in ArcGIS measures the distance between the centroid of each point and the position of the centroid of its nearest neighbour and averages all these distances. If the average distance is less than the average for a hypothetical random distribution, the distribution of the analysed features is considered clustered. A z-score value of -7.34 (with a standard deviation of 1.65) confirms the existence of a spatial cluster formed by the logistics centres of the study area.

Centrographic measures were then used to indicate the geometric centre of the cluster and the directions of dispersion of the logistics parks (Fig. 6, Table 3). The results were used to look for factors influencing their location and spatial layout. Centrographic analysis showed that the geometric centre of the sites was located 20 km south of the important junction of the A1 and A2 motorways and near the eastern border of the city of Lodz. This distance from the motorway junction may be indicative of its importance but there are probably other factors that have moved the centroid southwards. Arguably, the course of the S8 expressway was taken into account when planning the project. It runs 30 km south of the A2 motorway. 43% of the logistics parks were located within a 10 km radius of the geometric centre, most of them within the administrative boundaries of the city.

A standard deviation ellipse, whose elongated shape follows the course of the A1 motorway (Fig. 6), was used to analyse the dispersion of the distribution of sites. It is interesting to note that the A1 motorway (called the Amber Motorway) was put into service later than the A2 (called the Freedom Motorway). This may mean that it plays a more important role in logistics in the Lodz voivodeship. The ellipse includes 67% of the facilities and three intermodal terminals, while the other (2SD) encloses 98% of the facilities and four intermodal terminals.

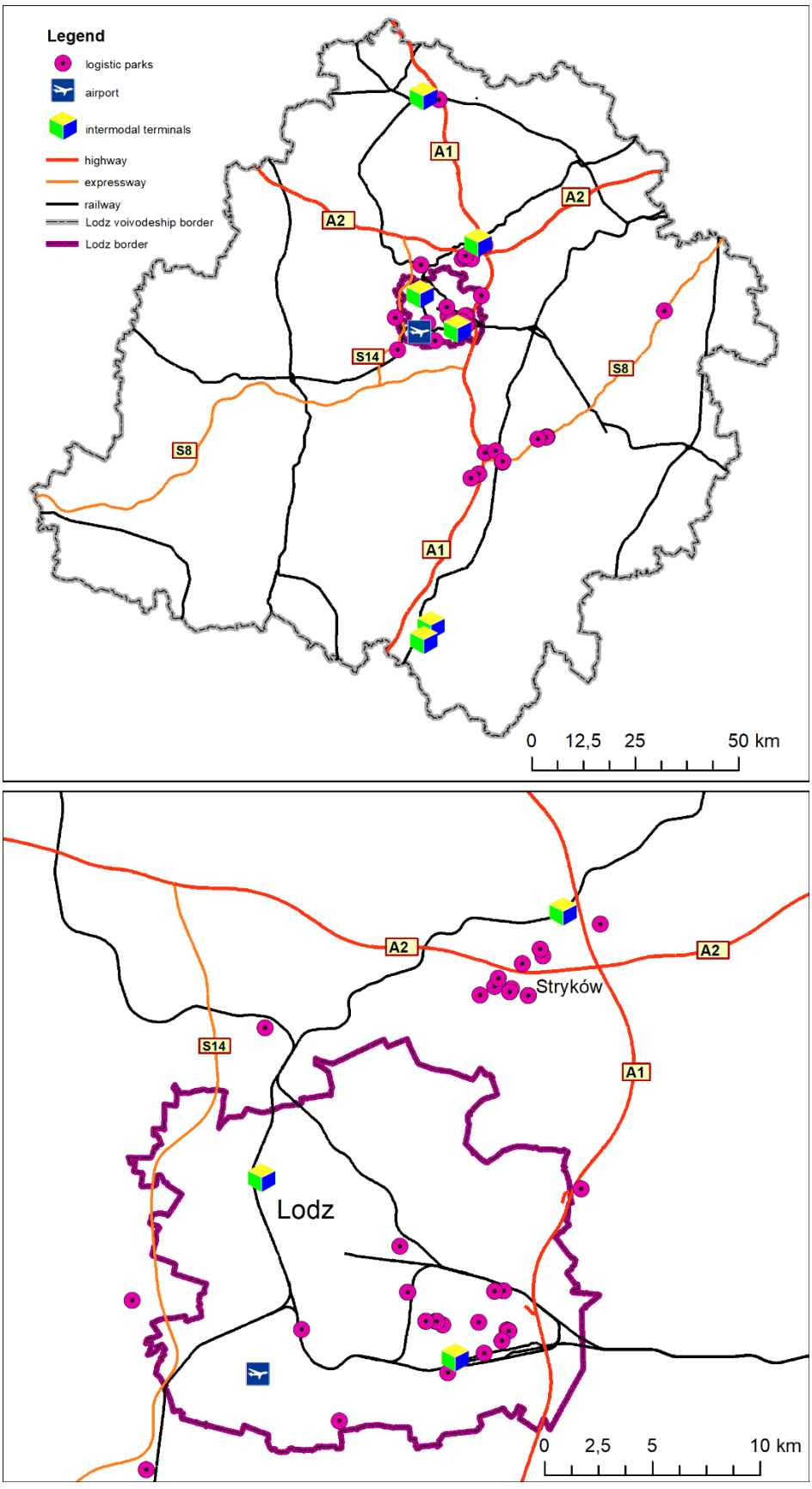

Fig. 4. Logistics parks in Lodz Voivodship in 2019 against the background of road (a) and rail (b) networks with rail terminals (Source: own elaboration with ArcGIS and utk.gov.pl)

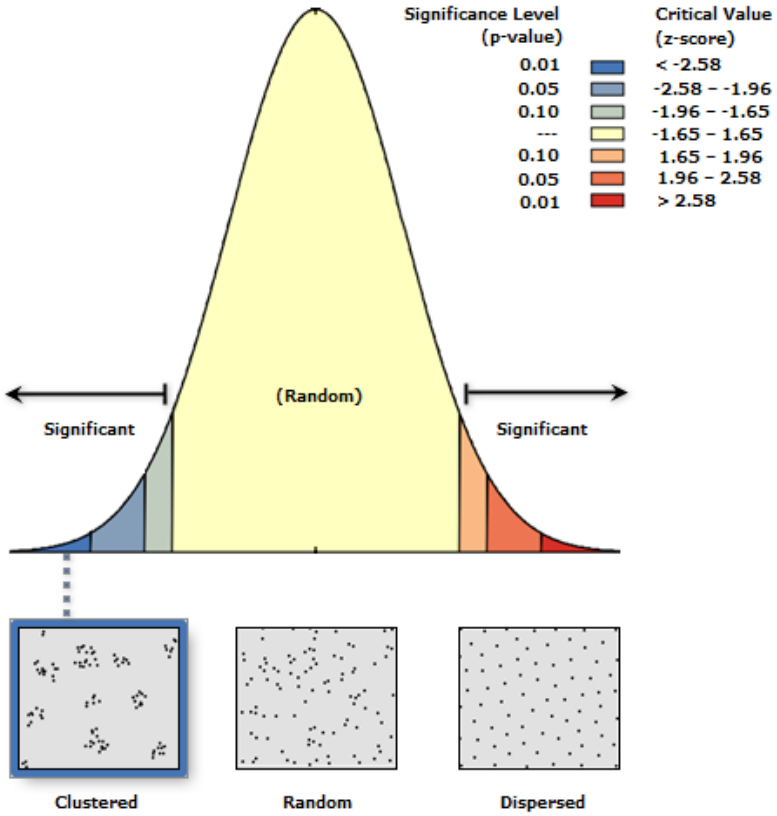

Fig. 5. Average nearest neighbour for the logistics park in Lodz voivodeship in 2018 (Source: own elaboration with ArcGIS)

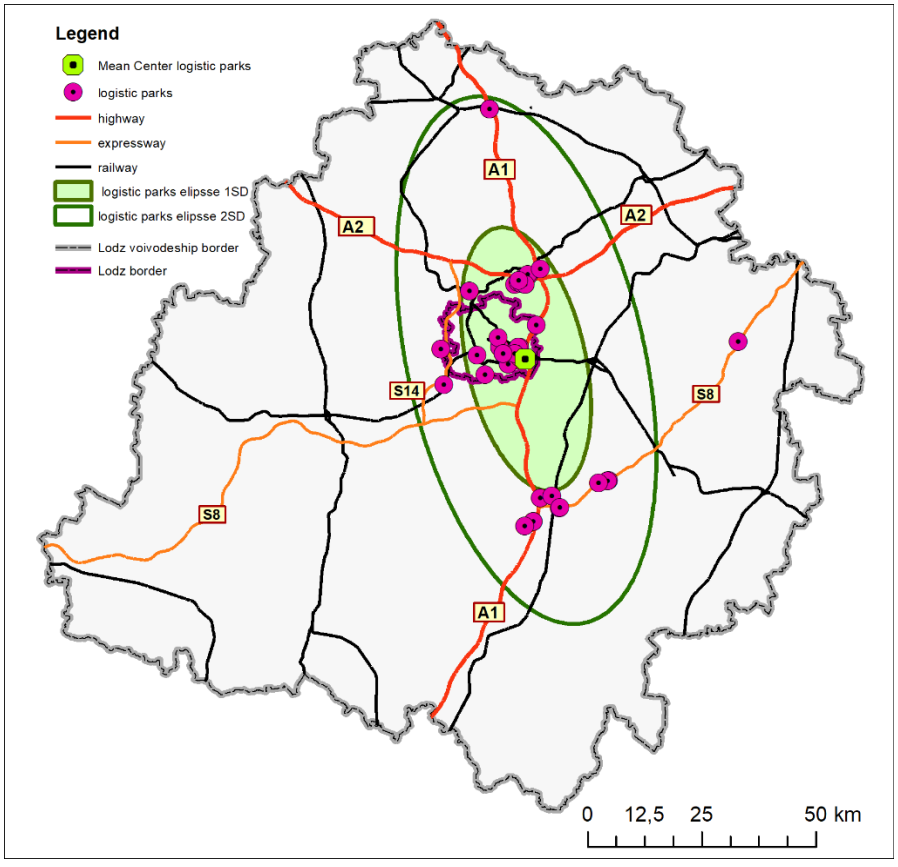

Fig. 6. Spatial Central Tendency and Distribution for logistic parks in Lodz voivodeship in 2018 (Source: own elaboration with ArcGIS)

Table 3. Dispersion statistics around the mean centre (X=2181148.3; Y=6751938.2)* (Source: own elaboration with ArcGIS)

Ellipse	XStdDist	YStdDist	Rotation	Area [m2]	% of objects
1SD	47692,6	20961,5	166,3	3140321352,2	67
2SD	47692,6	20961,5	166,3	12561285413,1	98

*Coordinate system

The designated centroid of the facilities allowed the location and distance to the nearest points relevant to logistics services to be indicated:

- Poland's largest cargo airport (Warsaw Chopin) – 150 km;
- the third largest cargo airport in Poland (Lodz Lublinek) – 13 km;
- the NATO airfield in Łask – 40 km;
- the nearest Container Terminal (Lodz Olechów) – 5 km;
- the nearest junction of the A1 motorway – 2 km;
- the nearest junctions of the junction of the A1 and A2 motorways – 20 km;
- the closest Baltic Sea port (Gdańsk) – 365 km;
- the nearest North Sea port (Hamburg) – 802 km;
- the nearest Mediterranean port (Trieste) – 1102 km.

The observed properties were confirmed by geovisualisation using the Kernel function (Fig. 7). The nucleus with the highest density is clearly located where the centroid lay, a slightly lower density occurs near the junction of two motorways. It can be noted that the road and rail networks are also the densest here and the Lodz Metropolitan Area provides the workforce for logistics. A new cluster is starting to form in the south near the city of Piotrków Trybunalski at the junction of the S8 expressway and the A1 motorway.

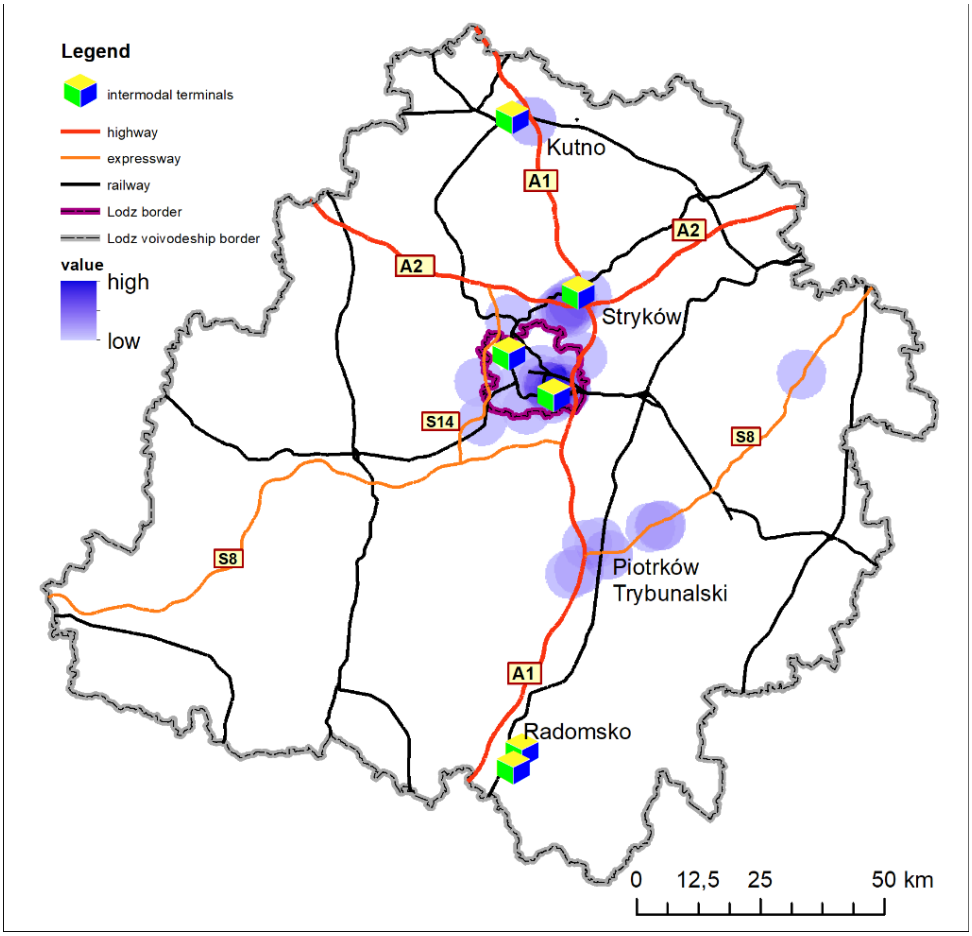

Fig. 7. The density of logistics parks in Lodz voivodeship in 2018 (Kernel function) (Source: own elaboration)

Arguably, intermodal terminals play a role, but not as important as it might seem. In the south around Radomsko, there are two terminals in operation and there is no logistics park there yet. In contrast, a few dozen kilometres north of Radomsko, near the city of Piotrków Trybunalski, there is not a single terminal, and seven logistics parks are already in operation.

The use of GIS capabilities made it possible to relate the location of a regional logistics centre in Poland to the geographical environment in which it operates. This approach has already been used to assess the potential of freight villages in relation to the geographical environment (ÖZCEYLAN ET AL., 2016). The authors considered that from an environmental point of view they should be located away from forests, rivers, and lakes. They took into account the possibility of storing hazardous materials in them, which pose a risk to the environment as a result of fires or other disasters. The following values were sought: distance from forest zones, rivers, lakes, slope, earthquake epicentre (ÖZCEYLAN ET AL., 2016). The authors' proposal was used to evaluate an existing cluster. In the case of the cluster analysed, distances were calculated in relation to the cluster centroid and the ellipse.

Inside the ellipse of standard deviations representing the dispersion of logistics parks were several forest areas, among them several nature reserves (Łagiewniki Forest, Rąbień, Gałków and others). Approximately 70 km north-east of the centroid was a larger (231 km^2) protected area (Bolimowski Landscape Park). This means that investors and local authorities issuing building permits did not take this criterion into account.

Other elements of the geographical environment do not adversely affect their location. The hydrographic network in central Poland is rich but dominated by small rivers that often have their sources inside the ellipse. This is due to their location on the 1st order watershed of the two Polish rivers Vistula and Oder. There is a lack of lakes nearby, with the only two artificial reservoirs located outside the ellipse at a distance of 53 km (Sulejów Reservoir on the River Pilica) and 105 km (Jeziorsko Reservoir on the River Warta) from the centroid. This means that the hydrographic network is conducive to the location of such facilities, as there are not many water barriers and the need for bridges over which to cross. The surface of the area is mostly flat with a few regions with elevations of up to 300 m above sea level (GOŹDZIK & WIECZORKOWSKA, 2002). The climate of Lodz voivodeship is moderately continental, weather patterns in Poland are transient and variable. Atlantic air moves in from the west, Arctic air comes in from the north, and subtropical air comes in from the south. Summer temperatures are pleasant (July average 19.2°C), with occasional brief heat waves, with maximum temperatures exceeding 30°C. Winter is cold (January average -1.4°C), with not very heavy snowfall. Sometimes there can be cold waves from Siberia, and temperatures can drop to -20°C[8]. Extreme weather conditions such as hurricanes, tornadoes and snowstorms do not occur in the study area. An earthquake epicentre has also not been observed. Of some importance may be the fact that logistics facilities have been built in areas that were previously arable land or uncultivated grassland. However, the soil here is poor, mainly sandy, or low fertility clay (ZIOMEK ET AL., 2002).

6. Discussion and conclusions

The analysed cluster is not one of the largest in Poland, but it is growing steadily. The biggest impetus for its development has been investment in the road infrastructure, especially expressways and motorways. They are now a permanent part of Europe's transport network. Within a decade (2011–2022), their length increased from 77 km to 497 km in the Lodz Voivodeship. The construction of individual logistics parks was planned even before these road projects were finished. Their growth has had an impact on increasing the available employment in Section H "Transportation and storage" (BY NACE REV.2) in the Lodz Voivodeship (Fig. 8).

It should be mentioned that, in the second decade of the 21st century, Lodz handled about 25% of the trains going from China to the EU and vice versa (JAKÓBOWSKI ET AL., 2018). There are probably going to be even more. In April 2013, the China Railway Express (CR Express) launched a rail connection between Chengdu-Lodz (POMFRET, 2018; POMFRET, 2021). Lodz has become an Eastern European hub for EU-China rail freight traffic. The DB cargo Eurasia German operator DB cargo Eurasia connects Lodz and Deyang by rail. The first train arrived from this Chinese city to the Polish city on December 4th, 2021 (PAPATOLIOS, 2021).

The geographical environment of central Poland favours investment in logistics services. As noted earlier, cities that lie between the main demand and supply regions (e.g. Memphis, Singapore, Chicago

[8] https://www.climatestotravel.com/climate/poland/lodz

and Zaragoza) can become logistics hubs. Their potential increases if their location in the transport network is optimal (rail, roads, airports) and they do not interfere with the natural environment (SHEFFI, 2012). In addition to the investment in the transport infrastructure to date, more is planned. New railway lines will be built and a Central Airport in Poland is planned about 100 km north-east of Lodz (WĄSOWSKA & ŽUKOVSKIS, 2019). Only river transport services are unavailable because, as mentioned earlier, there are mainly small rivers in this region.

With reference to Vans' mercantile model of settlement system development, the described logistic cluster economically strengthens several medium-sized cities (Kutno, Stryków, Piotrków Trybunalski) and the voivodeship city of Lodz. It can be thought that its increasingly better communication position in Poland and Europe (Fig. 2) will strengthen its rank in the settlement system of Poland and Europe. Consequently, it will transform from a post-industrial city into a multifunctional city, with logistics as one of the significant functions.

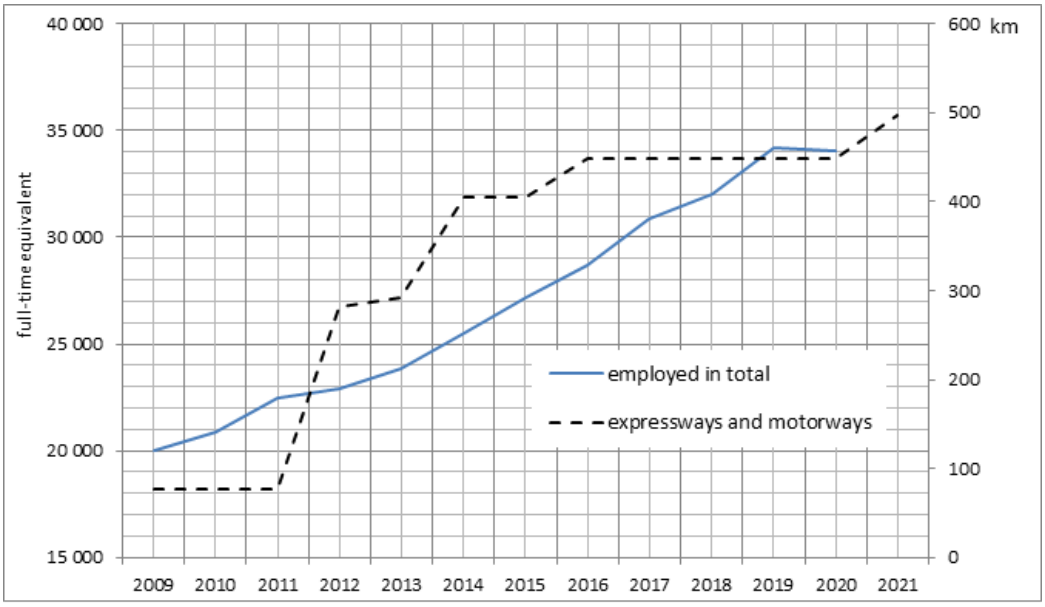

Fig. 8. Employment in Section H "Transportation and storage" and length of roads in the Lodz voivodship (2009-2020) (Source: own elaboration based on stat.gov.pl)

The development of the studied logistics cluster is worth observing and analysing in the future. The next stage of the research may be to conduct a comprehensive assessment of the location of the logistics facilities in terms of their impact on Lodz's urban freight traffic, its influence on all traffic in the region, and the associated negative effects (SAKAI ET AL., 2018). As noted earlier, logistics facilities have a significant impact on the urban environment as these facilities are the main initiators and receivers of cargo (ALJOHANI & THOMPSON, 2016). Therefore, it is worthwhile to undertake further research on their impact on individual cities, especially the largest city, Lodz. The location of these facilities within the administrative boundaries of the city, on the one hand, is beneficial because it concentrates jobs for residents. On the other hand, it is unfavourable because it inhibits its spatial development.

The type of goods handled by the logistics facilities was not taken into account in the study. This may be relevant to the efficiency of the logistics system, and the efficiency of the location of logistics facilities (SAKAI ET AL., 2018). It may be important to analyse the location of facilities storing environmentally hazardous materials in terms of their location in relation to residential development as well as forests, rivers, lakes, and protected areas (ÖZCEYLAN ET AL., 2016).

An interesting issue for further research is the link between this problem and the region's economy (labour market, daily travel to work, taxes). As each site has some spatial relationship with other logistics parks, it would be useful to address the spatial extent and network of links between them.

The analysed area has great potential for further development of transport and warehousing services and could be an interesting case for comparative studies with other regional logistics centres and for spatial-temporal studies. Such considerations may be useful for planning other new locations for these services.

It is worth noting the potential for using GIS in studies of this type. Above all, it plays a significant role in the collection of related data that can be used during current analyses, as well as in future years for comparative analysis. Spatial data usually comes in different digital formats, and from a variety of sources, so proper harmonisation of this data is essential. Linking them in a single Geographical Information System offers great analytical opportunities, using geostatistical methods and supports decision-making.

References

Aljohani K., Thompson R.G. 2016. Impacts of logistics sprawl on the urban environment and logistics: Taxonomy and review of literature. *Journal of Transport Geography*, 57: 255–263.

Bartosiewicz A., Szterlik P. 2019. Lodź na nowym jedwabnym szlaku. Analiza przypadku. *Studia Ekonomiczne. Zeszyty Naukowe*, 385: 94–109.

Boile M., Theofanis S., Ozbay K. 2011. *Feasibility of freight villages in the NYMTC region*. Rutgers University. Center for Advanced Infrastructure and Transportation Corporate Contributor(s): New York Metropolitan Transportation Council.

Çakmak E., Önden İ., Acar A.Z., Eldemir F. 2021. Analyzing the location of city logistics centers in Istanbul by integrating Geographic Information Systems with Binary Particle Swarm Optimization algorithm. *Case Studies on Transport Policy*, 9, 1: 59–67.

Cidell J. 2010. Concentration and decentralization: The new geography of freight distribution in US metropolitan areas. *Journal of Transport Geography*, 18, 3: 363–371.

Dablanc L., Browne M. 2020. Introduction to special section on logistics sprawl. *Journal of Transport Geography*, 88: 102390.

Dablanc L., Ross C. 2012. Atlanta: a mega logistics center in the Piedmont Atlantic Megaregion (PAM). *Journal of Transport Geography*, 24: 432–442.

Goździk J., Wieczorkowska J. 2002. Landforms. [in:] *The Lodz Atlas* (p. Sheet VIII). Łódzkie Towarzystwo Naukowe, Łódź.

Guerin L. Vieira J.G.V., de Oliveira R.L.M., de Oliveira L.K., de Miranda Vieira H.E., Dablanc L. 2021. The geography of warehouses in the São Paulo Metropolitan Region and contributing factors to this spatial distribution. *Journal of Transport Geography*, 91: 102976.

Heitz A., Beziat A. 2016. The Parcel Industry in the Spatial Organization of Logistics Activities in the Paris Region: Inherited Spatial Patterns and Innovations in Urban Logistics Systems. *Transportation Research Procedia*, 12: 812–824.

Heitz A., Dablanc L., Olsson J., Sanchez-Diaz I., Woxenius J. 2020. Spatial patterns of logistics facilities in Gothenburg, Sweden. *Journal of Transport Geography*, 88: 102191.

Heitz A., Dablanc L., Tavasszy L. A. 2017. Logistics sprawl in monocentric and polycentric metropolitan areas: the cases of Paris, France, and the Randstad, the Netherlands. *Region*, 7, 1: 93–107.

Intermodal transport in Poland in 2021. 2022. GUS, Warszawa.

Islam M., Moeinzadeh S., Tseng M-L, Tan K. 2020. A literature review on environmental concerns in logistics: trends and future challenges, *International Journal of Logistics Research and Applications*, 24, 2: 126-151.

Izdebski W., Szwed C., Skudlarski J., Kryś P. 2017. Formulating a uniform definition of a logistics centre. *Research in Logistics and Production*, 7, 4: 367–376.

Jakóbowski J., Popławski K., Kaczmarski M. 2018. *The Silk Railroad. The EU-China rail connections: background, actors, interests. OSW Studies Number 72, February 2018* (H. Kowalczyk, ed.). Centre for Eastern Studies.

Jażdżewska I. 2017. Changes in population density of the urban population in southern Poland in the period 1950-2011 against the background of political and economic transformation. *Miscellanea Geographica*, 21, 3: 107–113.

Jażdżewska I.A. 2018. The use of centrographic measures in analysing the dispersion of historic factories, villas and palaces in Lodz (Poland). *Folia Geographica*, 60, 1: 50–61.

Judge E.J., Werpachowski K., Wishardt M. 2004. Environmental and economic development issues in the Polish motorway programme: Some findings on local authority attitudes. *Journal of Transport Geography*, 12, 4: 287–299.

Kłysik K., Wibig J., Fortuniak K., Rembowski K., Fokczyński J., Podstawczyńska A. 2002. Climate. [in:] *The Lodz Atlas* (p. Sheet X). Łódzkie Towarzystwo Naukowe, Łódź.

Kukovic D., Topolsek D., Rosi B., Jereb B. 2014. A Comparative Literature Analysis Of Definitions For Logistics: Between General Definition And Definitions Of Subcategories. *Business Logistics in Modern Management*, 14: 11–122.

Liszewski S. 1997. The origins and stages of development of industrial Lodz and the Lodz urban region. [in:] S. Liszewski, C. Young (eds.), *A Comparative Study of Lodz and Manchester*, University of Lodz Press, Łódź: 11–35.

Meidutė I. 2005. Comparative analysis of the definitions of logistics centres. *Transport*, 20, 3: 106–110.

Myint S. W. 2008. An exploration of spatial dispersion, pattern, and association of socio-economic functional units in an urban system. *Applied Geography*, 28, 3: 168–188.

Napierała T., Adamiak M., Wiśniewski S. 2013. Regionalna sieć transportowa determinantą lokalizacji centrów logistycznych w województwie łódzkim. *Transport Miejski i Regionalny*, 9: 15–19.

Önden İ., Eldemir F., Acar A.Z., Çancı M. 2023. A spatial multi-criteria decision-making model for planning new logistic centers in metropolitan areas. *Supply Chain Analytics*, 1: 100002.

Özceylan E., Erbaş M., Tolon M., Kabak M., Durɹut T. 2016. Evaluation of freight villages: A GIS-based multi-criteria decision analysis. *Computers in Industry*, 76: 38–52.

Papatolios N. 2021. DB Cargo Eurasia adds Lodz in network. *RailFreight*.

Pelzman J. 1977. Trade Creation and Trade Diversion in the Council of Mutual Economic Assistance 1954-70. *The American Economic Review*, 67, 4: 713–722.

Philo C., Philo P. 2022. 2.15 or Not 2.15? An Historical-Analytical Inquiry into the Nearest-Neighbor Statistic. *Geographical Analysis*, 54, 2: 333–356.

Pomfret R. 2018. *The Eurasian land bridge: the role of service providers in linking the regional value chains in East Asia and the European Union*. Economic Research Institute for ASEAN and East Asia: 1–19.

Pomfret R. 2021. The Eurasian landbridge: Implications of linking East Asia and Europe by rail. *Research in Globalization*, 3: 100046.

Raimbault N., Andriankaja D., Paffoni E. 2012. Understanding the Diversity of Logistics Facilities in the Paris Region. *Procedia - Social and Behavioral Sciences*, 39: 543–555.

Rikalović, A., Soares G. A., Ignjatić J. 2018. Spatial analysis of logistics center location: A comprehensive approach. *Decision Making: Applications in Management and Engineering*, 1, 1: 38–50.

Rimienė K., Grundey D. 2007. Logistics Centre Concept through Evolution and Definition. *Engineering Economics*, 4, 54: 87–95.

Sakai T., Kawamura K., Hyodo T. 2016. Logistics Facility Distribution in Tokyo Metropolitan Area: Experiences and Policy Lessons. *Transportation Research Procedia*, 12: 263–277.

Sakai T., Kawamura K., Hyodo T. 2018. The relationship between commodity types, spatial characteristics, and distance optimality of logistics facilities. *Journal of Transport and Land Use*, 11, 1: 575–591.

Schmitt D., Gollnick V. 2012. Historical Development of Air Transport. *Air Transport System,* 19–38.

Shahparvari S., Nasirian A., Mohammadi A., Noori S., Chhetri P. 2020. A GIS-LP integrated approach for the logistics hub location problem. *Computers & Industrial Engineering*, 146: 106488.

Sheffi Y. 2012. *Logistics Clusters: Delivering Value and Driving Growth*. The MIT Press.

Taaffe E.J., Morrill R.L., Gould P.R. 1963. Transport Expansion in Underdeveloped Countries: A Comparative Analysis. *Geographical Review*, 53: 503–529.

Uyanık C., Tuzkaya G., Oğuztimur S. 2018. A literature survey on logistics centers' location selection problem. *Sigma*, 36, 1: 141–160.

Vance J.E. 1970. *The Merchant's World: The Geography of Wholesaling*. Prentice-Hall.

Wąsowska K., Żukovskis J. 2019. Air freight transport in Poland. *Zeszyty Naukowe Uniwersytetu Przyrodniczo-Humanistycznego w Siedlcach*, 50: 65–72.

Wiśniewski S. 2015. Significance of trans-European transport networks for logistics centre localization as exemplified by the Lodz region. *European Spatial Research and Policy*, 22, 1: 23–44.

Wiśniewski S. 2017a. Lodz in the regional and national transportation system. *Space – Society – Economy*, 19: 65–86.

Wiśniewski S. 2017b. The accessibility of Poland's Space to the Trans-European Transport Network. *Miscellanea Geographica*, 21, 3: 96–106.

Woudsma C., Jakubicek P., Dablanc L. 2016. Logistics Sprawl in North America: Methodological Issues and a Case Study in Toronto. *Transportation Research Procedia*, 12: 474–488.

Yuan Q., Zhu J. 2019. Logistics sprawl in Chinese metropolises: Evidence from Wuhan. *Journal of Transport Geography*, 74: 242–252.

Ziomek J., Iwańcz T., Laskowski S. 2002. Geology and soils. [in:] *The Lodz Atlas* (p. Sheet VII). Łódzkie Towarzystwo Naukowe, Łódź.