Development of an Integrated Public Transport System in Present-day's Agglomerations

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Summary
In the EU countries, the development of an integrated public transport system in modern agglomerations occurs thanks to the general policy of financing projects for the improvement and optimization of transport infrastructure within the framework of the sustainable development strategy. This article aims to systemate experience in the development of an integrated public transport system in present-day's agglomerations(example of Małopolskie Voivodeship and Krakow agglomeration) and identify opportunities to implement this experience in Ukraine. The methodology is based on the method of analysis of Krakow agglomeration cases, particularly projects of public transport development at the expense of local budgets (communes and cities) and EU funds. The statistical analysis method estimates the economic effects of an integrated public transport system development. The results demonstrate the transformation of the integrated public transport system of Krakow agglomeration and the achievement of the following economic effects: employment growth by 11.8 % in 2014–2020; an increase of Gross domestic product by 72 % in 2010–2020, the transformation of the structure of traffic flows, growth of traffic, growth of the length of district public roads, optimization of functioning and condition of regular bus transport lines due to optimization of routes of passenger transportation, development of railway passenger transportation system, growth of rail transportation of passengers. Development of an integrated public transport system in Małopolskie Voivodeship is ensured with budgetary funds and financing of EU infrastructure projects, which are mainly directed at the purchase of environmentally friendly modes of transport within the framework of sustainable development strategy.

Keywords:
Integrated transport system, public transport system, transport development projects, transport system of agglomerations.

1. Introduction

The space distribution of agglomeration capacity significantly explains the disparities in access inequalities between transport users in different locations. Transportation systems, in particular public transportation systems, are crucial to provide social and economic opportunities for urban areas accordingly to the concept of sustainable development and to reduce the negative impact on the environment (Guzman, Oviedo & Cardona, 2018). Economic and social opportunities arise through the development of integrated transportation systems. The accessibility of transportation services to the population, travel patterns, routes, and spatial distribution of jobs is determined. Adequate provision of public transport to the people can be a socially oriented policy that reduces some socio-spatial inequalities in cities through improved access to more economic and social opportunities (Martínez et al., 2018; Guzman & Oviedo, 2018). A balanced mix of different types of transportation infrastructure, the development of fare policies, and operational models of the transportation system help redistribute the connections and reduce the transportation disadvantages of disadvantaged social groups in society (Preston, 2009). With the implementation of the concept of sustainable development, such a social goal is compatible with the growing concern about the transition to sustainable forms of mobility in the context of reducing carbon dioxide emissions and promoting public and non-motorized transportation.

The planning of public transportation systems is crucial for developing an integrated public transportation system. It improves accessibility for all users. In particular, over the past ten years, the automation and digitalization processes of the transportation system have been significant, which significantly optimize routes, ways of informing passengers about the traffic, traffic flows, etc. It provides users with opportunities for employment, social activities, and participation in society. Recently, many transportation companies have been investing in developing public transportation systems to turn them into integrated automated systems (Chowdhury et al., 2018). One of the most popular options for promoting public transportation is to provide an integrated and quality public transportation system (Matas, 2004). In large cities and agglomerations, developing an integrated public transportation system is a topical issue that needs to be studied in detail.

This article systematized experience in the development of an integrated public transport system in present-day's

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agglomerations for its implementation in Ukraine (example of Małopolskie Voivodeship and Krakow agglomeration).

2. Literature review

Many studies assessed the integrated public transport systems regarding the measures and ways to facilitate the population's accessibility to transport. Scientists analyze different approaches and methods of public transport optimization, which are adapted to different contexts and accessibility of information about the transport structure of agglomerations (Geurs & Van Wee, 2004; Litman, 2013; Lucas, Van Wee & Maat, 2016; Albacete et al., 2017; Fayyaz, Liu & Porter, 2017; Johnson, Ercolani & Mackie, 2017). Economically, accessibility is considered one of the main competitiveness factors, which ensures the impact on economic growth through employment growth (Guzman, Oviedo & Rivera, 2017). Different indicators of transport accessibility analysis for the population, analysis of planning of road public transport, and the efficiency of optimization and redistribution of different transport types and transport routes are also proposed in the existing studies. Authors propose measures to reduce the environmental and spatial pressure of urban road transport on cities. The publications on the social consequences of transport systems investigate the accessibility indicators, highlighting that the public transport system optimization leads to a change in the population's accessibility level to transport and reduces individual development and economic stability (Martens & Di Ciommo, 2017; Pereira, Schwanen & Banister, 2017; Di Ciommo & Shiftan, 2017; Venter et al., 2018). The development of an integrated public transport system is also an important factor in social inclusion and the development outlying areas (Jones & Lucas, 2012; Jang et al., 2017; Boisjoly & El-Geneidy, 2017; Albacete et al., 2017). Despite the apparent progress in the use of accessibility indicators proposed by scientists (Chowdhury & Ceder, 2016), as Boisjoly & El-Geneidy (2017) point out, there is a gap between conceptual knowledge about accessibility and the use of accessibility indicators by practitioners. There are also problems with researching indicators and evaluating the effectiveness of integrated transportation systems development (Lucas, Van Wee & Maat, 2016).

3. Methodology

The methodology is based on analyzing cases of the Krakow agglomeration, particularly projects of public transport development at the expense of local budgets (municipality and cities) and EU funds. The statistical analysis method is used to estimate the economic effects of integrated public transport system development. Statistical analysis has used data from Statistics Poland (2022) regarding the population density of the Krakow and Małopolskie Voivodeship agglomeration; transport funding from EU funds; public expenditures of gminas and cities for transport and communication; part of employed persons concerning the working-age population in Małopolskie Voivodeship, 2014–2020; a large household income in Małopolskie Voivodeship, 2010–2020; and transport statistics in Małopolskie Voivodeship. The data from the Ministry of Development Funds and Regional Policy (2022), Public Transport Authority in Krakow (2021), Miejskie Przedsiębiorstwo Komunikacyjne S. A. of Krakow (2022), and European Commission was used to analyze the development of the integrated public transport system in Krakow agglomeration (2022a; 2022b; 2022c).

4. Results

The Małopolskie Voivodeship and Krakow belong to the Upper Silesian agglomeration of Poland (Metropolis GZM). Krakow is one of the oldest and second most populated cities in Poland; an important economic, cultural, and scientific center. The population density from 2010 to 2020 was 220–225 people per square kilometer (Figure 1).

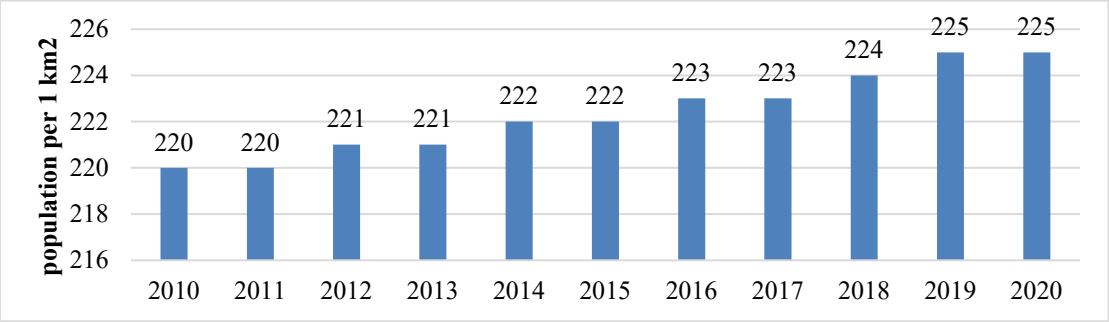

Figure 1. The population density in Małopolskie Voivodeship, 2010–2020.
Source: Statistics Poland (2022).

The integrated public transport system of Małopolskie Voivodeship began to develop at the beginning of Poland's accession to the EU and actively get financed transport development projects. Between 2016 and 2020, the volume of grants for financing development projects in Małopolskie Voivodeship increased by PLN 32559.4 mln, or 529 % (Figure 2).

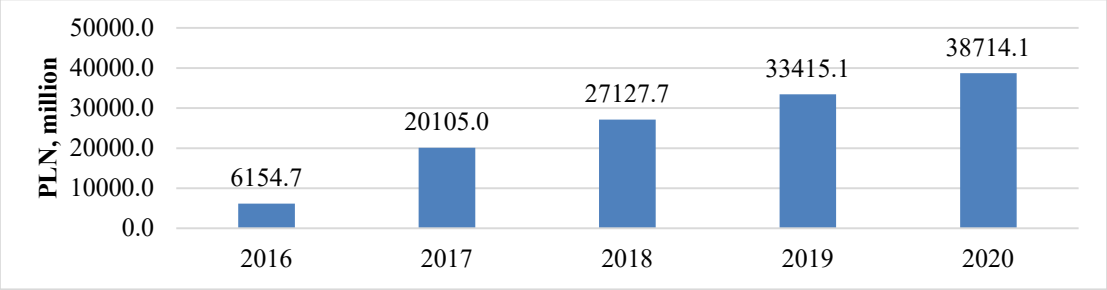

Figure 2. EU Funding – 2014–2020 in Małopolskie Voivodeship, value of grant contracts/decisions from EU funds total, million PLN.
Source: Statistics Poland (2022).

For example, from 2007 to 2013, the government implemented several projects under the Program Operacyjny Infrastruktura i Środowisko, in particular, the project "Integrated public transportation in the Krakow agglomeration – stage II", the amount of which was PLN 281.5 million (Ministry of Development Funds and Regional Policy, 2022). The project's primary purpose is to improve the comfort and safety of movement, increasing the share of public transport in passenger traffic. As a result, the Krakow agglomeration has significantly developed and optimized the passenger transportation system (Figure 3).

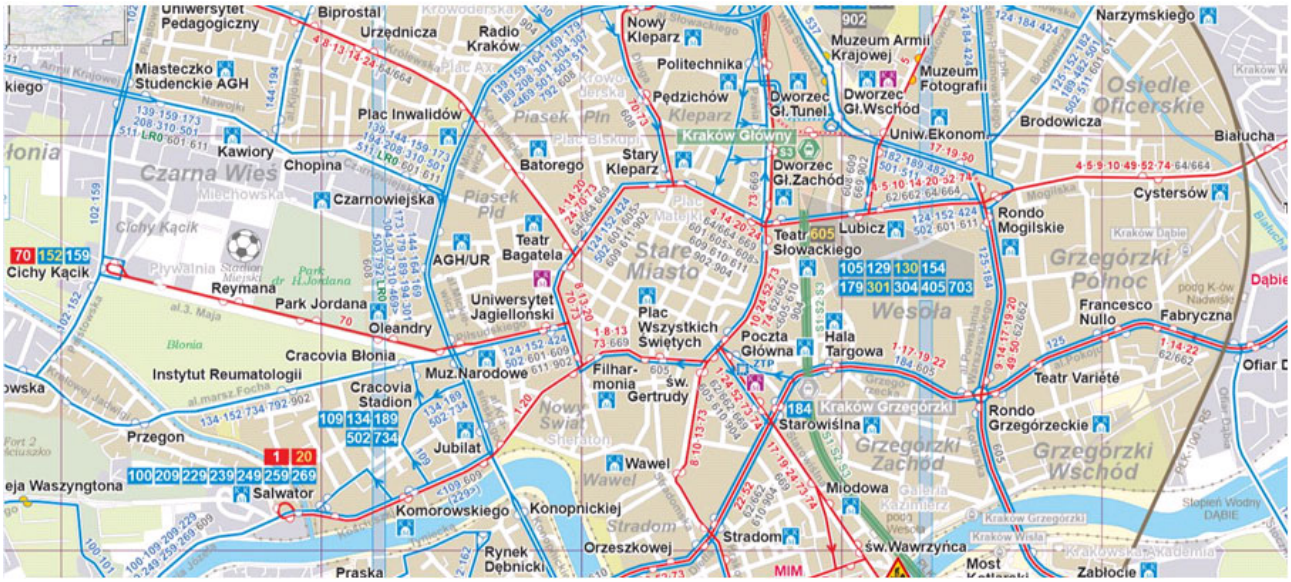

Figure 3. Krakow agglomeration public transport map (26.05.2022).
Source: Public Transport Authority in Kraków (2021).

The integrated Krakow agglomeration public transport system operates in the Krakow Public Transport Authority, which cooperates with two operators: MPK S.A. and Mobilis Sp. z o.o. (Figure 3, Figure 4).

Krakow's agglomeration lines provide passengers with connections to various cities within and outside of the city (Figure 3).

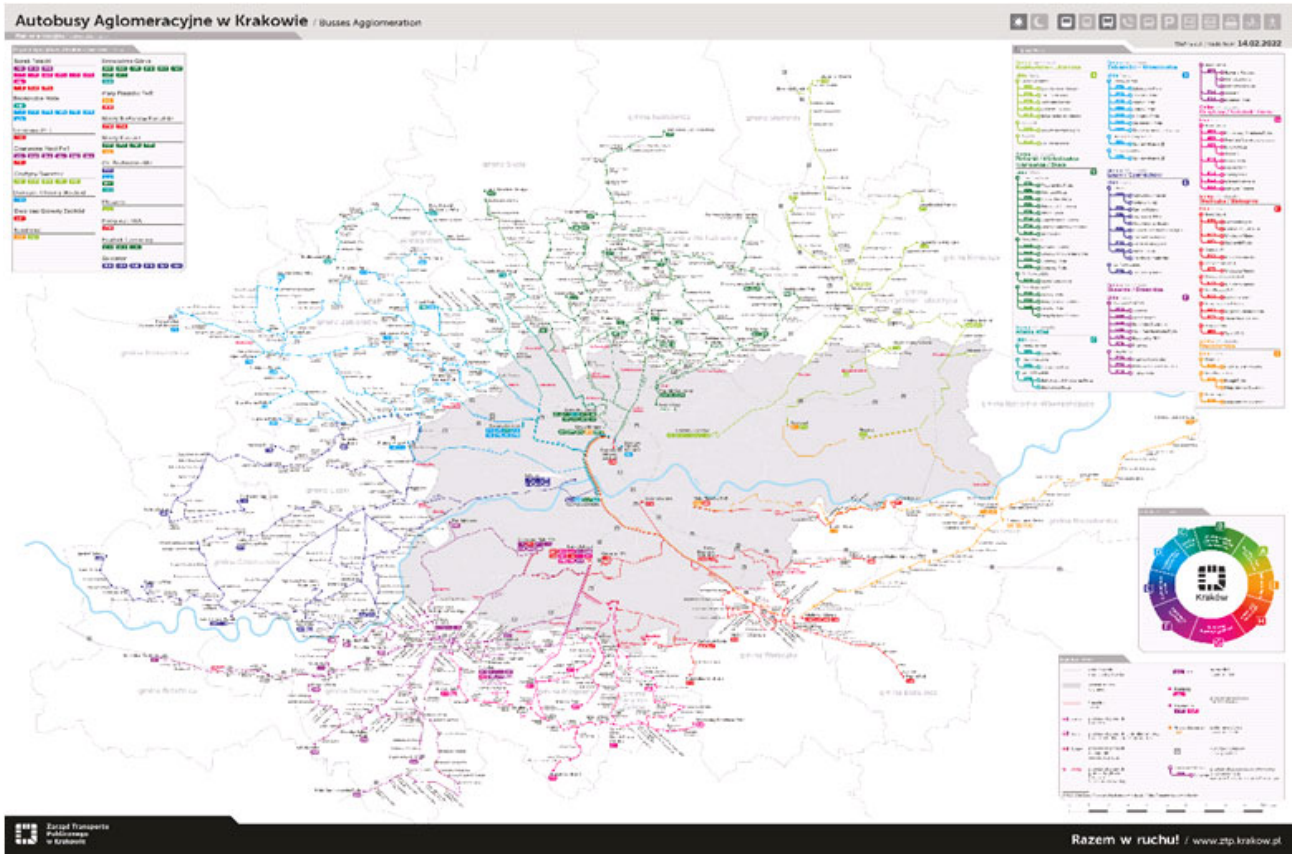

Figure 4. Agglomeration lines of Krakow, Poland (14.02.2022).
Source: Public Transport Authority in Kraków (2021).

The public transport system in the Krakow agglomeration provides passengers with access to optimized routes outside the city and new routes between cities and communities (Figure 3). In addition, passengers can purchase commuter "agglomeration" tickets for different periods (for 60 or 90 minutes, for 24/7, for one month) (Miejskie Przedsiębiorstwo Komunikacyjne S. A. of Krakow, 2022).

As part of developing an integrated public transport system in Krakow, the City Wayfinding System (SIM) Project is being implemented. The project's main objective is the organization of city signage according to unified graphic and design principles, providing for the creation of an integrated system of information about the city, in particular, transport routes in the context of modes of transport. The project aims to increase the level of public safety and traffic flow, build the identity of the urban space, and restore traditions and values. SIM provides for marking address points, names of streets, squares, bridges, signposts, and many elements of tourist indications. The City Wayfinding System (SIM) project for Krakow was selected in a competition organized in 2017 by the Department of Culture and National Heritage of Krakow, which took place in two stages:

1) recruitment of 34 contractors;
2) selection of contractors and development of the SIM concept, public consultation in early 2021 to optimize the model solution.

As a result, Towarzystwo Projektowe and Para Buch contractor were responsible for the project implementation, whose concept served as the basis for the citywide model solution based on simulation and functional models. The design concept considers the requirements of pedestrian and vehicular traffic and the needs of mass tourism.

EC programs for the development of an integrated system of public transport in agglomerations.

The EU European Regional Development Fund, based on the EU regional development policy, is financing projects to develop an integrated public transport system in Poland. As part of the development project, the Polish Regional Rail Service Koleje Małopolskie developed a

high-speed agglomeration passenger railroad to increase rail traffic in the region and reduce loading on the road transport system. The project also involved warranty, service, and maintenance. With the addition of the new high-quality, environmentally friendly trains, demand for rail passenger traffic has increased, and the level of loading on the road system has been significantly reduced. In addition, the new trains reduce the impact of the transportation system on the environment, improve passenger safety and reliability, and make transportation available for the various needs of users. Stable and safe The new IMPULS EMU trains are economical and safe, meeting the strictest European standards for durability and stability (PRM, TSI NOI, TSI, LOC&PAS, TSI SRT, and TSI CCS). Furthermore, their power consumption is low because of their ability to recover energy from overhead lines. Furthermore, the project contributed to developing the public transport system by establishing a new railway route in Małopolskie Voivodeship: a route connecting the critical economic and tourist centers of Cracow Main and Tarnów. Consequently, the number of passengers using regional rail transport services has increased. The total investment to finance the project "Acquisition of electric units for the development of rail transport in Małopolskie Voivodeship was PLN 305,217,550 (EUR 71,441,548), and the European Regional Development Fund EU invested PLN 175,717,855 for Małopolskie" for the period 2014–2020 (European Commission, 2022a) (Table 1).

Table 1: Technical information on the development of an integrated system of public transport in the Krakow urban area

	Project 1. "Acquisition of electric units for the development of rail transport in the Małopolskie Voivodeship"	**Project 2. "Acquisition of low-emission buses to serve local bus lines"**	**Project 3. "Construction of the Krakow - Sanktuarium passenger station on railway line 94 together with the affiliated infrastructure"**
Programme	Małopolskie Voivodeship – ERDF/ESF		
Thematic Objective	Sustainable transport & removing bottlenecks in network infrastructures	Support the shift towards a low-carbon economy	Sustainable transport & removing bottlenecks in network infrastructures
Programming period	2014–2020	2014–2020	2014–2020
Project duration	03/2016–08/2017	01/2016–09/2018	11/2015–06/2018
Total Investment	71 441 548 EUR	40 618 179 EUR	6 399 670 EUR
EU Investment	41 132 031 EUR	38 740 969 EUR	5 274 010 EUR

Source: European Commission (2022a; 2022b; 2022c).

Project 2

The EU Program "Małopolskie Voivodeship – ERDF/ESF" in Poland implemented a Project to increase the number of low-emission public transport in Krakow, Poland, through the purchase of 107 new environmentally friendly buses (compliant with the Euro 6 emissions standard). In 2018, the project developed a short-term charging system consisting of five charging stations located within Krakow. Thanks to the project, the attractiveness of urban bus transportation to Krakow was increased, contributing to the economic and cultural development of one of Poland's main economic centers. Furthermore, the project provided a higher level of transport accessibility and improved environmental friendliness, safety, reliability, and digitalization through internal and external monitoring systems and alarms, which provide instant communication with traffic control services. The project enabled the development of the Małopolskie Voivodeship agglomeration because low-emission buses are used in Krakow but also in 17 surrounding suburban areas, which optimizes transport connections. The total investment for the project "The purchase of low-emission, low-floor buses and stationary ticket machines to serve local bus lines" amounted to EUR 40 618 179, of which the European Regional Development Fund financed EUR 38 740 969 (European Commission, 2022b).

Project 3

A new modern transportation hub in Krakow in Poland's southern region has provided citizens with more environmentally friendly public transportation. The Krakow-Sanktuarium passenger station, which is part of the city's rail line 94, has made it easier for people to access popular parts of the city and has helped reduce traffic jams and pollution. The integrated transfer hub is part of the solution to improve residents' quality of life. Making public transportation more attractive should affect traffic conditions, reduce pollution emissions, and improve residents' overall quality of life. The project consisted of building a new train station with two platforms of 200 meters each. It can be reached via two pedestrian bridges on the north and south sides of the platforms and escalators and three elevators. The facility is fully accessible for passengers with disabilities and has a large bicycle parking area. The addition of the new station to the network has halved the distance between Skawina and the

famous Zakopianka shopping center, from half an hour to 15 minutes. The station is an integrated part of the city's transportation network, which means passengers can quickly transfer from train to streetcar or bus. As just one component of the planned regional rapid commuter rail network, the new station was built near locations known for high traffic congestion. This strategic location helped the project achieve its primary goal of increasing the use of public transportation by residents of the Krakow metropolitan area. By providing citizens with an integrated, comfortable, and convenient rail option connecting popular city areas, the project helped reduce car use and thus pollution. The project paid particular attention to the station's infrastructure and amenities. For example, two pedestrian bridges provide easy connections for travelers heading from the station to the Zakopianka shopping center or the neighboring Divine Mercy Sanctuary in Łagiewniki. The South Pedestrian Bridge also provides direct access to the John Paul II Center from the platforms. The station was designed to accommodate travelers with disabilities. It includes an open parking lot with 11 dedicated spaces at the south pedestrian bridge exit. The west side of the station also includes a 36-space bicycle parking area. According to project leaders, the new station has already improved the quality of life for residents. They also noted that due to the increased attractiveness of public transportation, some passengers have given up using cars in favor of the train. It, in turn, has resulted in lower pollution levels – another essential factor in calculating the quality of life. The total investment for the project "Construction of the Krakow-Sanktuarium passenger station on railway line 94 together with the accompanying infrastructure" amounted to 6 399 670 euros, and the European Regional Development Fund of the EU invested EUR 5 274 010 through "Regional Research and Innovation" for the period 2014–2020 (European Commission, 2022c).

5. Discussion

Economic effects of integrated public transport development in Krakow agglomeration

Table 2: Public expenditure of gminas and cities with powiat status budgets in Małopolskie Voivodeship. Expenditure in Division 600 – Transport and communication, million PLN

	2014	2015	2016	2017	2018	2019	2020	Growth, %
Total	1 740,39	1 793,42	1 561,53	1 699,55	2 139,11	2 173,75	2 151,06	24 %
Current expenditure total	938,24	987,65	1 029,80	1 085,43	1 275,08	1 254,67	1 275,21	36 %
Grants	27,95	29,17	32,25	33,33	53,53	59,98	69,46	148 %
Property expenditure, total	802,15	805,77	531,73	614,12	864,03	919,07	875,85	9 %
Investment property expenditure	771,75	805,77	510,52	601,87	857,43	906,94	862,45	12 %

Source: Statistics Poland (2022).

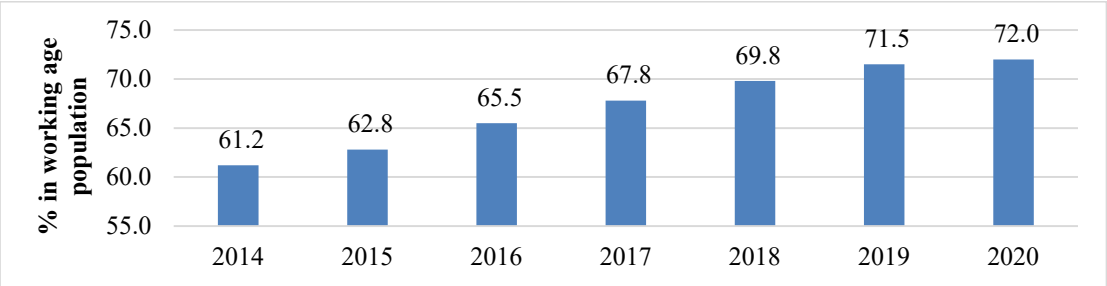

Figure 5: Share of employed persons concerning the working-age population in Małopolskie Voivodeship, 2014–2020
Source: Statistics Poland (2022).

During the implementation of public transport development programs in Małopolskie Voivodeship, particularly in particular, in Krakow, the public expenditures of communes and cities from their budgets increased significantly – by 24 % in total (Table 2). Current expenditures for transportation increased by 36 % between 2014 and 2020, and the volume of grants increased by 148 %. It should be noted that grants were provided as part of the project "Integrated public transportation in the Krakow agglomeration", implemented under the Regional Operational Programs for Smart Growth, which aims to increase Poland's competitiveness and innovative economy through the development of transport (Flanders investment & trade market survey, 2021).

Among the main economic effects of developing an integrated transport system in Krakow is the growth of employment (Figure 5) from 61.2 % in 2014 to 72 % in 2020.

Gross domestic product increased by PLN 79,525 million or 72 % over the period 2010–2020, which was contributed by indirect effects of the development of an integrated public transport system between the communes and cities of Małopolskie Voivodeship (Figure 6).

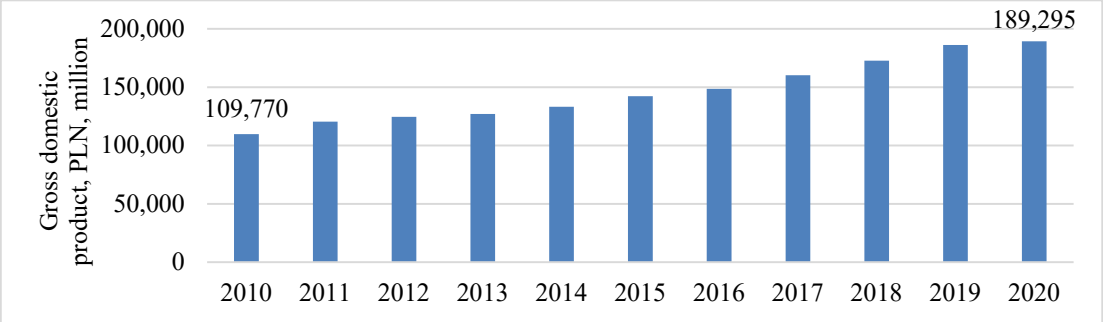

Figure 6: Gross domestic product total in Małopolskie Voivodeship, 2010–2020
Source: Statistics Poland (2022).

From 2014 to 2020, the structure of traffic flows is transformed, including the growth of air transport passenger traffic (Table 3) by 26 %, with a gradual increase in the number of arrivals, departures, and transit passengers. The economic effect of the development of the integrated transport system is an increase in the length of regional public roads of Małopolskie Voivodeship – by 8 % in the years 2014–2020, in particular, due to the adjustment of the system of road transport (buses, intercity routes). At the same time, they are reducing the total length of regular bus transport lines – by 43 % national and 25 % international lines due to optimization of passenger routes.

Table 3: Transport statistics in Małopolskie Voivodeship, 2014–2020

Transport	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**Growth , %**
Air transport: Passenger traffic at airports	Arrivals, departures and transit, person							
	3 817 792	4 221 171	4 983 645	5 835 189	6 769 369	8 404 676	2 589 384	-32 %
	The share of passenger traffic, Poland = 100, %							
	14,1	13,8	14,6	14,6	14,8	17,2	17,8	26 %
District public roads	Gmina and powiat hard surface roads, km per 100 km^2							
	143,8	145,6	147,8	154,0	153,7	156,2	155,5	8 %
	Gmina and powiat unsurfaced roads, km per 100 km^2							
	37,8	36,3	37,2	37,2	36,9	35,9	34,7	-8 %
Regular bus transport lines	National lines, total km							
	10 533	11 684	8 484	7 396	7 372	8 470	6 035	-43 %
	International lines, pcs							
	4	5	8	7	0	2	3	-25 %
Rail transport	Railway lines – indicators							
	Railway lines total per 100 km^2							
	7,2	7,2	7,0	7,1	7,2	7,1	7,1	-1 %
	Railway lines, km per 10 thousand population							
	3,2	3,2	3,1	3,2	3,2	3,2	3,2	0 %
Public road	Public road total, km per 10 thousand population							
	89,3	89,4	90,5	93,0	92,5	92,9	92,1	3 %

Source: Statistics Poland (2022).

Among the effects of integrated public transportation system projects, support for rail passenger transportation: the total length of rail lines was maintained at a % level in 2014–2020. In addition, the length of public roads also increased by 3 % from 2014 to 2020.

6. Conclusion

The study revealed significant transformations of the integrated system of public transport of the Krakow agglomeration and the achievement of such economic effects: growth of employment by 11.8 % in 2014–2020, growth of Gross Domestic Product by 72 % in 2010–2020, the transformation of the structure of traffic flows of air passengers, growth of the length of district public roads, optimization of functioning and condition of regular bus transport lines due to optimization of passenger transportation routes, development of rail transport system Development of integrated public transport system in Małopolskie Voivodeship is ensured with budgetary funds and financing of EU infrastructure projects which are mainly directed at purchase of environmentally friendly modes of transport within the framework of sustainable development strategy. Regarding the development of transport in Ukraine, it is necessary to build a high-speed agglomeration passenger railway to increase railway traffic; widening of lanes between cities, especially those close to the EU borders. Regarding the organization of traffic in cities, it is important to build equipped parking lots for vehicles, the introduction of a system of accounting for bus traffic in large cities (including electronic tickets).

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