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## TRAFFIC CONGESTION LEVEL IN 10 SELECTED CITIES OF POLAND

**Summary.** Transport has a great impact on human activities but contributes to many negative phenomena occurring in road traffic, for example, road traffic accidents, emission of toxic exhaust fumes into the atmosphere and a high share of cars in road traffic. For the above reasons, many initiatives have been taken in the field of road traffic management and urban logistics. Based on a literature review, it was found that the problem of the phenomenon of traffic congestion in urban areas remains an ongoing issue. In the first part of this article, the theoretical issues of traffic flow and congestion formation in the city road networks were presented. While the second part outlines the situation of transport congestion in 10 Polish cities based on the worldwide TomTom Traffic Index in the years 2008-2018. This study is a brief analysis of the trends relating to transport congestion based on the TomTom Traffic Index in these cities.

**Keywords:** city logistics, economic, extra travel time, TomTom Traffic Index

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## 1. INTRODUCTION

Nowadays, transport plays an important role in the economy and life of people. The transport sector is influenced by a wide range of external social and economic factors such as demographics, living standards of the population, urban planning, organisation of production, structural changes in the society and accessibility to transport infrastructure [55]. From the point of view of proper development of the economy, transport infrastructure plays a huge role. The region's development depends on its transport accessibility. To satisfy the needs of society, transport is carried out using a variety of transport systems, depending on the predisposition of the population and the susceptibility of transport of goods and cargo. Inhabitants of the city have public transport at their disposal (road or rail), individual vehicles, taxi, cycling transport or on foot. One of the possibilities of sustainable transport is non-motorised transportation, namely, cycling transport, with the inclusion of cycling in urban transport [26, 44]. In many European cities, there is a city bike system that complements the existing transport network, for example, Amsterdam, Berlin, Brno, Bucharest, Copenhagen, Lublin, Warsaw, Zilina. Cycling transport is a mode of transport that provides efficient transport requirements especially for short as well as long distances [26]. It can also be an alternative for the bored driver's phenomenon of traffic congestion in urban areas.

The transport market does not have an equal status in the transport market within the European Union [4, 38]. Transportation of goods and people is a fundamental concern of modern societies [54]. Public transport plays a relevant role in urban areas as it conveys passengers to schools, public healthcare establishments and work. It is also an alternative to using cars. Considering the aforementioned information on the use of vehicles for public transport, more attention has been drawn to the use of alternative fuels. The use of alternative fuels is one of the recent main solutions allowing the reduction of pollutant emissions [8]. In many scientific papers, the subject of research is using various alternative fuels [23, 33, 43], and reduction in the consumption of lubricating oils and plastic lubricants [31]. A comprehensive explanation of the selected problems of the efficiency of public transport can be found in detail in other scientific articles [15, 46, 47].

Transport needs in the urban area are similarly associated with the supply of shopping centre goods, public buildings or small local stores. These tasks are carried out utilising appropriately selected means of transport (trucks and delivery vehicles). Vehicles of this type limit visibility to other road users, take up a lot of space and hinders manoeuvrability, which is particularly severe in crowded city centres. Transport of cargos via small commercial vehicles within Central Europe is very common [35]. More information about the use of heavy goods vehicles on city road infrastructure and its issues in transport safety, such as the vehicle load, vehicle speed and curve radius, can be found in the following literature: [2, 42, 49].

Environmental impacts of transport are unfavourable and often have an unavoidable character [50, 51]. It is necessary to take a different look at the state, region and city transport policies due to factors such as expanding transport requirements, increasing number of congestions, and negative impacts on quality of life [16, 17, 25, 48]. This new approach, to meet the requirements of sustainable transport and functional usage of both city and regional area, must accept the elimination of negative factors, such as air pollution, increasing risk of transport accidents with its negative impacts, waste of time of public transport, etc. [25]. In contrast, transportation problems related to traffic accidents are constant problems constantly addressed by the scientific community, as evidenced by numerous publications in this area [9, 13, 18, 19, 32, 34, 39]. Many traffic accidents are due to an incorrect assessment of the current situation by the driver of the vehicle [42].

Transport is an area with obvious and perceived problems such as noise, air pollution, traffic congestion and health problems [26]. Car travel is related to climate change, depending on fossil fuels, and traffic congestion [14]. For a growing number of developing cities, the capacities of streets cannot meet the growing demand for cars, thus causing traffic congestion [57]. More information on some solutions in road infrastructure can be found in the following literature: [19, 29]. The phenomenon of transport congestion has been the subject of several scientific research, for example, [7, 37, 57]. Congestion mainly arises in or near densely populated areas with high levels of car ownership, such that the road capacity is insufficient to accommodate all the trips that might be made, particularly during morning and evening travel to and from work [36]. Most drivers of individual vehicles travel the same route throughout the week, which can be called a routine route. Some of them, due to the impatience of waiting in traffic gridlocks, look for an alternative route to the current routine route. Measures to tackle congestion, whether by increasing capacity or managing demand, need to allow for the possibility of faster journeys leading to more and/or longer trips being made by road users previously deterred by the expectation of time delays [36].

The presented transport issues show the importance of transport and its numerous needs in urban areas. However, there are positive factors, as well as negative factors associated with the movement of residents. The main aim of this study is to show the trends related to the occurrence of the phenomenon of transport congestion in selected Polish cities and the possibility of limiting it in the urban zone. In the further part of this article, statistical data on the level of traffic congestion in Polish cities are presented based on the TomTom Traffic Index. The possibilities of limiting the negative impact of transport on the urban environment and residents were demonstrated, as well as the possibilities of limiting traffic congestion through the integrated actions of the local governments in the area of urban transport.

## 2. TRAFFIC CONGESTION

Traffic congestion is probably the main problem of the transport system in urban zones in recent times. Congestion causes global concerns, such as increased commuting times and fuel usage as well as environmental deterioration [57]. The negative effect caused by traffic congestions is most notable in large cities, where traffic density is relatively high, with a characteristically low and often variable speed (acceleration and deceleration) [41]. While there are considerable technological and policy opportunities for tackling the detriments associated with pollution from vehicle emissions and road traffic accidents, congestion seems a more intractable challenge [36]. Among the causes of traffic congestion, we can distinguish physical and psychological factors. Physical causes measure traffic, speed and density of the street. Psychological factors are more difficult to measure and each driver accepts a different level of congestion. Some drivers accept slight traffic congestion, whereas others do not, thus causing more stress for them. Traffic congestion is a complex spatial-temporal process [22]. Congestion can be recurrent (regular, occurring on a daily, weekly or annual cycle) or non-recurrent (traffic incidents, such as accidents and disabled vehicles) [27]. Congestion in the urban zone can be considered as a phenomenon on a local and global scale. Local congestion, such as single interactions, only decreases the velocity of individual vehicles, whereas global congestion often decreases the velocity of the overall street network and requires additional traffic control [56].

Factors that cause congestion can be related to microeconomic considerations for road infrastructure [21]. They may also be affected by the macroeconomic phenomena related to the demand for road use and depending on a set of realities related to the modes and volumes of

traffic [21]. Random variables like weather, visibility, driver behaviour are major factors that explain the intensities of congestion [21].

The travel time index (TTI) [10] given by the Texas Transportation Institute compares the travel time rates in the peak period and travel time rate during free flow. TTI is calculated as given below:

$$TTI = \frac{\text{Actual Travel Time Rate}}{\text{Travel Time Rate during Free Flow Conditions}} \quad (1)$$

Traffic congestion in the urban area is common in large agglomerations as well as in medium-sized cities. This phenomenon is characteristic of cities with a high level of socio-economic development. In cities, we usually deal with a large concentration of transport needs in the same time and space that occur with a certain periodicity and is particularly severe in city centres area. William Vickrey [56] identified six types of congestion:

- simple interaction on homogeneous roads: where two vehicles travelling close together delay each other;
- multiple interactions on homogeneous roads: where several vehicles interact;
- bottlenecks: where several vehicles struggle to pass through narrowed lanes;
- “trigger neck” congestion: when an initial narrowing generates a line of vehicles interfering with a flow of vehicles not seeking to follow the jammed itinerary;
- network control congestion: where traffic controls programmed for peak-hour traffic inevitably delay off-peak hour traffic;
- congestion due to network morphology, or polymodal polymorphous congestion: where traffic congestion reflects the state of traffic on all itineraries and for all modes. The cost of intervention for a given segment of a roadway increases through possible interventions on other segments of the road, due to the effect of triggered congestion.

Traffic congestion has been studied at three levels over the past decades, namely, the regional level, the road level, and the lane level [20]. At the regional level, the relationships between regional traffic congestion and urban form are explored for improving management and planning strategies [1, 53]. Most existing studies examine traffic conditions at the road level. In earlier studies, traffic data were acquired from infrastructure sensors installed in some road segments, such as loop detectors [6, 24] and video cameras [5] from which traffic volumes and traffic flow speed were obtained too [20]. However, the limitation of these fixed sensors is that these technologies are expensive and can cover only limited areas and are not representative of the traffic conditions over larger areas. In recent years, cooperative vehicular systems such as Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications are explored in innovative Intelligent Transportation Systems (ITS) for traffic condition monitoring [3, 40, 59]. Whereas V2V or V2I communications improve the accuracy of traffic congestion detection, additional costs for installing such communication systems in vehicles are needed [20]. Consequently, these solutions have not found a wider application in practice. Traffic bottlenecks determined based on GPS data are detected at the level of the road section, and not on the lane level.

Presently, the rapid development of technology, positioning and collection data/storage increases the application of GPS tracking in the fields of traffic and engineering. GPS data contains a wealth of information about the travel patterns of people and actual traffic conditions. Thanks to the mentioned advantages of GPS devices, one can analyse data regarding

the dynamics of traffic flow. This technology is similarly used in the TomTom Traffic Index study, based on which the results of traffic congestion levels are published in many countries around the world.

### 3. DATA AND METHODS

In the world ranking of the TomTom Traffic Index (TTTI), cities with different numbers of inhabitants are compared. The cities were divided into three groups according to population sizes: up to 800,000, over 800,000 and above 2 million inhabitants.

Worldwide congestion ranking data TTTI for 10 selected Polish cities was used for this study. TTTI is published to provide drivers, industry and policy makers with unbiased information about congestion levels in urban areas [12]. The data for these cities was obtained from TTTI reports published on their website [12]. In addition, the following parameters of traffic flow in the cities were investigated: extra travel time, traffic speed, live traffic speed, morning and evening peak, congestion level depending on the type of road, and time of the peak in individual cities.

To avoid misunderstandings during the data analysis, the terminologies used in this research are presented and defined. The factors definitions given below are based on TTTI and used in this paper:

*Congestion level* can be defined as the increase in overall travel times when compared to a Free Flow (uncongested) situation [12].

*Extra travel time* can be defined as the extra travel time during peak hours versus an hour of driving during a Free Flow (uncongested) situation [12]. Multiplied by 230 days for the annual figure.

*Morning peak* can be defined as the increase in morning peak travel times when compared to a Free Flow (uncongested) situation [12].

*Evening peak* can be defined as the increase in evening peak travel times when compared to a Free Flow in an uncongested situation [12]. The hours of morning and evening peak may vary in different cities depending on the day of the week. In most cases, within a week they are the same for the city in question.

*Road network length* is the total length of the evaluated road network including highways and non-highways, expressed in kilometres or miles.

*Live traffic delay* is the current total time of delays in all jams on all monitored roads in the city area.

*Live traffic speed* is the current average speed on all monitored roads in the city area based on the TomTom Traffic Flow information [12]. These last two parameters include highways, major roads and minor roads.

For 10 selected cities in Poland, a comparison of transport congestion indicators over a period of 10 years (2008-2018) was carried out. The situation in the following cities was analysed: Warsaw, Wroclaw, Krakow, Poznan, Lodz, Szczecin, Katowice, Tricity, Bydgoszcz and Lublin.

### 4. RESULTS AND DISCUSSION

Table 1 presents selected data on population and vehicles and the available transport network, for compared cities from 2017. A characteristic feature of all Polish cities is

the dynamic increase in the level of motorisation of the society and a decrease in the volume of transport services in public transport. Therefore, the number of cars per capita and the intensity of street traffic is still increasing, leading to the occurrence of traffic congestion and a significant increase in travel time. According to Eurostat data, in 2015, the motorisation rate in Poland amounted to 546 cars per 1000 inhabitants, compared to 323 in 2005. This means that currently, statistically, more than every second Pole has a car [30].

Tab. 1

Selected data for 10 compared cities in 2017 [11, 12, 52]

City	Number of inhabitants in thous.	Area in [km <sup>2</sup> ]	Number of registered vehicles	Total road network length [km]	Highways [km]	Non-Highways [km]
Warsaw	1764,6	517	1,519,596	8,019	320	7,699
Wroclaw	638,6	293	518,181	3,099	124	2,975
Krakow	767,3	327	568,808	3,681	107	3,574
Poznan	538,6	262	469,411	4,147	218	3,929
Lodz	690,4	293	452,952	3,271	84	3,187
Szczecin	403,9	301	262,868	2,448	91	2,357
Katowice	296,3	165	261,360	13,719	412	13,307
Tricity	747,1	414	538,780	4,826	76	4,75
Bydgoszcz	352,3	176	249,020	2,872	146	2,725
Lublin	339,9	147	228,977	3,634	109	3,525

The investigation of the occurrence of traffic congestion was based on the measurement of the speed of passage of particular sections of roads, determined on the GPS data collected in real-time from moving vehicles. For individual cities, average delays are calculated due to congestion (extra travel time), the average speed of vehicles during communication peaks on the entire road network covered by the survey (and optimal traffic speed) and the largest bottlenecks. The delay indicator due to traffic congestion level is calculated in relation to the free passage time without any difficulties.

Figure 1 presents a comparison of the traffic congestion level indicator for 10 cities in Poland in 2018.

The comparison shows that the most difficult situation occurs in the cities of Warsaw, Wroclaw, Krakow, Lodz and Poznan, where they reach about 70% during morning rush hours (Warsaw, Krakow), and during the afternoon traffic summit they exceed 80% (Warsaw, Wroclaw, Krakow, Lodz). The best situation is in Katowice (traffic congestion level below 30%).

Figure 2 presents the extra travel time per day and year for the compared Polish cities in 2016.

The analysis of data presented in Figure 2 shows that the smallest losses caused by the phenomenon of traffic congestion occurred in Katowice – 17 minutes (65 hours per year) and Szczecin – 25 minutes (97 hours per year). In two cities, the additional travel time is 32 minutes (Bydgoszcz and Tricity). Four cities have a similar level of time loss ranging from 36 to 38 minutes (Lublin, Poznan, Wroclaw, Krakow). The most difficult situation occurred in Warsaw – 41 minutes extra travel time and Lodz – 46 min. The smallest losses in annual terms occurred in the cities of Katowice and Szczecin. In two cities, Bydgoszcz and Tricity, annual losses were

around 120 hours. Lublin, Poznan and Wroclaw oscillate around 140 hours per year. The biggest time losses occurred in Lodz – 178 hours per year.

Figure 3 shows the impact of the number of registered vehicles in different cities and transport congestion level expressed as a percentage.

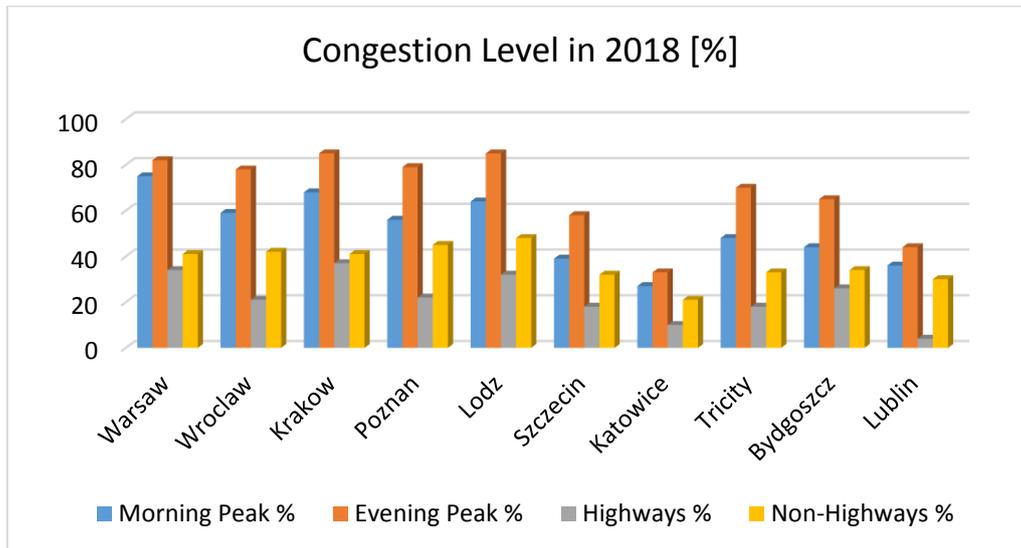


Fig. 1. Traffic congestion level for compared cities in 2018

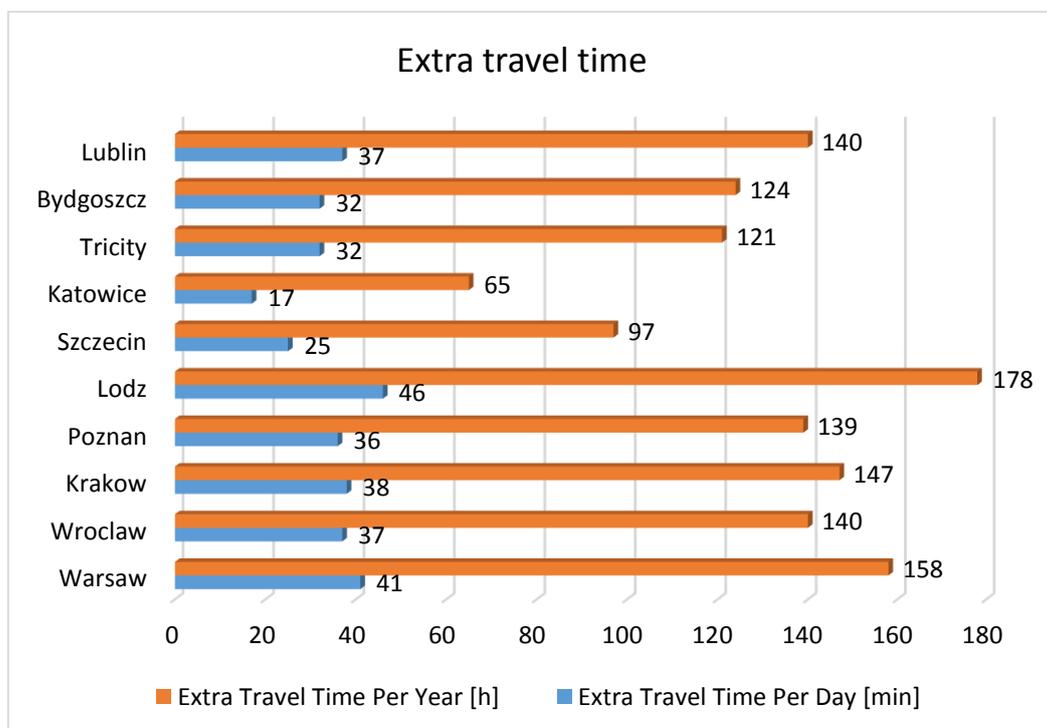


Fig. 2. Extra travel time per day and year for the compared cities in 2016

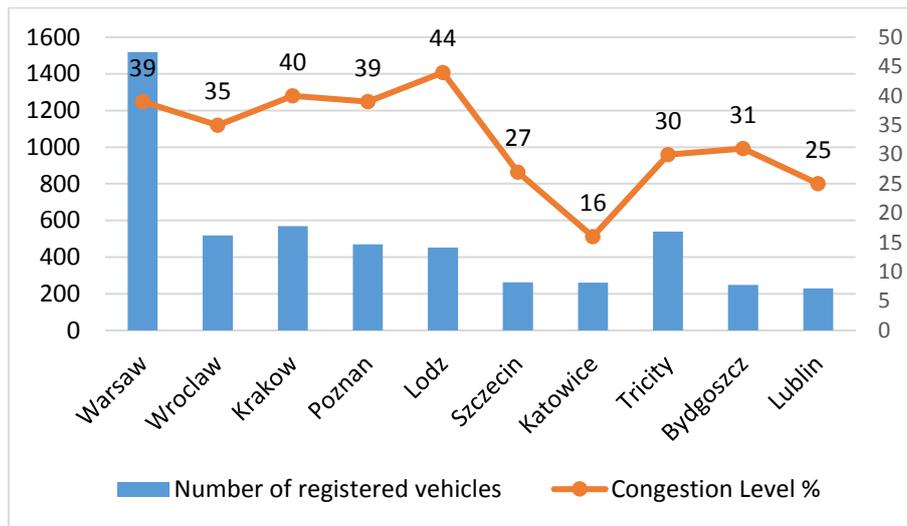


Fig. 3. Traffic congestion level (2018) and number of registered vehicles (2017) for the compared cities

Based on the analysis of the data presented in Figure 3, it can be concluded that in most cities, traffic congestion depends on the number of registered vehicles. This trend is not confirmed in the case of the city of Warsaw, where a huge number of vehicles (compared to other cities) corresponds to a moderate level of traffic congestion. Similarly, in the case of the city of Katowice, the moderate number of registered vehicles corresponds to the lowest level of transport congestion (16%).

Figure 4 presents a graph of the optimal value of traffic speed in 2016 for 6 compared cities, however, this value was not included for four cities in the TomTom database. The lowest optimal speed of vehicle traffic was in Warsaw – 36 km/h, and the highest in the city of Lodz – 45 km/h. Although the value of optimal speed is the highest in the city of Lodz, it is still the most crowded city in Poland.

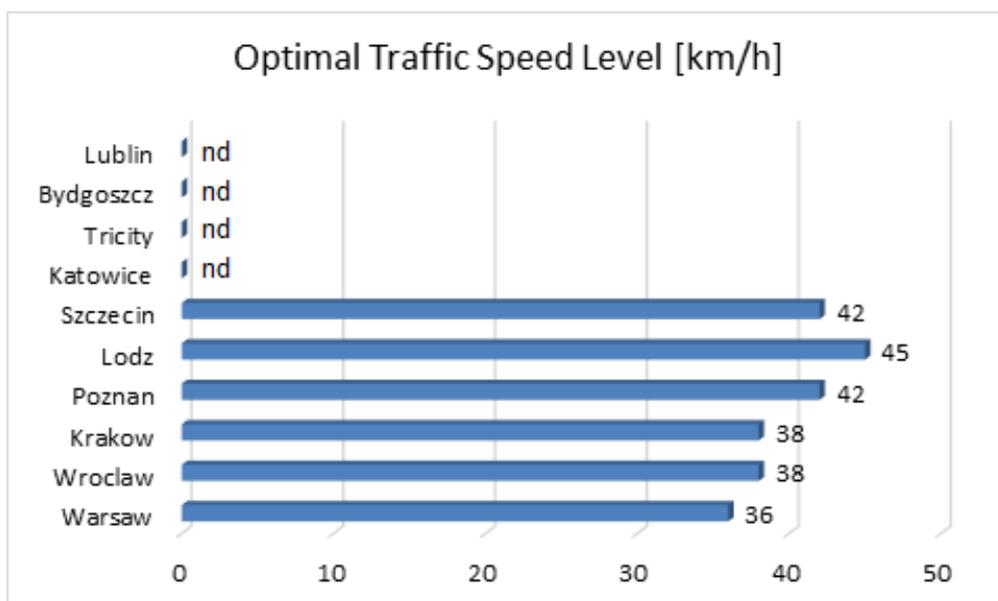


Fig. 4. Optimal traffic speed level for the compared cities in 2016

The historical data about traffic congestion level expressed by extra travel time (in percent) in the period of time from 2008 to 2018 is shown in the graph in Figure 5.

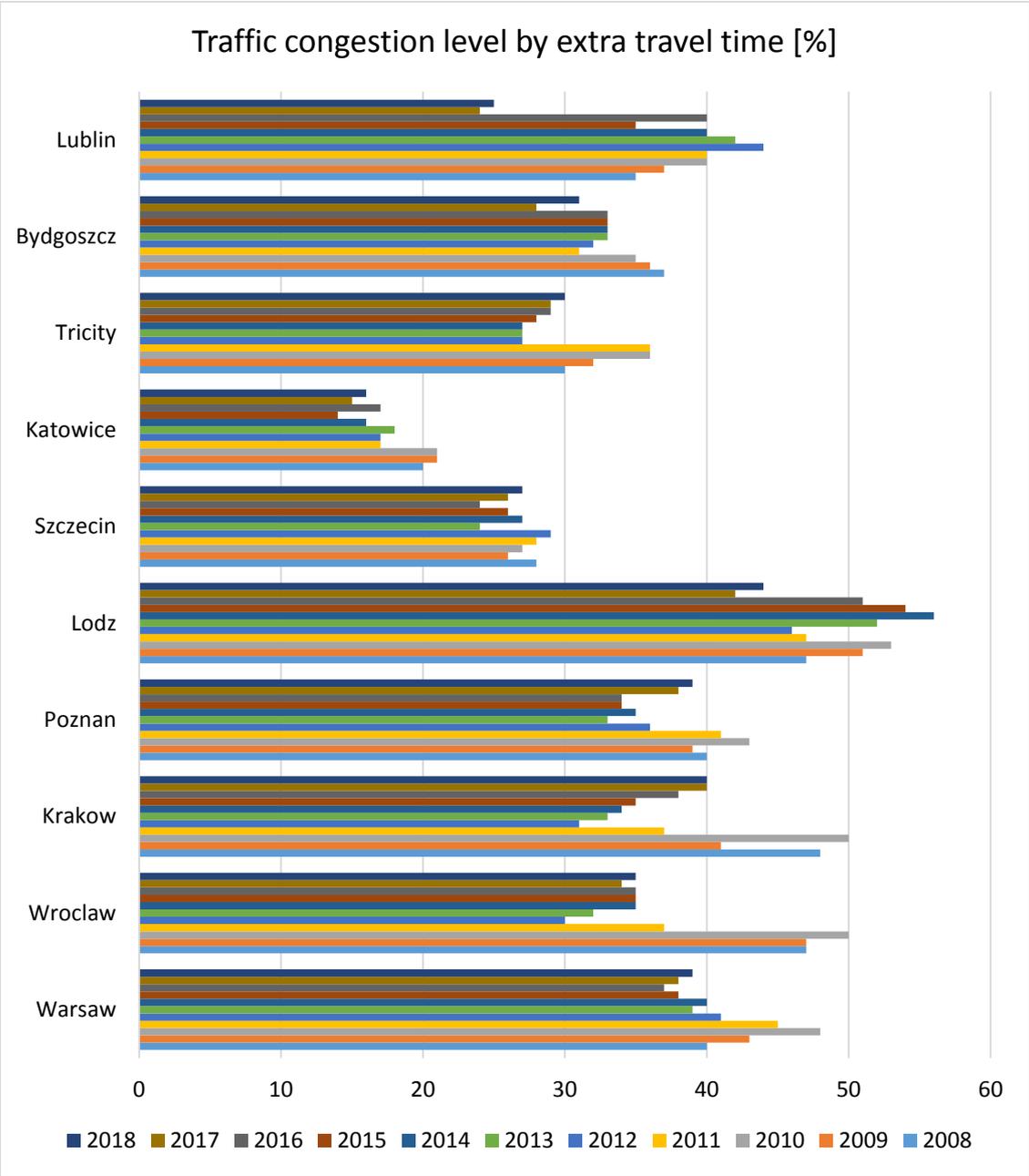


Fig. 5. Traffic congestion level expressed by extra travel time in the compared cities

Based on the data presented in Figure 5, it can be concluded that over the years, the level of traffic congestion fluctuates in Lublin, Lodz and Poznan. In several cities, traffic capacity improved in the period under consideration (Bydgoszcz, Tricity, Katowice, Krakow, Wroclaw, Warsaw). In Szczecin, on the other hand, the situation regarding the extra travel time indicator is practically stable. The worst situation in road traffic capacity is in Lodz, which ranks 15th among the most crowded cities in the world TTTI ranking. The presented summary also shows

that in 2018, the traffic congestion level increased in 9 cities, and only in Krakow was it recorded the same as in the previous year.

In Figure 6, the graph of live traffic speed for the last 48 hours is presented compared to the average speed of vehicles and optimal traffic speed, on the example of the city of Lodz.

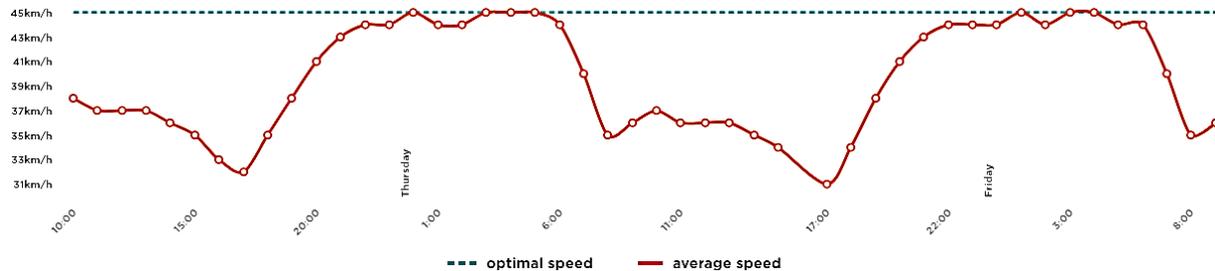


Fig. 6. Live traffic speed for the last 48 hours of the city of Lodz [12]

As can be seen from the chart shown in Figure 6, the average speed of vehicles is far from the optimal traffic. Based on a 48-hour data logging interval, it can be seen that only in the night period that these speeds may coincide. The periods of the morning and evening communication peak are clearly visible. A similar situation regarding the comparison obtained average speed of vehicles and optimal traffic speed is observed in the other analysed cities.

Several measurements applications could significantly reduce traffic congestion level in the city: the implementation of various telematics systems as well as the correct setup and synchronisation of traffic light signalling at intersections (that is, creating a “green wave”), increasing the capacity of roads and construction of others, traffic regulation, limiting the right of entry to certain areas, or charging of the traffic within the city areas [28]. As noted by many authors [3, 5, 24, 25, 37, 59], intelligent transport systems are very important in reducing traffic congestion levels in urban agglomerations. Intelligent transport systems in the form of traffic light synchronisation (green wave) and a system for informing drivers about obstacles through information boards are some of the ways to combat congestion. Such solutions occur in most Polish cities. Another way to reduce the phenomenon of traffic congestion is represented by the development of park and ride facilities, for users that are coming from the extra-urban area [45]. This system worked successfully in Katowice, where leaving the vehicle and using public transport does not incur additional travel costs, just a ticket from the parking lot. Another option is to replace individual motor vehicles with alternative urban transport systems such as city bikes available in Warsaw and Lublin. Of course, this is not a satisfactory solution that can be implemented by all vehicle owners; nevertheless, it allows reducing traffic congestion. It should be emphasised, however, that the phenomenon of traffic congestion may occur in places where, hitherto, there have been no impediments to the flow of vehicles.

## 5. CONCLUSIONS

Currently, the phenomenon of congestion is particularly onerous for traffic users (individual drivers, suppliers of stores and institutions, couriers, etc.), and indirectly influences effects of agglomeration on the well-being of residents as evident in noise and bad air quality. Congestion in urban areas is presently one of the most pressing problems in transport [27]. We conclude, that on the current level of demand for transport and the development of private cars, a complete elimination of the phenomenon of traffic congestion in the cities seems impossible to achieve.

Therefore, in the case of problems related to traffic flow, the generally accepted direction of activities is to bring traffic congestion to an economically justified and acceptable level by transport users.

The comparison of 10 Polish cities shows that it is possible to reduce the level of traffic congestion in urban areas. Although efforts by the municipal authorities produce positive effects, it is, however, an ever-changing environment, susceptible to transport disruptions. Effective management of traffic flow in the city is a very difficult and demanding task but extremely necessary to modern agglomerations. As already mentioned, many factors influence the reduction of traffic congestion in urban areas. One of them is the use of ITS and the building of modern infrastructure, considering current and future transport needs. Due to the modernisation and reconstruction of existing congested transport hubs, it is possible to limit traffic congestion. A good example of this is the city of Lublin, where due to the reconstruction of several critical points of the communication network and the city beltway, the traffic congestion level has been reduced since 2017. Detailed analysis of solutions applied in the individual cities can contribute to the application of positive solutions and create effects in the form of limiting the traffic congestion level in urban areas. However, this approach requires further analysis and scientific considerations in the future.

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