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THE BICYCLIST SAFETY ANALYSIS BASED ON ROAD INCIDENTS MAPS

Summary. Increasing road congestion leads to frustration and irritation of drivers, which often contributes to dangerous driving maneuvers. This causes dangerous situations - collisions or road accidents. The driver, while moving the car, is protected by the vehicle body and, above all, by the crumple zone. Unprotected road users, such as pedestrians or cyclists, usually do not have any protection. The article aims to assess the state of bicycle traffic safety in the Małopolskie Voivodeship in 2012-2019. This assessment was made based on road incident maps. In the first stage of work, the indicators for the number of incidents per 1 million inhabitants and the severity of the incidents were calculated for the entire Małopolskie Voivodeship and particular counties in 2012-2019. The data from the Accident and Collision Record System and the Central Statistical Office were used for this purpose. Then, the safety of bicycle traffic in the Małopolskie Voivodeship was analyzed based on the developed road incident maps. Although the number of road incidents increases from year to year in the analyzed period, they are less severe over time. Presenting road incidents data on maps allows for the highlighting of critical locations on the city's transport network from the point of view of cyclists' safety.

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Keywords: road safety, bicycle traffic, road incident map, road traffic engineering

1. INTRODUCTION

The bicycle has become an integral element of the transport system of many cities around the world. National strategies assume a significant increase in the use of bicycles as a means of transport, and for tourism purposes, which is usually accompanied by plans to develop infrastructure for cycling. The increase in the use of bicycles as a means of transport and recreation is observed especially in cities and agglomerations, where a significant part of the travel distance does not exceed 5 km, which corresponds to the functional and technical characteristics of the bicycle. Cycling as one of the possible forms of transport has many advantages and disadvantages. On the one hand, in a situation of a large share of bicycle traffic in total traffic volume, it may have a positive impact on changing the modal division towards a more balanced one, which at the same time translates into benefits related to the reduction of pollutants emitted from transport into the atmosphere. It can also promote a healthy and active lifestyle, which has a positive impact on the well-being of the population. The benefits of a healthy lifestyle and active transportation are widely known [2],[6],[10], [12].

However, despite the many benefits of cycling, many scientific works indicate that concerns about the safety of cycling constitute one of the greatest obstacles to the widespread adoption of cycling as an alternative to the use of private vehicles [5], [18]. Cyclists are among the most vulnerable road users, and in the event of a road accident with a motor vehicle, they are the ones who suffer the most serious injuries. Moreover, the World Health Organization (WHO) [17] reported that in 2021 more than half of all road traffic deaths were among vulnerable road users, i.e., pedestrians, cyclists, and motorcyclists. There may be many reasons for this state of affairs. The geometric shape of roads has a significant impact on cyclists' safety. Proper planning of roads and infrastructure for cyclists is a fundamental activity influencing their effective and safe use by cyclists. Ideally, roads should be designed with the safety of all road users. This would mean providing appropriate infrastructure not only for vehicle drivers but also for pedestrians, cyclists, and motorcyclists. Measures such as pedestrian paths, cycle lanes, safe crossings, and other traffic-calming measures can be crucial to reducing the risk of injury among these road users.

The aim of all actions taken to improve road safety is to reduce the number of accidents and their victims. It is becoming more and more common to strive not only to improve the situation, but also to completely eliminate road accidents, i.e., the implementation of the so-called Vision Zero [14]. People have the right to make mistakes, and a safe transport system should provide its users with the ability to move comfortably, but at the same time safely. Achieving such a goal requires taking many actions, the effectiveness of which largely depends on the identification of particularly dangerous places where a large number of road accidents are recorded. In practice, various research methods can be used to find particularly dangerous places and identify the causes of road accidents, such as analyzes of data on road accidents and collisions based on data collected by the police, detailed studies of the most serious accidents, observations of road users' behavior, audits and road traffic safety control, conducting public consultations.

In world literature, we can find many works dedicated to road traffic safety. These works are devoted to safety, among others various road users [3], [9], safety level on various elements of the transport network [4], [11], [19], in built-up areas, and outside of them [7], [8]. The aim

of the article is to analyze the safety of bicycle traffic in the Małopolskie Voivodeship in Poland in the years 2012-2019. This analysis was carried out based on the developed maps of road incidents. The second section, after the introduction, presents the methodology for conducting research. The third section presents an analysis of selected road safety measures for the studied area. This section analyzed the number of accidents per 1 million inhabitants for the entire Małopolskie Voivodeship, and for individual counties during the analysis period. Then, the accident severity index was analyzed for the entire Małopolskie Voivodeship, and for individual counties. For this purpose, data from the Accident and Collision Registration System, and from the Central Statistical Office (in Polish: GUS) were used [15]. The next, fourth section presents an assessment of the safety level of bicycle traffic in the Małopolskie Voivodeship based on the developed maps of road accidents, and maps of road accident victims. The last section contains conclusions from the analyses presented in the article.

2. METHODOLOGY OF THE CONDUCTED RESEARCH

The area of analysis was the Małopolskie Voivodeship, which, apart from three other voivodeships in Poland such as Silesia, Podkarpackie, and Pomerania, is included in the group of voivodeships in which in recent years the highest share of fatalities in road accidents in built-up areas has been recorded (as much as 72%) [16]. In order to assess the safety level of bicycle traffic in the Małopolskie Voivodeship in the years 2012-2019, first of all, an analysis of the most important characteristics of road incidents with cyclists was carried out, such as:

- indicators: the number of incidents per 1 million inhabitants, and the severity of incidents for the entire voivodeship in the subsequent years of the analysis, and with precision to the poviat,
- distribution of road incidents involving cyclists,
- characteristics of the incident location, and the vehicles of the incident participants with cyclists,
- distribution of causes of road incidents involving cyclists due to the fault of vehicle drivers, and pedestrians.

The number of incidents per 1 million inhabitants was calculated based on the following formula [13]:

$$W_M = \frac{Z \cdot 10^6}{M} \tag{1}$$

where:
W_M - the number of incidents per 1 million inhabitants,
Z - the total number of incidents in the analyzed period,
M - the number of inhabitants.

In turn, the formula [13] was used to calculate the incidents' severity index:

$$WC = \frac{X}{Y} \tag{2}$$

where:
WC - incident severity index,
Y - number of incidents in the analysis period,
X - the equivalent number of incidents.

The value of the equivalent number of road incidents is determined from the formula:

$$X = \sum x_i \tag{3}$$

where:
x_i - conversion factor of a given *i-th* road incident into the number of equivalent road incidents calculated from the equation:

$$x_i = \eta_{Z,i} \cdot q_Z + \eta_{H,i} \cdot q_H + \eta_{R,i} \cdot q_R + \eta_{P,i} \cdot q_P \tag{4}$$

where:
$\eta_{Z,i}, \eta_{H,i}, \eta_{R,i}, \eta_{P,i}$ - the number of fatalities, seriously injured people, slightly injured people, and vehicles damaged as a result of the incident, respectively,
q_Z, q_H, q_R, q_P - the weight of individual effects of road incidents due to the occurrence of specific effects of a road incident in relation to the costs of an average road collision.

Table 1 presents the values of the weights of individual effects of road incidents due to the occurrence of specific effects of road incidents in relation to the costs of an average road collision. The weight values were adopted on the basis of data presented in the research work of T. Szczuraszek [13].

Tab. 1

The values of the weights of individual effects of road incidents due to the occurrence of specific effects of a road incident in relation to the costs of an average road collision

Individual effect of a road accident	The values of the weights
Fatal injury	26,7
Serious injury	10,0
Slightly injury	0,5
Damage to a vehicle involved in the accident	1,0
Damage to the vehicle involved in the collision	0,5

In addition, maps of the concentration of road incidents, and maps of the concentration of road accident victims were developed, down to the poviat, representing:

- the number of road incidents involving cyclists,
- the number of people slightly injured in road accidents involving cyclists,
- the number of people seriously injured in road accidents involving cyclists,
- the number of fatalities in road accidents involving cyclists.

The maps were prepared on the basis of data obtained from the Accident and Collision Registration System database. The data were grouped into classes depending on the number of the examined feature per year. Maps were made separately for each year of analysis, as well as jointly for the analyzed period. Due to the limitations of the article's volume, the article presents only summary maps for the total period.

From a cognitive point of view, the most valuable part of the work is the development of maps representing the location:

- road accidents resulting in slightly injured victims,
- road accidents resulting in seriously injured victims,
- road accidents resulting in fatalities.

These maps allow the identification of the most dangerous locations on the road network where road accidents with victims occur. Knowledge of these places allows taking preventive actions regarding the reconstruction of road infrastructure or the introduction of measures to improve road safety.

3. ANALYSIS OF SELECTED MEASURES OF CYCLING SAFETY IN THE MAŁOPOLSKIE VOIVODESHIP

The Małopolskie Voivodeship is located in the southern part of Poland. It is divided into nineteen counties and three communes with county rights. Firstly, two indicators were used to analyze road incidents in the Małopolskie Voivodeship in 2012-2019: the indicator of the number of incidents per 1 million inhabitants, and the incident severity indicator (Fig. 1).

In the analyzed period, the number of road incidents per 1 million inhabitants in the Małopolskie Voivodeship increased by approximately 2,000. In 2014, there was a decrease compared to 2013 (by approximately 190), and in 2018 a decrease can be observed compared to 2017 (by approx. 60). In turn, analyzing the variability of the severity index of incidents involving cyclists, it can be concluded that from 2012 to 2019 the value of the index decreased by approximately 0,29. In 2014, the value of this indicator increased even though the number of incidents per 1 million inhabitants in the analyzed period was the lowest.

Figure 2a shows the number of road incidents per 1 million inhabitants in individual counties in the Małopolskie Voivodeship during the analysis period. The greatest number of road incidents per 1 million inhabitants during the analysis period took place in the city of Nowy Sącz, while the least in Dąbrowa County. The variability of the incident severity index in individual counties in the Małopolskie Voivodeship during the analyzed period has been presented in the Figure 2b. The highest value of the road accident severity index can be observed for the Miechów poviat, while the lowest for the city of Tarnów. It can also be stated that individual poviats are characterized by high values of the number of road incidents per 1 million inhabitants. The lowest values of the incident severity index were recorded for the Tarnów, Oświęcim, and Krakow counties.

During the analyzed period, there were 8,105 incidents involving cyclists in the Małopolskie Voivodeship. In these incidents, 2,613 people were slightly injured, 1,366 people were seriously injured, and 136 suffered fatal injuries (Fig. 3). In turn, analyzing the distribution of types of road incidents involving cyclists, it can be concluded that side collisions of vehicles dominated, accounting for almost 58% of all incidents. Then there were incidents such as vehicle rollover (11.19%), rear collision (7.58%), frontal collision (6.70%), others (5.66%). The share of other types of incidents was less than 5%.

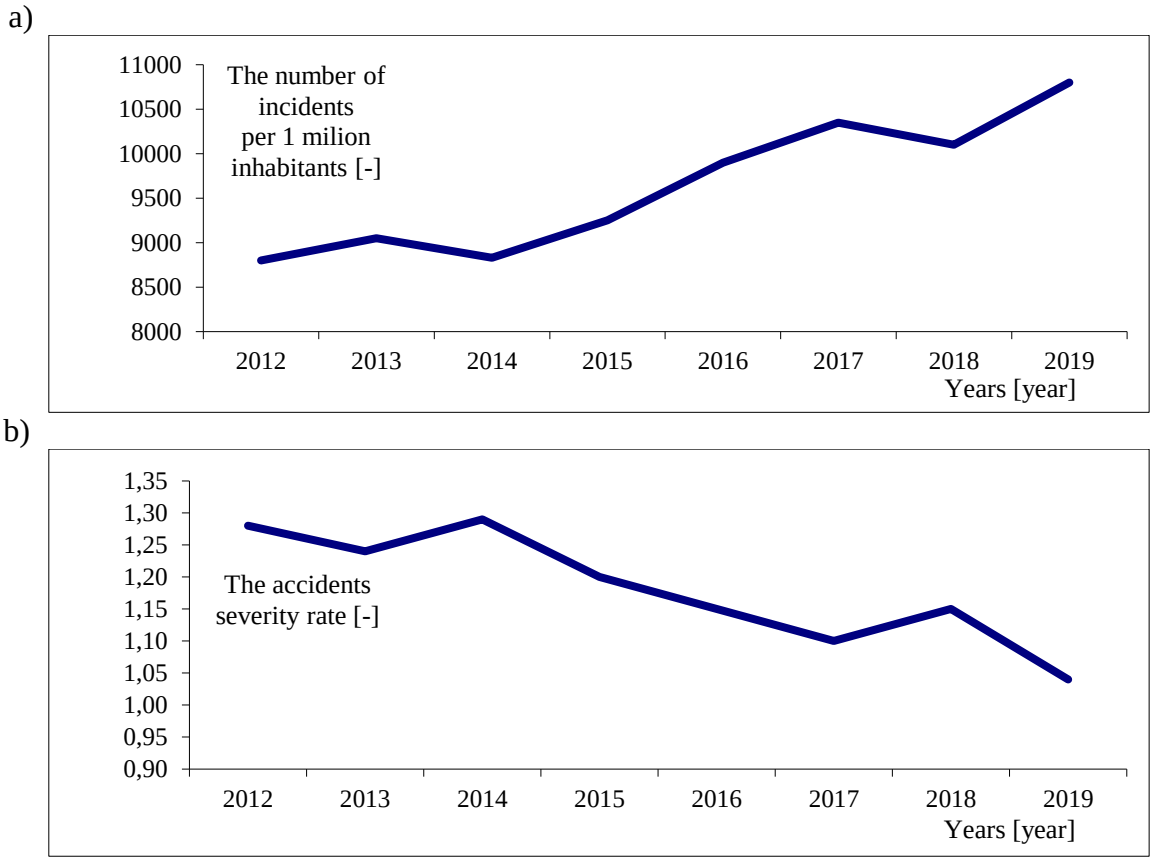


Fig. 1. (a) Distribution of the number of road incidents involving cyclists per 1 million inhabitants, b) Incident severity index in the Małopolskie Voivodeship in the analyzed period

Descriptive statistics of incidents in the analyzed period also allow the conclusion that, taking into account the characteristics of the place of the incident, most of them took place on the road (69,90%). Much less on the sidewalk, pedestrian path (7,08%), cyclist crossing (5,75%), cyclist road (4,70%), pedestrian crossing (4,55%), road, traffic lane, bicycle lock (2,87%), in the area of entry and exit from the property (2,49%). The share of incidents involving cyclists in other parts of the transport network was negligible (< 1,0%). In turn, taking into account the type of intersection where an incident involving a cyclist occurred, it can be concluded that most incidents took place at intersections without traffic lights (as many as 88,51%), much less at intersections with circular traffic (8,32%), and at other intersections (3,18%). Taking into account the vehicles of the incidents participants with cyclists, it should be stated that in the vast majority of cases, incidents occurred between cyclists and passenger cars (as many as 88% of cases), then with heavy vehicles over 3.5 tons (2,64%), and with heavy vehicles up to 3,5 tons (2,07%). The share of incidents between cyclists and other types of vehicles was less than 1,0%.

Fig. 4 shows the distribution of causes of road accidents involving cyclists due to the fault of drivers (Fig. 4a), and due to the fault of pedestrians (Fig. 4b) in the Małopolskie Voivodeship in the years 2012-2019. The most common cause of accidents in the case of accidents between cyclists and motor vehicles was failure to give way (38,24%). Then, failure to adjust speed to traffic conditions (8,17%), incorrect overtaking (6,62%), incorrect turning (6,44%), failure to maintain a safe distance between vehicles (5,06%). The share of other causes of accidents with cyclists due to drivers' fault was less than 5%. However, the most common accidents involving

cyclists were due to the fault of pedestrians when a pedestrian entered the road in front of a moving bicycle (64,10%), carelessly entered the road from behind a vehicle or an obstacle (12,18%), or when pedestrians crossed the road in an unauthorized place (7,05%). The share of other causes of cyclist-pedestrian accidents due to pedestrians' fault did not exceed 5%.

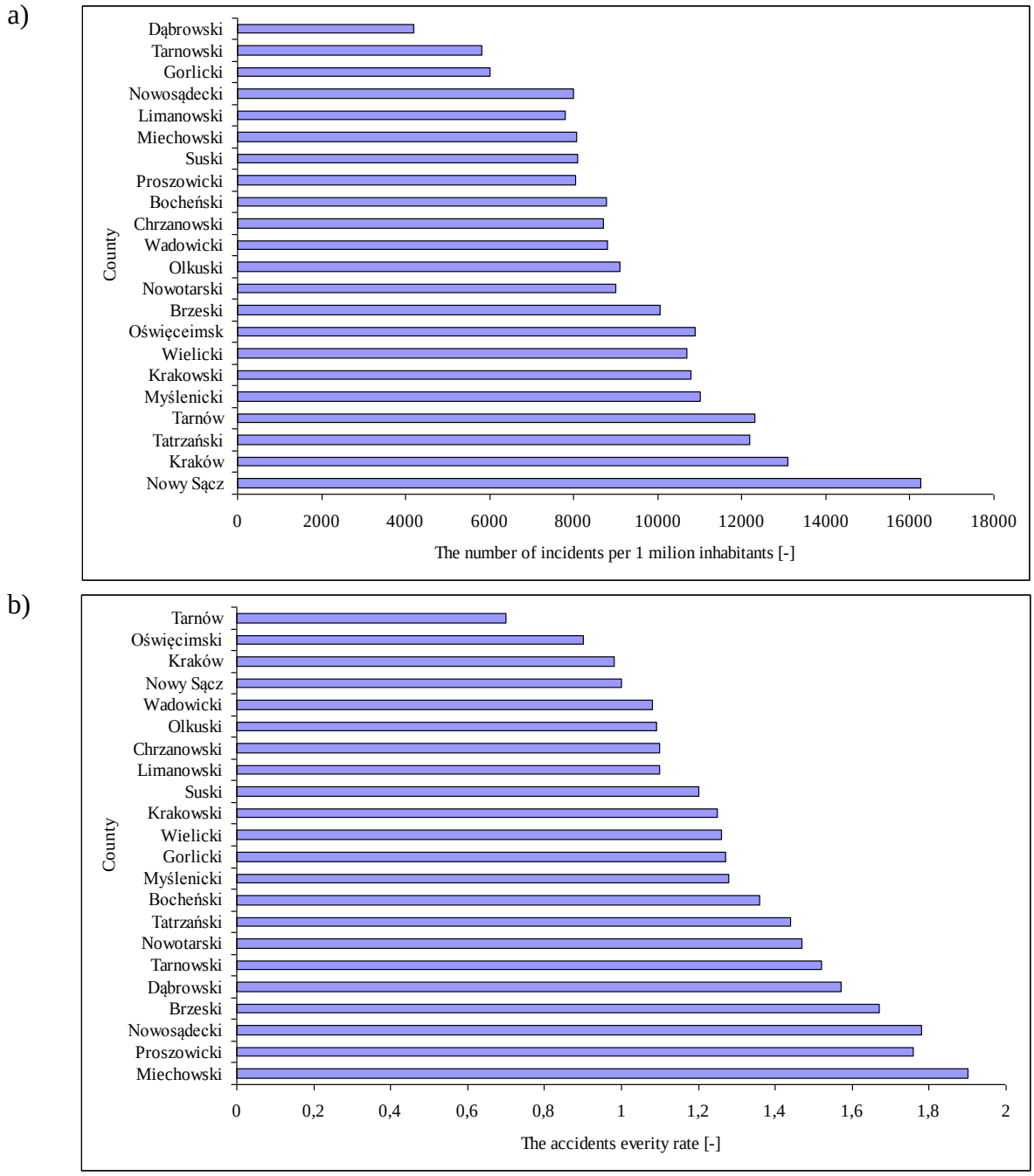


Fig. 2. (a) Distribution of the number of road incidents involving cyclists per 1 million inhabitants, b) Incident severity index in individual poviats in the Małopolskie Voivodeship in the analyzed period

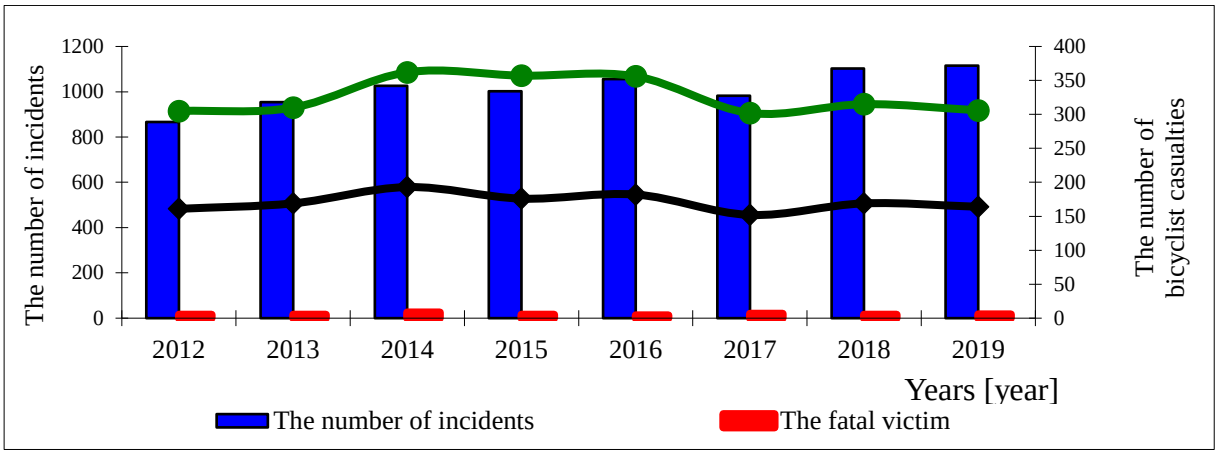
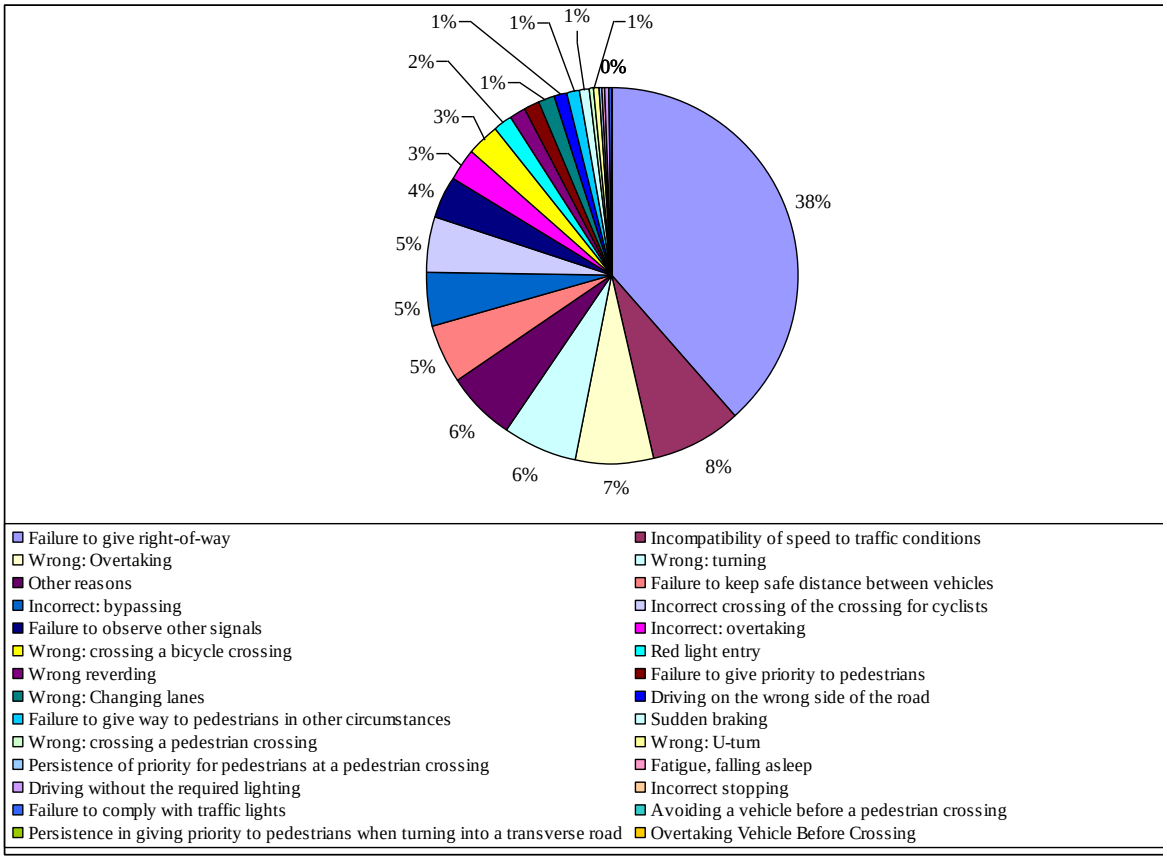


Fig. 3. Distribution of road incidents involving cyclists in the Małopolskie Voivodeship in the analyzed period Source: own study based on data from the Accident and Collision Registration System database [1]

a)



b)

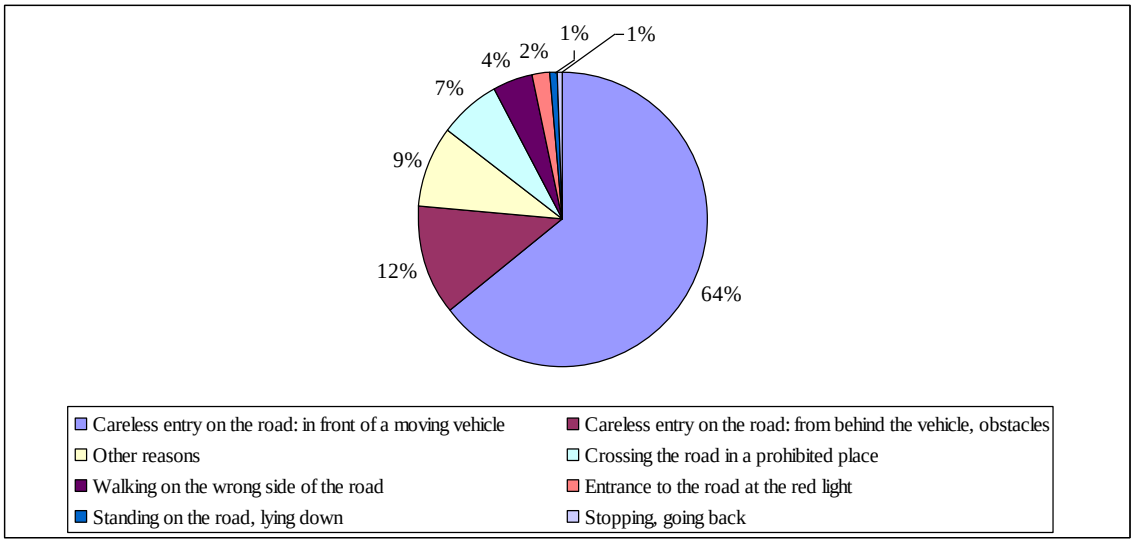


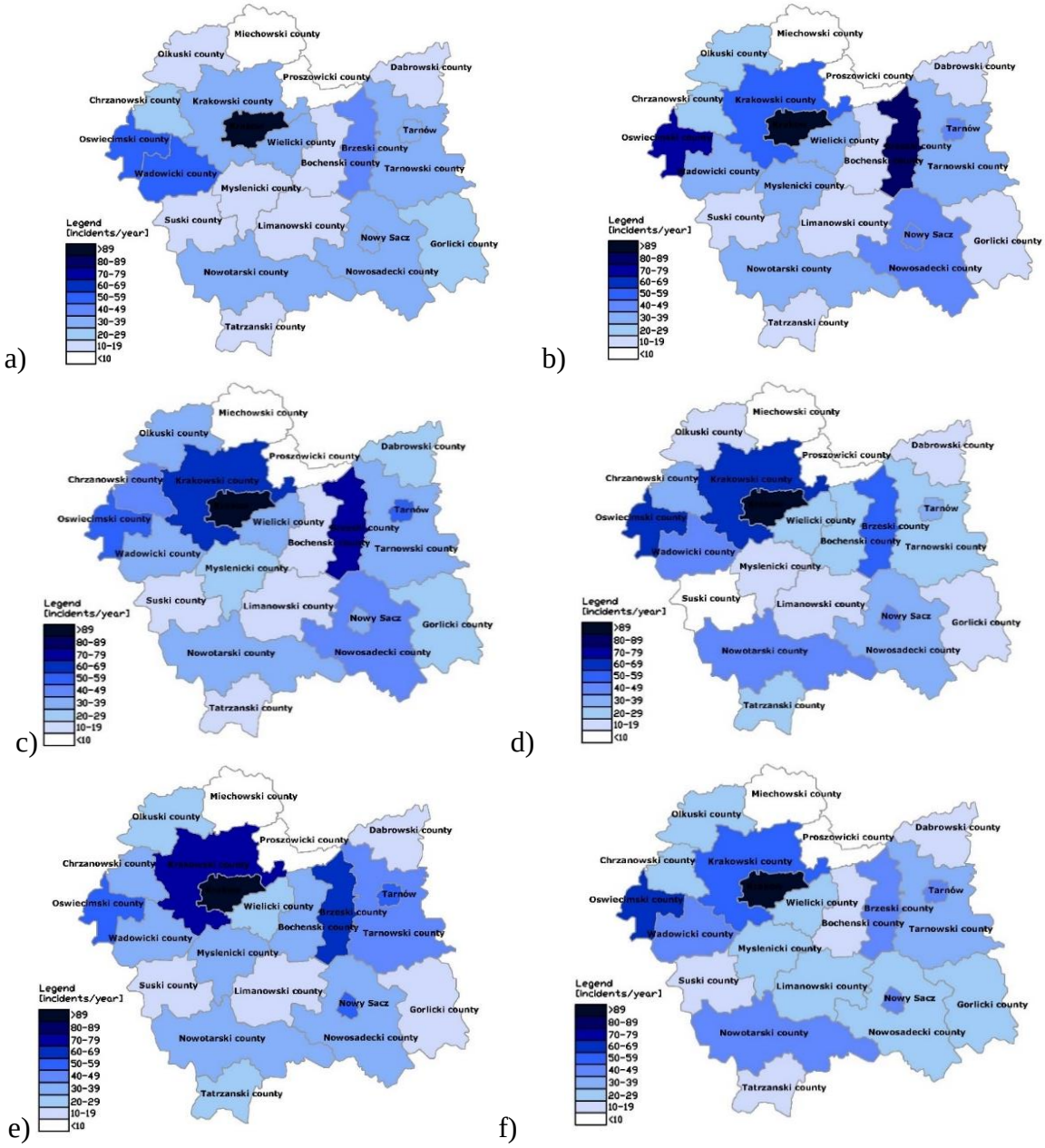
Fig. 4. Causes of road accidents involving cyclists in the Małopolskie Voivodeship in the analyzed period (a) due to the fault of the vehicle drivers, (b) due to pedestrians' fault

4. ASSESSMENT OF THE CYCLING SAFETY IN THE MAŁOPOLSKIE VOIVODESHIP BASED ON ACCIDENTS MAPS

In a further stage of work, maps of road accidents and maps of road accident victims were developed. In each analyzed year, the largest number of road incidents involving cyclists occurred in Kraków (Figure 5). Kraków is a tourist city with high levels of road traffic. In Kraków, the most incidents involving cyclists took place in 2019, and there were 483 road incidents. The fewest incidents were recorded in the Miechowski and Proszowicki counties (44 and 47 respectively). There is variability in the number of road incidents in particular counties in the analyzed period, except for the city of Kraków and the Proszowicki county. The lowest number of incidents involving cyclists was recorded in 2012 (894 incidents).

Figure 6 presents the number of people slightly injured in road accidents involving cyclists in the analyzed period in the Małopolskie Voivodeship. The largest number of slightly injured persons in the city of Kraków was recorded in 2016 (175 slightly injured). The largest number of people slightly injured in road accidents in the entire voivodeship was recorded in 2014 (366 slightly injured, and the least in 2017 (307 slightly injured). The smallest number of slightly injured (less than 30) was recorded in the counties: Proszowicki, Miechowski, Limanowski, and Suski. Similarly, as in the case of the number of road incidents in the analyzed period, there is a variation in the number of slightly injured persons in road incidents in particular counties, except the city of Kraków and Proszowicki county. The largest number of seriously injured individuals was recorded in the city of Kraków in 2016 (83 seriously injured) (Figure 7). The smallest number of seriously injured persons (less than 20) was recorded in the following counties: Miechowski, Suski, Proszowicki, Gorlicki, Dąbrowski, and Limanowski. The lowest number of seriously injured people was recorded in 2017 (155), while the highest number in 2014 (196). There is variability in the number of road incidents in particular counties, except the city of Kraków and counties: the city of Olkusz, Miechowski, Proszowicki, Suski, Limanowski, and Gorlicki. Figure 8 presents maps with the number of fatal victims in road accidents involving cyclists in the Małopolskie Voivodship in the analyzed period. In each case,

the variability of the number of fatalities in particular years in each of the counties is visible. The largest number of fatal victims (7 fatal victims) was recorded in Wielicki county in 2014. The lowest number of fatalities (2 fatal victims) was recorded in the following counties: Dąbrowski, Limanowski, and Proszowicki. The highest number of fatal victims in road accidents involving cyclists (25 fatal victims) was recorded in 2014, and the lowest (13 fatal victims) in 2016.



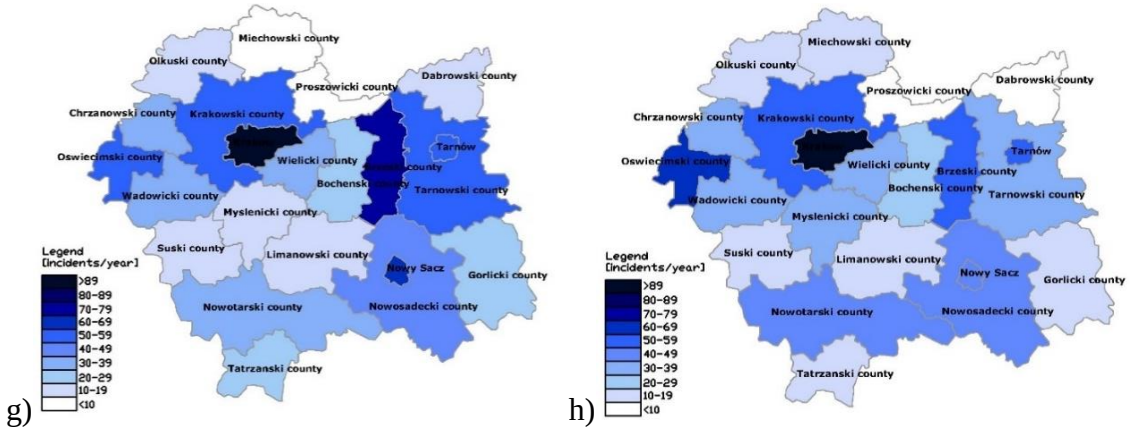
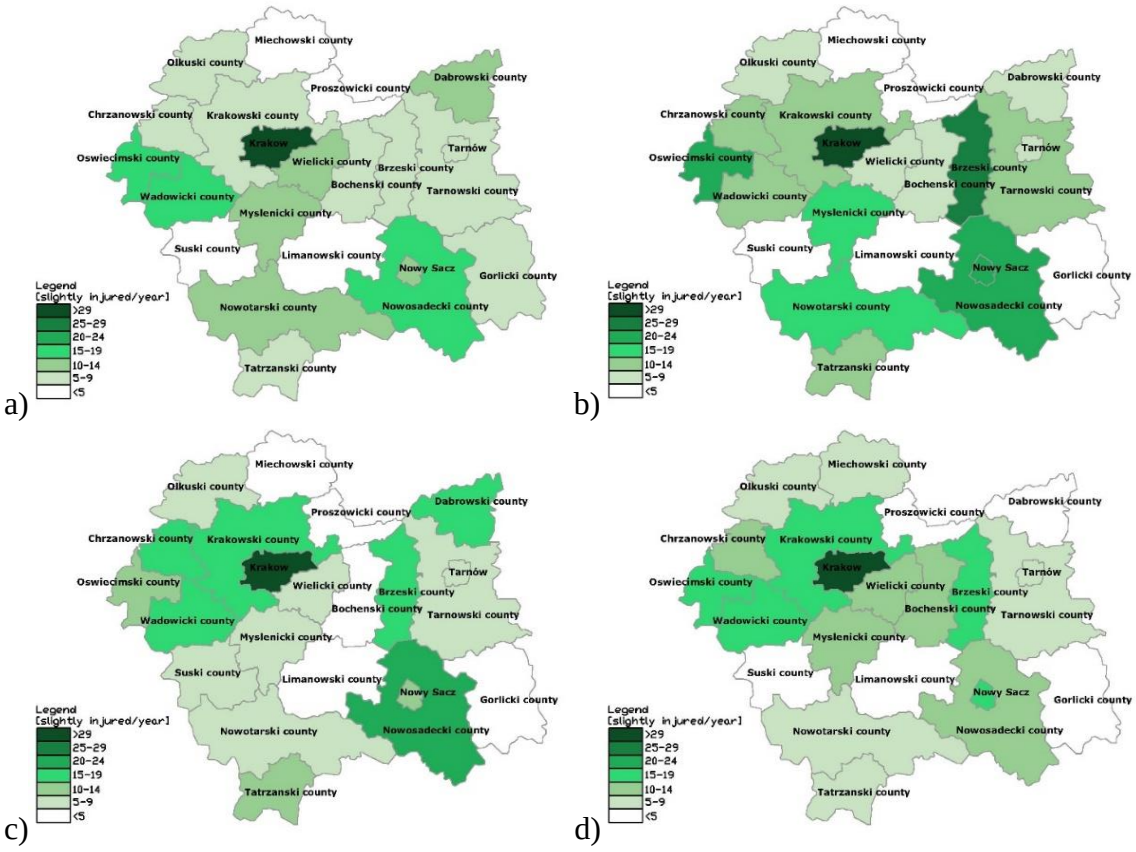


Fig. 5. Maps of road incidents involving cyclists in the Małopolskie Voivodeship in the analyzed period; a) 2012, b) 2013, c) 2014, d) 2015, e) 2016, f) 2017, g) 2018, h) 2019



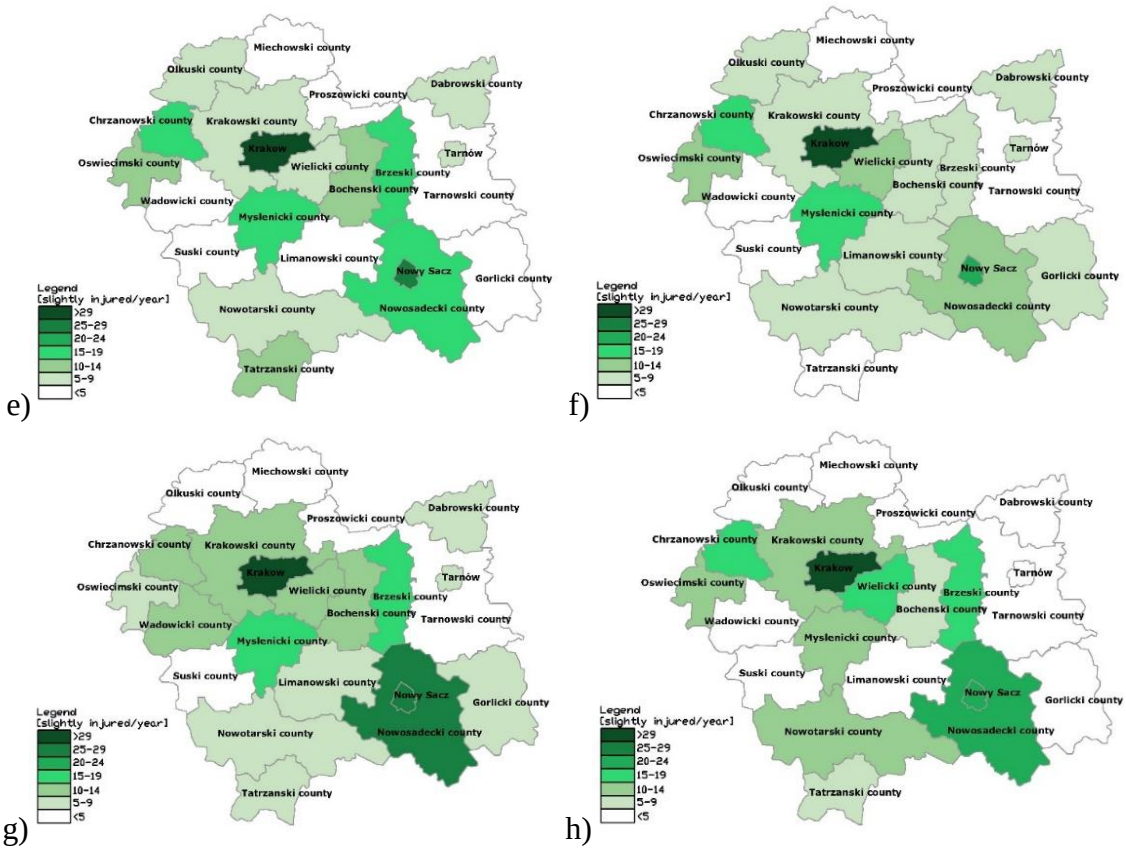
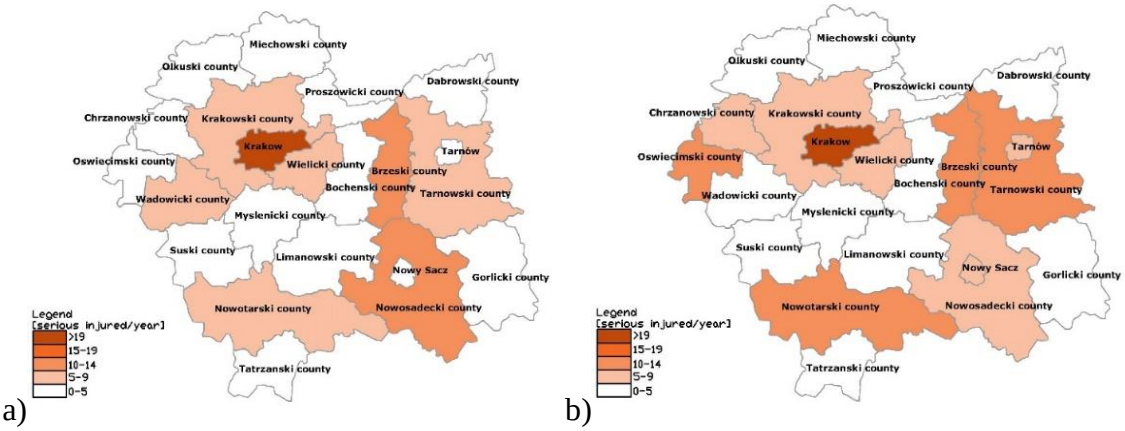


Fig. 6. Maps showing the number of people slightly injured in road accidents involving cyclists in the Małopolskie Voivodeship in the analyzed period; a) 2012, b) 2013, c) 2014, d) 2015, e) 2016, f) 2017, g) 2018, h) 2019



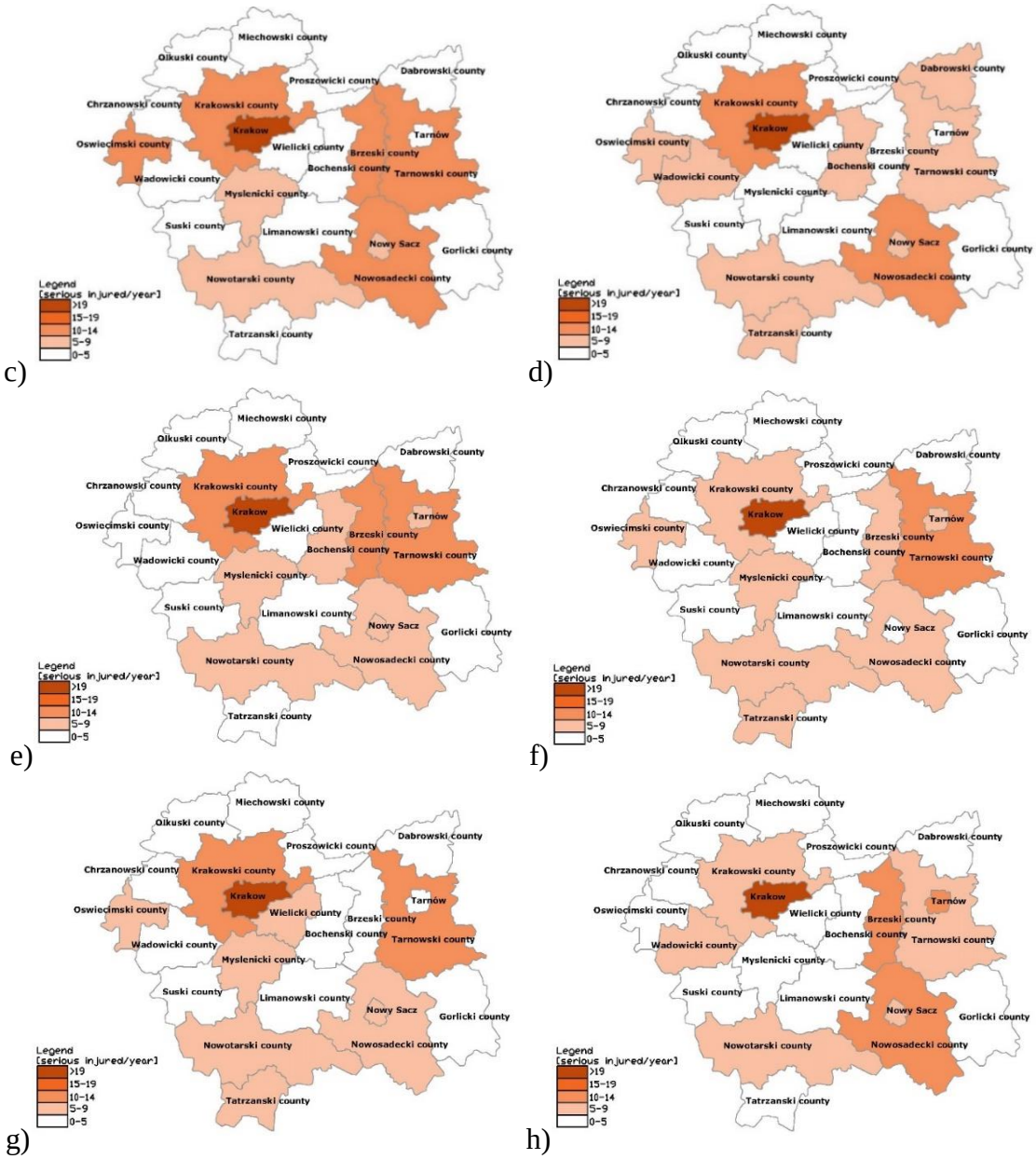
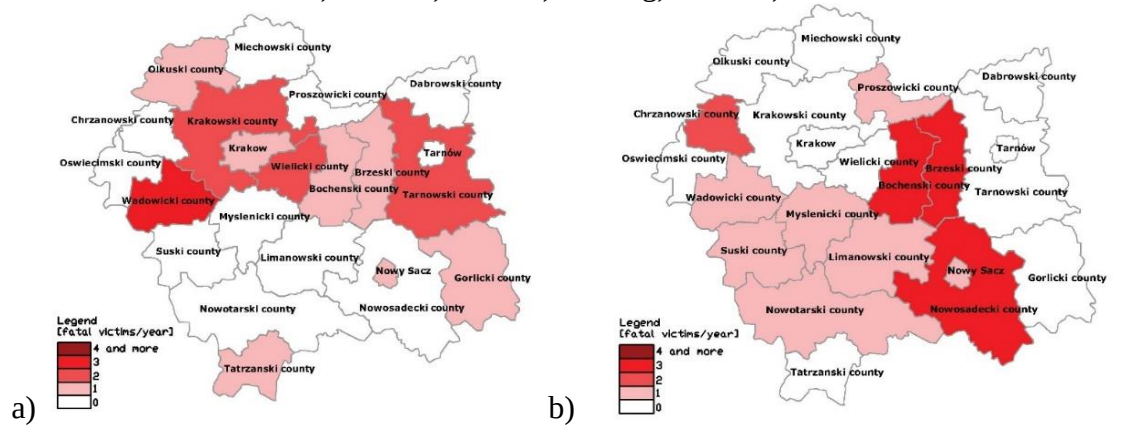


Fig. 7. Maps showing the number of seriously injured people in road accidents involving cyclists in the Małopolskie Voivodeship in the analyzed period; a) 2012, b) 2013, c) 2014, d) 2015, e) 2016, f) 2017, g) 2018, h) 2019



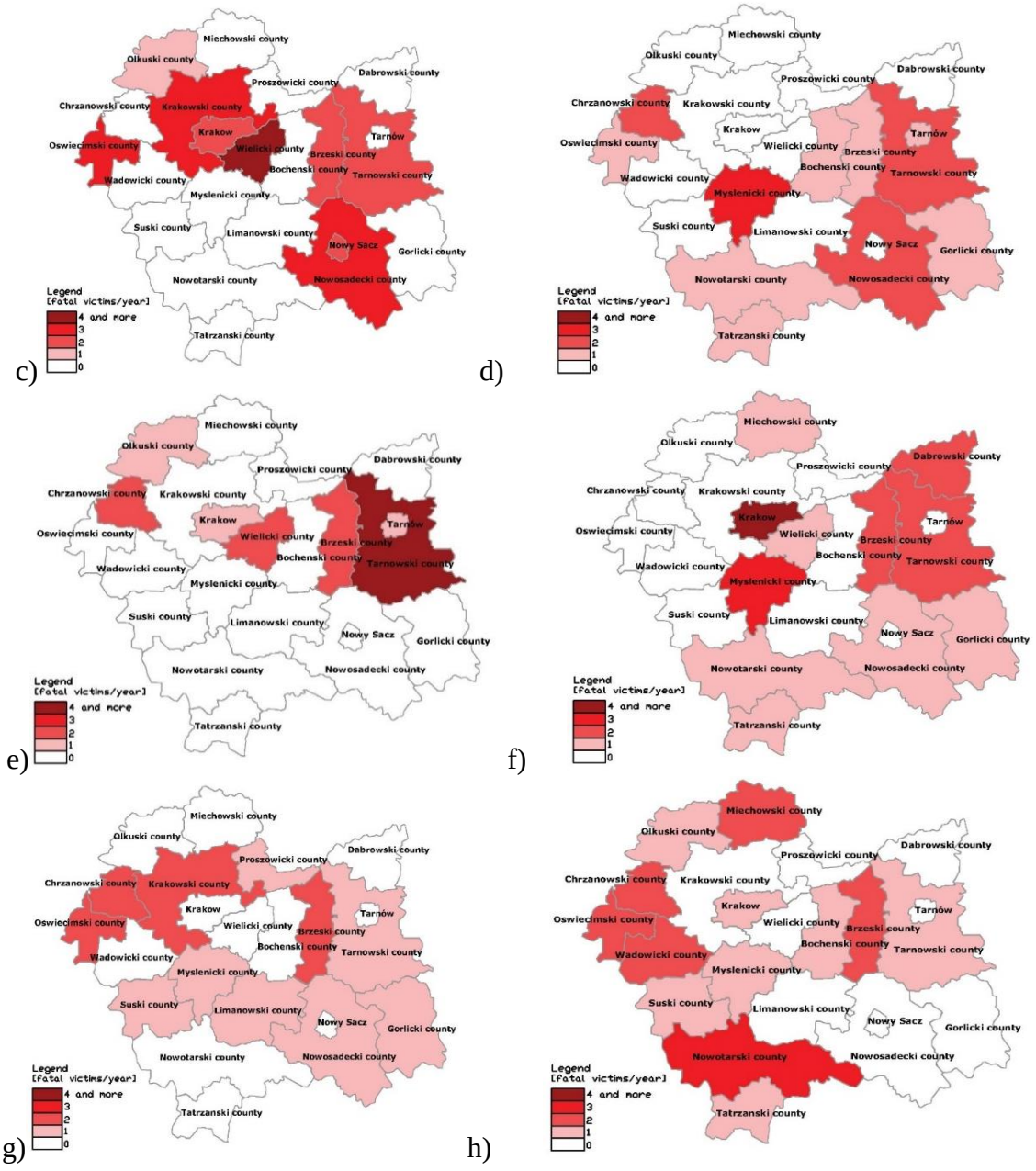


Fig. 8. Maps showing the number of fatal victims in road accidents involving cyclists in the Małopolskie Voivodeship in the analyzed period; a) 2012, b) 2013, c) 2014, d) 2015, e) 2016, f) 2017, g) 2018, h) 2019

Figure 9 presents the location of road accidents in the Małopolskie Voivodeship in the analyzed period, as a result of which individuals were slightly injured. The highest density of road accidents was in the city of Kraków (Figure 9). However, the smallest in the central and northern part of the voivodeship, where counties such as: Proszowicki, Miechowski, Limanowski, and Suski. The presented locations of road incidents in which slightly injured persons were reported are related to the data presented in Figure 6. The lowest concentration of markers representing the location of the incidents can be observed in those counties with the lowest number of slightly injured people.

In the case of road accidents in which the victims suffered injuries classified as severe (seriously injured), the highest density of markers occurs in the city of Krakow. The smallest density of markers occurs in counties such as: Miechowski, Suski, Proszowicki, Gorlicki, Dąbrowski and Limanowski (Figure 10).

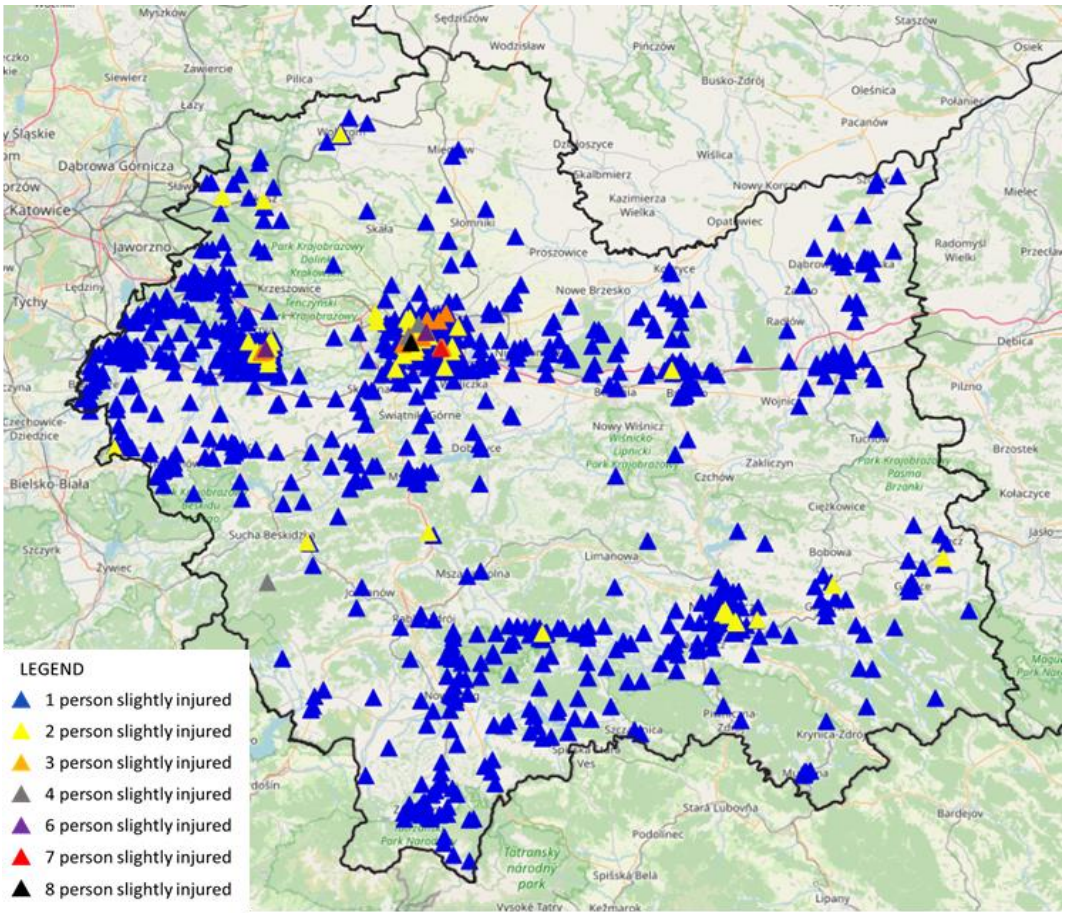


Fig. 9. Location of road accidents with slightly injured in the Małopolskie voivodship in the analyzed period

On the other hand, in the case of road accidents resulting in fatal victims, one accident occurred most frequently in the given locations, and only in a few cases – two accidents (Figure 11). Presentation of data on road incidents in this way (Figures from 9 to 11) allows for the identification of sensitive places (areas, roads, streets, intersections, etc.) on the city's transport network from the point of view of cyclists' safety. At a later stage, it is possible to analyze and search for solutions that may contribute to the improvement of road safety.

5. CONCLUSIONS

The article aimed to analyze the cycling safety in the Małopolskie Voivodeship based on road incident maps. The results of the analyses presented in the article allowed for the formulation of the following conclusions:

- in the analyzed period, the number of incidents is increasing based on the values of the indicators: the number of incidents per 1 million inhabitants and the severity of the incidents

for the Małopolskie Voivodeship. Despite the increase in the number of incidents, the incidents' severity indicator in the Małopolskie Voivodeship is decreasing, which should be considered a positive effect of all activities aimed at improving road safety,

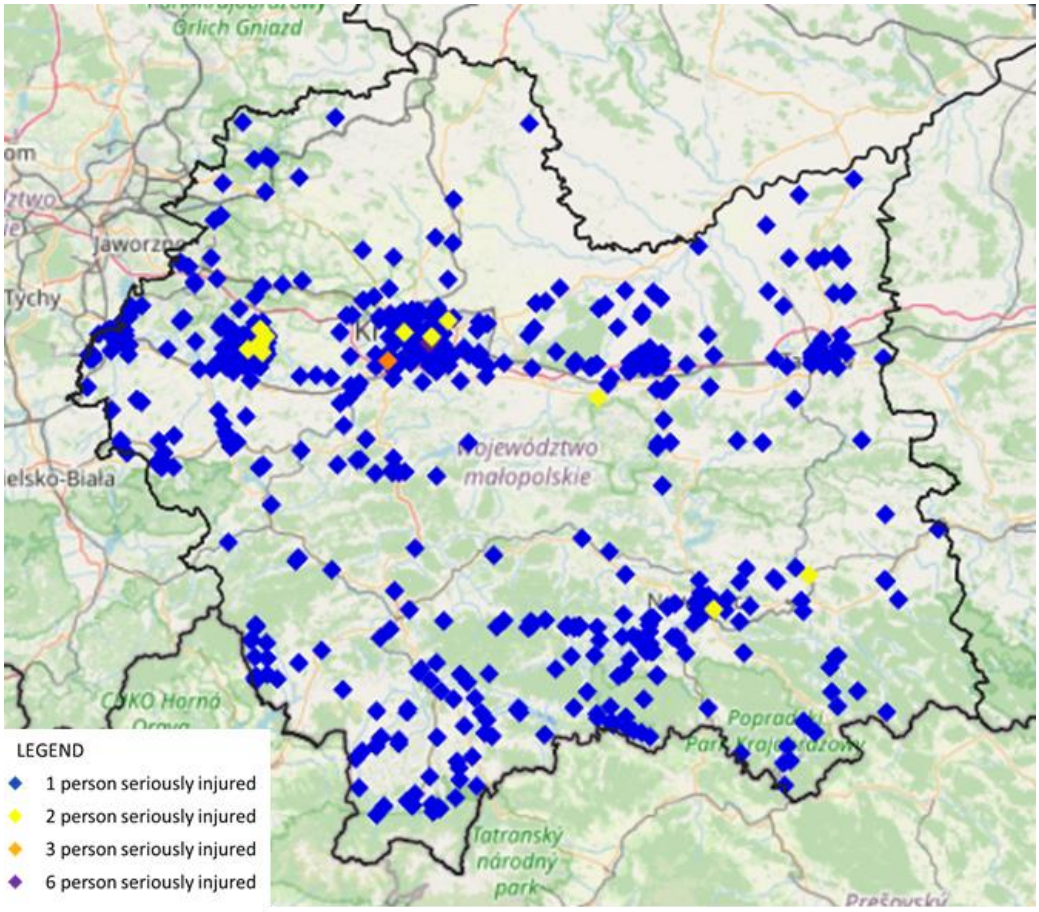


Fig. 10. Location of road accidents with seriously injured victims in the Małopolskie Voivodeship in the analyzed period

- Cracow is characterized by the highest number of road incidents, slightly injured people, and seriously injured individuals,
- the lowest number of road incidents involving cyclists took place in the Miechowski and Proszowicki counties,
- the lowest number of people slightly injured in road incidents involving cyclists was recorded in the following counties: Proszowicki, Miechowski, Limanowski, and Suski. On the other hand, the lowest number of seriously injured persons was recorded in the following counties: Miechowski, Suski, Proszowicki, Gorlicki, Dąbrowski, and Limanowski,
- Wielicki county is characterized by the highest number of fatalities in road accidents involving cyclists. On the other hand, the lowest number of fatal victims was recorded in the counties: Dąbrowski, Limanowski, and Proszowicki,
- Presenting road incidents' data on maps allows for the highlighting of critical locations on the city's transport network from the point of view of cyclists' safety. The information obtained in this way allows for taking actions aimed at improving the state of road safety.

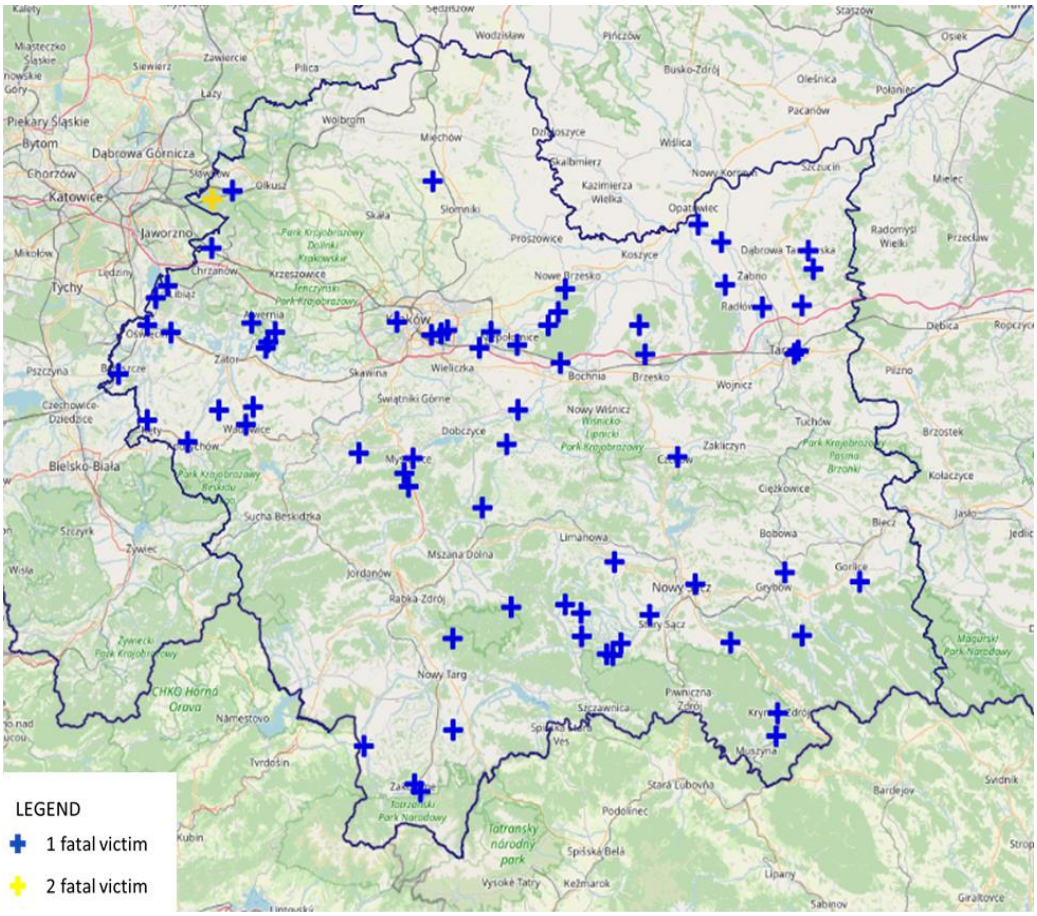


Fig. 11. Location of road accidents with fatal victims in the Małopolskie Voivodeship in the analyzed period

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