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The Impact of Urban Transport Infrastructure and Its Development on the Users' Sense of Safety: The Case of Kraków

Abstract

Objective: This paper assesses the impact of the new infrastructure in the city of Kraków on the sense of safety of the users of the local transport infrastructure in terms of its growth and influence on the residents' safety.

Research Design & Methods: The research was conducted using questionnaire interviews in a group of 203 respondents in May 2022.

Findings: In the respondents' opinion, Kraków's transport infrastructure positively impacts their sense of safety, and the solutions introduced to increase road safety have served their purpose. The city's transport infrastructure for cyclists is regarded as its weakness, while the best safety-related solutions can be observed in the infrastructure for pedestrians.

Implications/Recommendations: The expansion of the transport infrastructure in urban areas represents a major factor underpinning the development of spatial structure in cities. A well-functioning urban transport system is a condition *sine qua non* for the provision of an effective and efficient transportation service for the city's residents, thus improving broadly understood quality of life. Given a large number of traffic users, the city authorities are under the obligation to ensure that the transport infrastructure is safe for them. The new initiatives and proper infrastructure management help improve the comfort of travel and the quality of life for residents and visitors alike.

Contribution/Value Added: This study contributes to academia and practice by offering data and recommendations to improve the safety of users of city infrastructure.

Article classification: research article

Keywords: transport; urban transport; urban transport infrastructure; road traffic safety

JEL classification: R41

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Introduction

Transport is an integral aspect of human presence in the environment. It stems from the human need to travel from one place to another and move objects between different locations. To satisfy this need, diverse sectors of the economy have been developed, and the infrastructure for transport is regularly built and continuously expanded.

Transport infrastructure is also an integral element of the economy as it enables the provision of transportation services. The lack of cohesion between transport activity and other sectors of the national economy may adversely affect the opportunities of a given nation for growth and lower the living standards of the population.

In recent years, significant changes can be observed in Poland's transport infrastructure. The access to countryside municipalities and their integration with the main cities have improved, thus driving urban population growth. The transport infrastructure in cities is unique in that it entails interactions within diverse groups of users. Since safety is one of the factors that determine the quality of life in cities, the impact of infrastructure on the perceived sense of safety is an issue that calls for examination. The changes that can be observed in Kraków in relation to projects expanding the transport network reveal some infrastructural solutions that can considerably improve user safety.

The aim of the paper is to assess the impact of the transport infrastructure being developed in the city of Kraków on the sense of safety of its users.

Literature review

The term "transport infrastructure" refers to all roads and fixed facilities for three types of transport: land, water, and air, which are needed to enable traffic streams while ensuring safety (Tarka, 2012). The literature offers many definitions of "infrastructure" depending on the degree of the incorporated details. Neider (2019) describes transport infrastructure as "all structures and fixed facilities having a permanent location, which allow for the movement of means of transport and handling equipment, goods and passengers". In contrast, Kristiansen states that "transport infrastructure refers to the means and conditions that may be required to enable the physical movement of individuals and goods, and therefore ensure general conditions for production and services" (quoted after Domańska, 2006). Biehl, in turn, understands transport infrastructure as "a direct instrument of government policy, the long-term strategy of which always requires public resources to be increased, which essentially means more investment in infrastructure, and renders the planning, implementation and financing of such investment projects the main instrument of regional policy". For this reason, developing transport infrastructure in any country is not solely governed by the market alone, but also represents a vital part of national development policies (quoted after Domańska, 2006).

Transport infrastructure performs a number of different roles, such as (Kaczyńska & Korycińska, 2014):

- meeting specific socioeconomic needs by providing spatial linkages;
- fulfilling transport policy tasks by determining the manner in which such linkages can be established;
- determining the built heritage − infrastructure facilities with a long lifecycle can have a lasting impact on spatial development and often become monuments of architecture and symbols of the location where they were built.

Transport infrastructure is regarded as part of national assets, and its accessibility defines the growth of every economy. It is the foundation of socioeconomic activity and its circulatory system that provides access to resources, markets, and goods (Górniak, 2020).

The extension of the transport infrastructure in urban areas is an important factor in the growth of spatial structures in contemporary cities. The transport infrastructure of an urban area incorporates a large number of facilities that form the city's transport network, and an appropriate level of its development is essential for the proper functioning of the public transit system in the city, which is a significant aspect of the broadly understood quality of life (Krajewska & Łukasik, 2017; Vennemo, 2023).

Transport infrastructure is made up of components required for mass (public) and individual transportation. Public transportation infrastructure includes means of transport by road, rail, air, sea, rivers, and lakes, as well as radio navigation systems for air and sea transport. Components of individual transport infrastructure include streets, pavements, and cycleways.

In city transport, road and rail transport vehicles prevail (buses, trolleybuses, passenger cars, trams, and suburban and underground trains). It is quite natural, therefore, that the transport infrastructure in a city needs to accommodate different forms of transport. It is made up of such components as (Wojewódzka-Król & Załoga, 2016):

- roads and streets with fixed facilities that help organise vehicle and pedestrian traffic;
- tram, railway, and underground railway tracks;
- stops, stations, and interchanges;
- bus, tram, and trolleybus depots;
- power supply networks for trams, railways, underground trains, and trolleybuses;
- power substations;
- parking lots.

The recent years have seen considerable strain being placed on transport infrastructure in cities (Głądała, 2020; Gonzalez-Aliste et al., 2023). Excessive pressure on transport infrastructure, known as congestion, is caused by such factors as the ever increasing urban population and too many cars in urban areas. This results in significant reductions of traffic speed, longer congestion periods, and congestion spillover to the access roads. The problem of congestion is a universal problem in cities, most acutely felt in large urban agglomerations and metropolitan areas (Krysiuk, 2016). What is more, there is a close correlation observable in Poland between the motorisation rate and the city size: the bigger the city, the greater the number of vehicles (Pietrzyk-Wiszowaty, 2018). This is also transposed into the dwindling numbers of passengers in public transit systems.

The significant inefficiency and insufficient capacity of urban road systems leads to many problems and jeopardises the safety of road users, particularly their vulnerable groups, i.e. pedestrians and cyclists (Zbyszyński et al., 2015; Svatý et al., 2019).

The concept of "safety" is an entrenched human need and a vital value required for both individuals and social groups to grow. It is most often understood as a state of certainty, calmness, being free from external threats (Lewandowski, 2010). Safety issues and potential hazards are caused, deliberately or not, by human actions that result in the weakening or disrupting of the transport system, including public transport, and(or) death(s) of passengers or service personnel (Pietrzyk-Wiszowaty, 2018).

The meaning of safety in road traffic is expounded by Siedlecka and Mądziel (2016) in their study. The authors define it as "a condition of the public road enabling smooth and efficient operation of traffic without endangering the lives and property of road users".

The International Association of Public Transport (2011) names three pillars of safety in collective transport (Janczarska-Bergel, 2022):

- human factors – qualified personnel;
- procedures – a well-designed safety programme based on accident analysis and risk assessment;
- technologies – monitoring, introduction of innovative visual (warning) elements, and better lighting (e.g. crossings).

Since traffic safety is closely related to vehicles, road users, and their immediate surroundings, it can be said that – in addition to the road infrastructure – the level of safety depends on the vehicle designs and the skills of drivers, cyclists, and pedestrians (Wojtas & Szkoda, 2018, Costin et al., 2018, Szruba, 2019).

The development of transport infrastructure involves many dilemmas relating to investment policies in urban areas, while the decisions made ought to factor in upgrading the quality of life by increasing the safety of the city residents and traffic users (Kubejko-Polańska & Marcinko, 2015).

Research methodology

The research on the impact of Kraków's transport infrastructure on the sense of safety of its users was conducted in 2022, and was preceded by a pilot study. The surveyed group included 203 adult respondents living in the city of Kraków and its environs, who were users of the city's transport infrastructure. Their characteristics are presented in Table 1.

Table 1. The characteristics of the respondents

Age	Women	Men	%
18–25	68	45	56
26–35	26	21	23
36–45	10	12	11
46–55	9	5	7
56–65	0	2	1
65+	1	4	2
Share	56%	44%	100

Source: Own elaboration.

The research was conducted using the CAWI method. The survey questionnaire included questions on the perception of the city's s transport infrastructure by its users and questions relating to the respondents' characteristics. The sample's selection was non-random.

Based on the information from the respondents, the study aimed to:

- identify the degree to which the transport infrastructure affects safety in comparison to other road traffic factors;
- find out how the users assess the condition of Kraków's transport infrastructure and its development prospects;
- identify the elements of transport infrastructure which are perceived by the individual groups of respondents to be the most dangerous;

- find out how the respondents view some examples of infrastructural solutions applied in Kraków to improve road safety.

The findings were analysed and presented in the form of tables and figures.

Results and discussion

The results of the survey are presented in the tables and figures below. First, the respondents were asked to indicate the means of transport they chose most often while travelling in Kraków (Fig. 1).

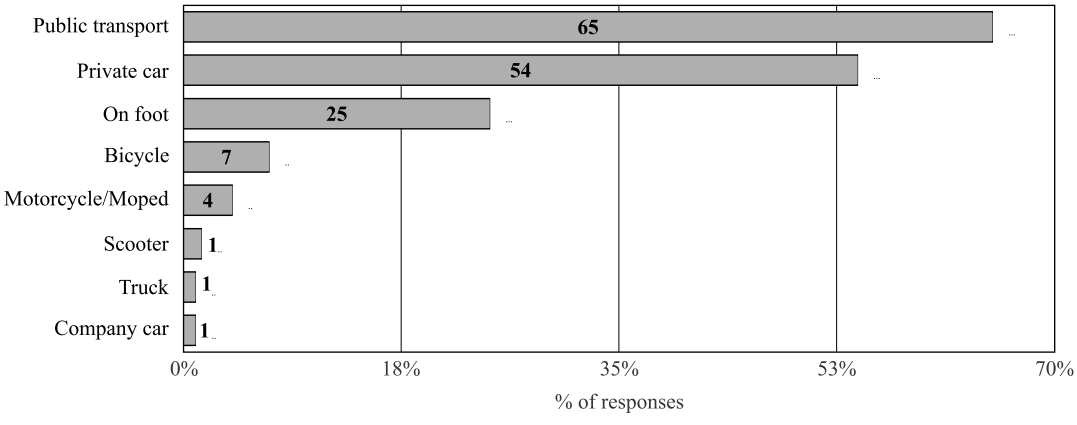

Figure 1. Means of transport chosen for travelling in Kraków

Source: Own elaboration.

The majority of the respondents use public transport and private cars for mobility in Kraków. Walking is also popular and is frequently combined with other forms of transport.

The respondents were also asked about the frequency of their use of the city's transport infrastructure and the average overall daily travelling times (Fig. 2).

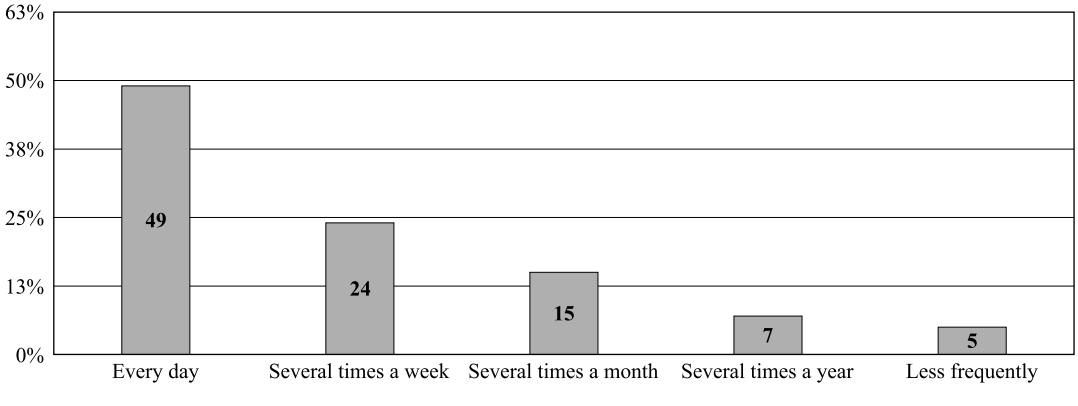

Figure 2. The frequency of using Kraków's transport infrastructure

Source: Own elaboration.

The survey indicates that half of the respondents use transport infrastructure daily, and 24% up to several times a week, while 15% not more than several times a month.

The question on the average daily time spent travelling in Kraków was open-ended, and the elicited responses varied from 20 minutes to 10 hours. The most frequent answer was one hour (33%), followed by two hours (28%) and one and a half hour (13%). Only 7% of the respondents need less than an hour to reach their destination and travel back.

The elicited answers found that the respondents have frequent interactions with Kraków's transport, and use it in various situations and at different times of day.

The next part of the survey included questions on the city's transport infrastructure. First, the respondents were asked if they felt safe as road users in Kraków (Fig. 3).

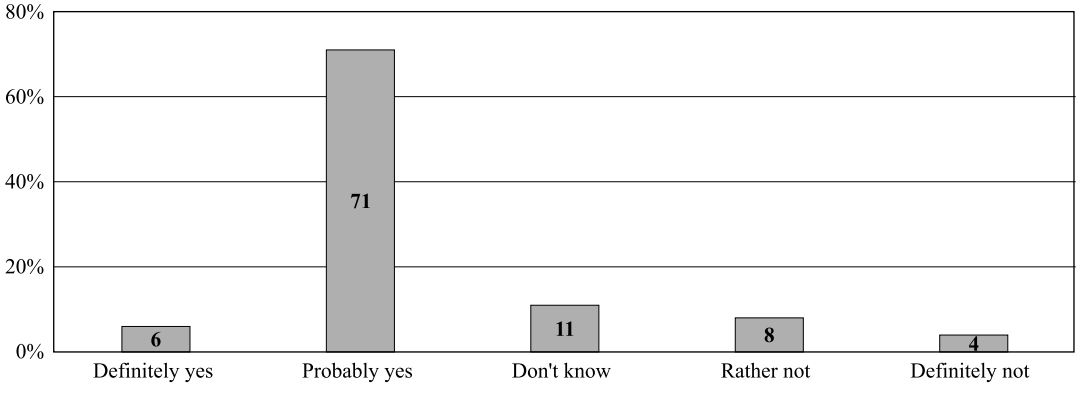

Figure 3. The sense of road safety in Kraków

Source: Own elaboration.

The majority of the respondents felt safe (77% in all), 12% did not feel safe, but as many as 11% were not able to define their opinion in this regard.

The respondents were also asked to assess the current condition of Kraków's infrastructure on a scale from 1 to 5, where 1 was Very Poor, and 5 – Very Good (Fig. 4).

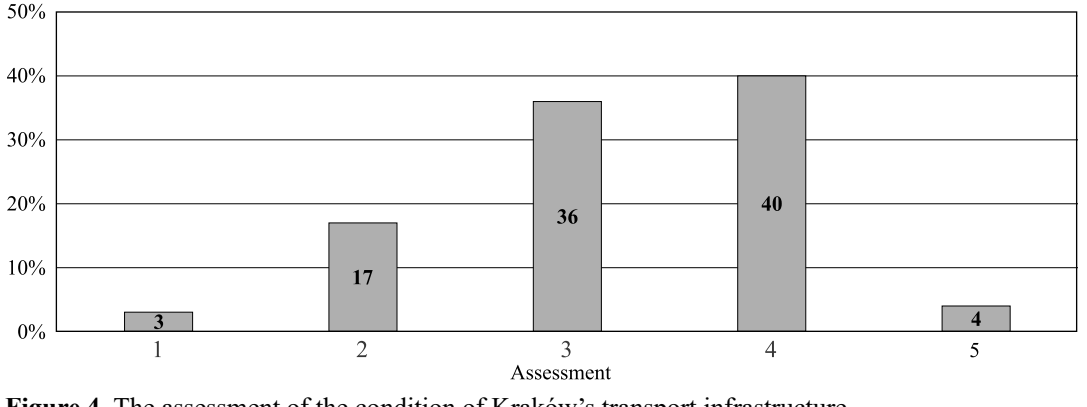

Figure 4. The assessment of the condition of Kraków's transport infrastructure

Source: Own elaboration.

The state of the transport infrastructure was assessed as good by 40% of the respondents, whereas only 4% regarded it as very good. As many as 20% of the respondents did not think very highly of the city's infrastructure, possibly because of daily congestion caused by its limited capacity, as well as omnipresent repair and maintenance works which hamper unimpeded travel in the city's main thoroughfares.

The question on the state of the city's infrastructure was followed by one concerning its impact on the respondents' perceived safety (Fig. 5).

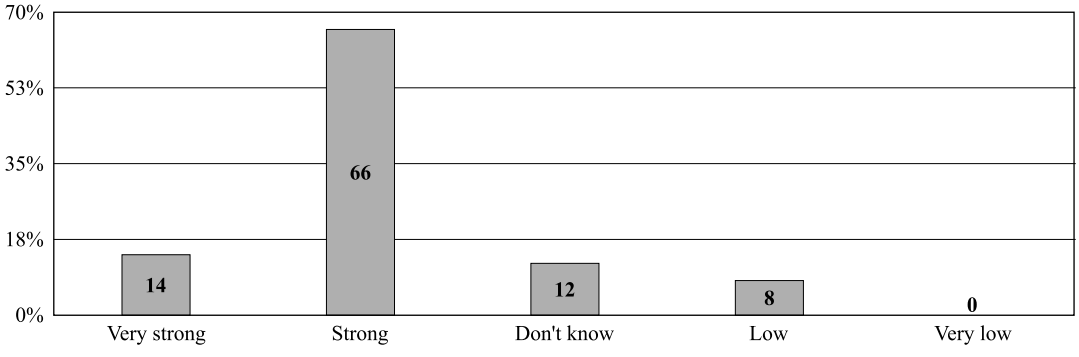

Figure 5. The impact of Kraków's transport infrastructure on the sense of safety

Source: Own elaboration.

The road infrastructure considerably affects the sense of safety for 66% of the interviewees, as compared to 8% who believe that this impact is insignificant, whereas 12% of the respondents did not have an opinion on this matter.

In the next part of the survey, the respondents were asked about those locations in Kraków in which they felt the least safe as road users, pedestrians, cyclists, and drivers.

The respondents were to select not more than three locations which are perceived as the least safe for pedestrians (Fig. 6). Most respondents listed roadsides, shared paths for pedestrians and cyclists, and pedestrian crossings. According to police statistics, the latter are indeed frequent sites of traffic incidents. Kraków is no exception: Poland's second-largest city still has many streets with roadsides only, which offer no protection from the approaching vehicles.

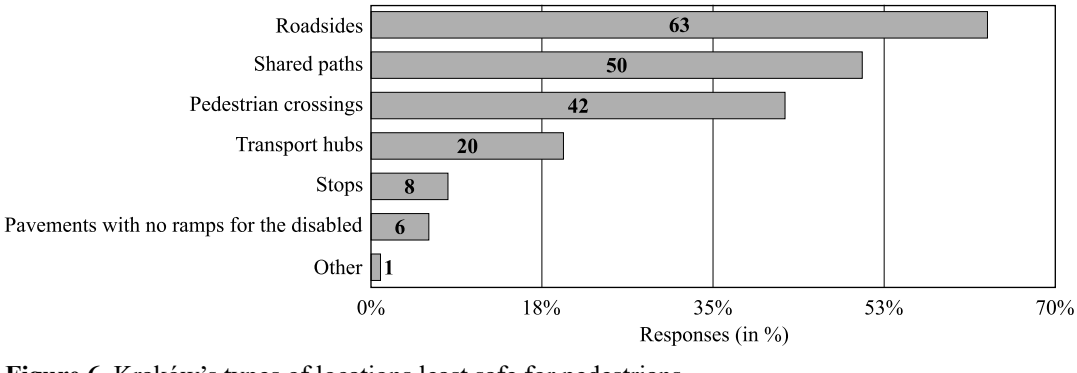

Figure 6. Kraków's types of locations least safe for pedestrians

Source: Own elaboration.

Figure 7 shows the distribution of dangerous sites for cyclists, as listed by the respondents.

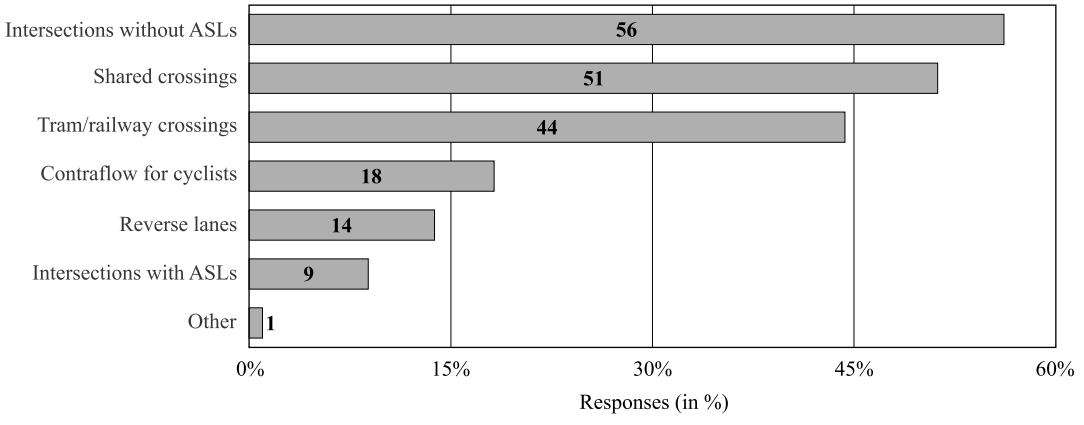

Figure 7. Types of locations least safe for cyclists in Kraków

Source: Own elaboration.

Most respondents listed intersections without advanced stop lines (ASLs), i.e. facilities that alert drivers to cyclists' presence and also streamline their safe passage along the cyclist-dedicated lanes and crossings. For this reason, shared crossings for pedestrians and cyclists were named as the second least safe arrangement. The respondents also cited contraflows and reverse lanes.

Figure 8 lists the respondents' answers concerning sites which are regarded as dangerous for drivers travelling in Kraków.

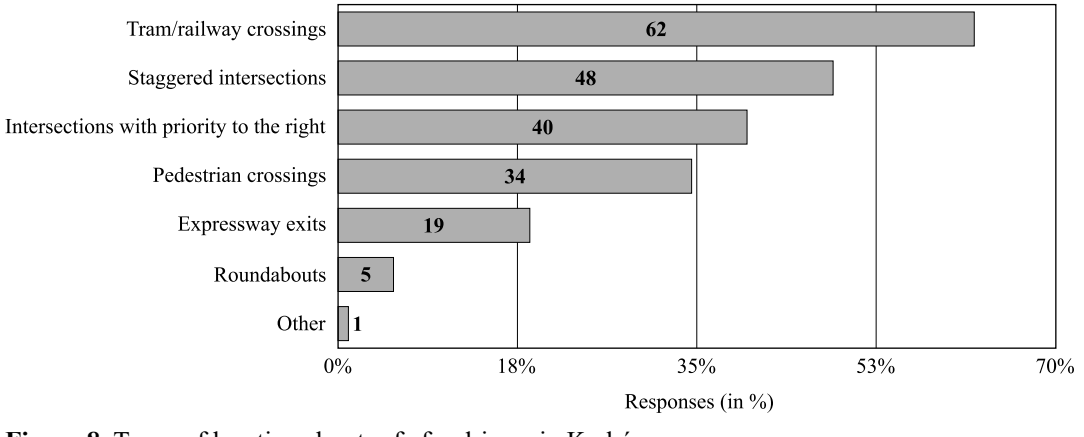

Figure 8. Types of locations least safe for drivers in Kraków

Source: Own elaboration.

According to the respondents, the least safe places for drivers are tram and railway crossings, where accidents do not happen very often, but their consequences can frequently be catastrophic. The second listed were intersections where general traffic rules should be obeyed due to the absence of traffic lights. The respondents also indicated pedestrian crossings where drivers have to watch out for other road users who have right of way at that particular location.

Once the interviewees named the most critical locations of Kraków's road infrastructure, they were asked about those elements of the road infrastructure which in their opinion improve the safety of users: pedestrians, cyclists, and drivers. The respondents could select not more than three answers. As regards pedestrians' safety, the respondents considered the illumination of the pedestrian crossings to be the factor that could contribute the most to pedestrian safety (Tab. 2). The second most popular answer suggested constructing pavements in place of the existing roadsides, mainly with a view to ensuring the safety of youngest road users, the elderly, and persons with disabilities. This was followed by solutions aimed at protecting pedestrians through calming the traffic, such as speed bumps or pedestrian-activated measures such as light signals or other signalling devices.

Table 2. Elements of road infrastructure improving pedestrians' safety in Kraków

Elements of road infrastructure	Responses (in %)
Illumination of pedestrian crossings	54
Pavements in lieu of roadsides	41
Speed bumps	35
Marked pedestrian crossings, variable message signs	26
Interactive, pedestrian activated crossings	25
Splitting pavements into pedestrian and cycle lanes	21
Speed cameras	21
Lane separators close to pedestrian crossings	14
Crossings with pedestrian refuges or road narrowing	13
Speed limit signs	9
High curbs	7

Source: Own elaboration.

A similar question was asked in relation to measures that improve cyclists' safety (Tab. 3).

Table 3. Elements of road infrastructure improving cyclists' safety in Kraków

Elements of road infrastructure	Responses (in %)
Uninterrupted cycleways	75
Surface condition of cycleways	40
Appropriate signage	34
Illuminated crossings at intersections	30
Advanced stop lanes (ASLs)	29
Bicycle crossings across carriageways	28

Source: Own elaboration.

Most respondents named the component of the cycling traffic that is missing in Kraków, that is the continuity of cycleways. The absence of uninterrupted cycleways can lead to dangerous situations involving cyclists and drivers or pedestrians since their respective routes frequently

intersect. The respondents take the view that appropriate signage and lighting illuminating intersections are more desirable solutions to be applied. Similar conclusions were formulated by Reynolds et al. (2009), who pointed out that cycle lanes are the key factor in improving cyclist safety, and named street lighting and paved roads as additional factors that can restrict hazards of accidents and cyclist injuries.

In the next question, the respondents were asked to list up to three infrastructure solutions improving driver safety (Tab. 4).

Table 4. Elements of road infrastructure improving driver safety in Kraków

Elements of road infrastructure	Responses (in %)
Condition of road surface	28
Street lighting	25
Roundabouts	18
Interactive pedestrian crossings – signalling pedestrians' presence	15
Appropriate signage, variable message signs (VMS)	13
Speed cameras	7
Speed limit signs	7
Narrowed lanes and changes to road geometry to calm traffic	7
Road bumps/humps	6

Source: Own elaboration.

The respondents listed the road surface condition as the key element that determines safety. Drivers also regard street lighting as a significant aspect as it enables better and faster responses to stimuli from the environment after sunset. Roundabouts were the subsequent solution listed by the respondents, since they have fewer collision points than traditional intersections, while devices designed to reduce vehicle speeds were less frequently listed by the respondents.

The respondents were also asked to evaluate the state of road infrastructure in view of many road repairs being conducted in the period prior to the study and financed from the EU or local funds. Given the fact that many investment projects were not halted during the COVID-19 pandemic, the respondents were asked whether the recent changes were visible and whether they made any difference; their opinions are presented in Figure 9.

Most of the respondents observed certain or even considerable improvement during the past two years. Therefore, they were subsequently asked whether the development and improvement of the infrastructure increases their perceived safety (Fig. 10).

The number of the respondents with an increased sense of safety was nearly the same as that of those interviewees who felt no improvement. This is a disheartening result, as Kraków's road infrastructure was regarded as an important element of safety by 80% of the interviewees.

In the subsequent part of the survey, the respondents were asked to evaluate specific infrastructure solutions and their impact on their sense of safety. The first question was about countdown timers at Kraków's intersections (Fig. 11).

Even though the impact of countdown timers on improving road safety has not been corroborated by research, as many as 74% of the interviewees admitted that these devices do improve their

sense of safety. This is an interesting finding in the light of the psychological effect such devices can have on drivers.

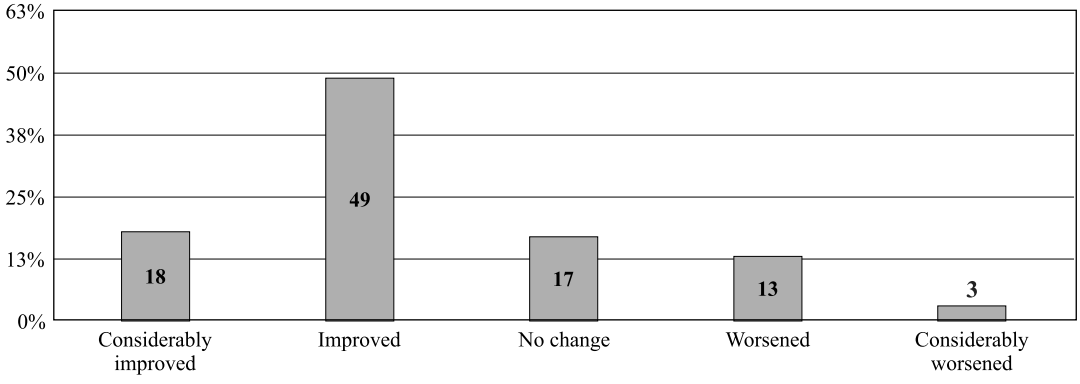

Figure 9. The assessment of the development of Kraków's road infrastructure in 2020–2022

Source: Own elaboration.

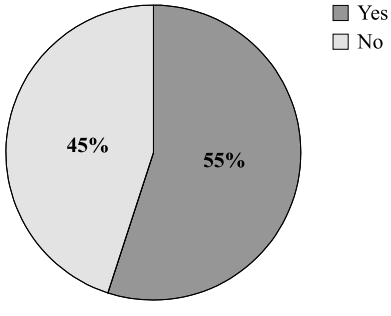

Figure 10. The evaluation of the impact of the development of Kraków's road infrastructure on increased sense of safety

Source: Own elaboration.

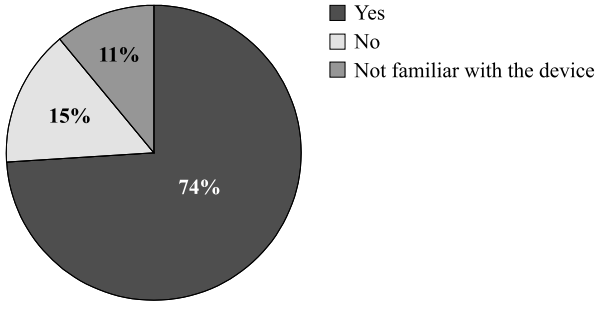

Figure 11. The evaluation of countdown timers on safety improvement

Source: Own elaboration.

The next question tackled the issue of cyclist safety in Kraków's streets. Figure 12 shows the distribution of the answers to the question whether the application of ASLs at intersections helps improve cyclists' sense of safety.

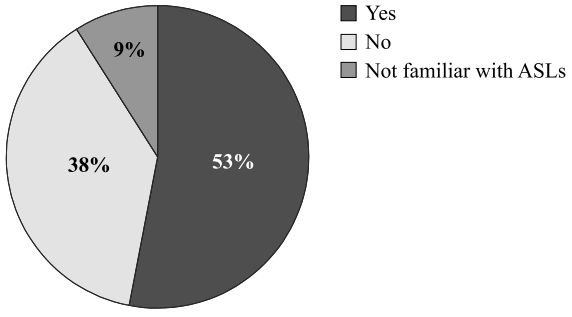

Figure 12. The evaluation of ASLs on safety improvement

Source: Own elaboration.

Slightly more than half of the interviewees were of the opinion that ASLs improve safety, whereas 38% respondents did not share such a view. One reason for this could be the lack of knowledge among both cyclists and motorists passing by on how such solutions ought to be used.

Since pedestrians are the most vulnerable group of road users, and most road incidents take place at pedestrian crossings, the respondents were presented with four types of such crossings and asked to assess them on a scale from 1 (Least Safe) to 5 (Most Safe) (Fig. 13).

In terms of the weighted average, refuge island crossings were most favourably assessed (with an average of 3.9). Such crossings enable pedestrians to cross the street in two stages and also offer safe harbour in the case of driver errors. Narrowed crossings were the next most popular solution listed by the respondents with regard to their sense of safety (3.8). Reducing the width of the carriageway to one lane makes the crossing shorter and therefore safer. Drivers slow down at such spots not only because of pedestrians; they need to make sure that no other vehicle is coming from the opposite direction. Humped zebra crossings were the solution ranked as third by the respondents (3.7); they force the drivers to slow down and act as an obstacle to speeding motorists. Crossings with lane dividers (separators) installed before the crossing were the least popular with the respondents (3.3). The significant number of 2 and 3 ratings accorded by the respondents suggests that they do not feel such a solution guarantees a safe passage across the street. Similarly, such crossings are not found reliable by drivers owing to the potential risk to the vehicle, mentioned above.

The last two questions were open-ended and asked about the kinds of problems experienced by road users in Kraków and about their suggestions related to improving safety. The first question asked about the facilities in the city's road infrastructure aimed at improving safety. The respondents were requested to list those solutions which are not effective or give road users a false sense of safety. The menu options most frequently cited were speed cameras and speed limit signs, followed by ASLs and pedestrian crossings with lane dividers. Slightly fewer respondents cited other types of pedestrian crossings: humped, with refuge islands, and with narrowed lanes, probably due to the illusory sense of safety that they offer to pedestrians. Some respondents also listed unlit pedestrian crossings and bicycle carriageway crossings.

Finally, the respondents were asked to propose solutions that would, in their opinion, improve the safety of Kraków's roads. A substantial majority of the answers opted for the illumination of pedestrian crossings. Furthermore, many respondents suggested to separate pedestrian traffic

from bicycle and motor traffic. Others opted for new pavements, upgrading of the road surface, and the provision of appropriate and easy to understand signage. Many of the submitted proposals were not directly related to infrastructure but, rather, called for making changes in the regulations and educating road users.

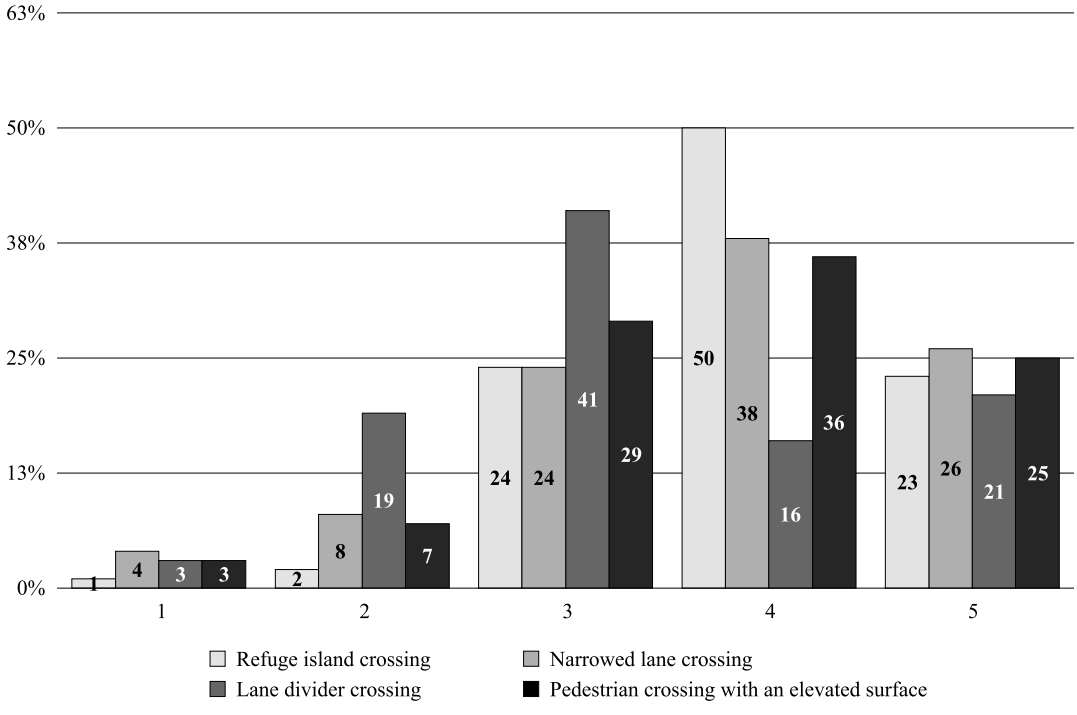

Figure 13. The assessment of four types of pedestrian crossings in terms of safety

Source: Own elaboration.

Conclusions

The study led to the following conclusions:

1. Most of the interviewed users of Kraków's transport infrastructure note that its condition has improved.
2. Pedestrians in Kraków have the lowest sense of safety in those locations which had direct contact with other traffic users – cyclists or motorists. For this reason, roadsides, shared (multi-use) paths, and pedestrian crossings are those components of Kraków's transport infrastructure that require additional measures to improve pedestrian safety.
3. For cyclists, the intersections of various routes, roads, and paths are the least safe places in the city. As is the case with pedestrians, the points of contact with other traffic users can be problematic, such as intersections without shared crossings for pedestrians and cyclists or tramway crossings. The respondents also suggested some solutions to improve cyclist safety and convenience, such as contraflows and reverse lanes.
4. Drivers in Kraków consider intersections with trains or trams or sites where there are no automatically controlled traffic lighting and users need to know basic traffic regulations to be

the city's least safe locations. These include train and tram crossings, staggered intersections, priority-to-the-right intersections, and expressway exits. Such places need to be properly and clearly marked.

5. Solutions that can most significantly improve pedestrian safety are those that increase their visibility at street crossings and those that inform drivers about pedestrians' presence, thus allowing them to slow down and offer safe passage to the pedestrians.
6. One solution that would definitely improve cyclists' safety is the continuity of cycleways.
7. The most considerable factor increasing the drivers' sense of safety is the improved condition of the road surfaces and street lighting.
8. ASLs are a solution that is well received by most respondents. One potential source of problems is the conflict between drivers and cyclists, when the driver needs to quickly leave the intersection, whereas the cyclist wants above all to ride safely alongside the faster and larger vehicles driving by.

The findings from the research suggest that the infrastructure for cyclists is the Achilles' heel of Kraków' transport infrastructure. What first and foremost calls for improvement is the continuity of cycleways, a factor which has been cited as the main condition underpinning the respondents' improved sense of safety. Another weakness of Kraków's transport infrastructure is its low capacity, limited by congestion; this calls for changes in the present road infrastructure and in the user attitudes. Since the city's investment projects often take a long time to complete, the users do not feel safe while travelling in diversion roads, or are forced to seek alternative routes. On the other hand, the pedestrian infrastructure is Kraków's definite asset as far as the respondents' perceived safety is concerned; the users note and appreciate the solutions being introduced.

The study found that the users of Kraków's transport infrastructure are aware that the infrastructure affects their safety.

Due to the growing number of traffic users, the city authorities are under the obligation to ensure safety to the users of its transport infrastructure. By introducing new measures and addressing the infrastructure's needs, the comfort of travel and the quality of life are increased for both residents and visitors.

The study's limitations that could be addressed in future research include the use of a larger sample in studies encompassing a broader variation of characteristics. Furthermore, the respondents' perceptions could be set against those of the policymakers to identify the differences in the assessment of the city's transport infrastructure and assess the planned solutions to improve the safety of its users. The safety of the residents and visitors alike is a crucial factor in ensuring a high quality of life in the city. Therefore, research in this area ought to be continued.

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