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The “Engineer” publishes the most significant results of scientific and applied research carried out in universities of transport profile, as well as other higher educational institutions, research institutes, and centers of the Republic of Uzbekistan and foreign countries.

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Assessing the risk of public transport in southern cities of Azerbaijan using the "bow tie" method

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Abstract: Buses are an important component of the urban public transport system, meeting the daily mobility needs of the population. However, various risks arise during the operation of public transport, which can cause serious problems in terms of safety and comfort of passengers. In this study, risk factors of public transport in the southern cities of Azerbaijan were analyzed and a risk assessment was carried out using the "bow tie" method.

Keywords: public transport, risk analysis, risk assessment, risk matrix, BowTie

1. Introduction

Urban public transport systems are complex systems that include social, economic, political, technological and organizational aspects. In order to develop and implement effective ways to improve the system, these elements, as well as the interrelations between the factors that make up the system, must be considered comprehensively and holistically [1,2]. The main risk factors in the field of land transport (freight and passenger transportation) are traditionally poor road conditions, deficiencies in vehicle maintenance and, above all, the human factor, which occurs due to the inattention or negligence of drivers. [3] Part of the research includes preventing or reducing the damage caused by air pollution by reducing the use of private cars, as well as helping to make cities more resilient to large-scale climate events, allowing for a quicker return to normal life.[3] Risks are analyzed quantitatively and qualitatively.

2. Research methodology

One of the methods of risk analysis in the transportation services industry is the "bow tie" method. This method helps to identify the main and most important threats from the point of view of the enterprise and the associated risk management opportunities. The method consists of creating cause and effect analysis tables related to the main types of risks arising in the transportation services industry. BowTie analysis diagrams appeared in 1979 during a lecture on risk analysis at the University of Queensland, Australia. In the early 1990s, the Royal Dutch Shell Group adopted the BowTie method as a corporate standard for risk analysis and management. Shell conducted extensive research into the application of the BowTie method and developed strict rules for identifying all details based on its best practices. After Shell, the BowTie method quickly gained support in the oil and gas industry, since the diagrams helped to visualize control over risk management practices. Over the past decade, the BowTie method has also spread to aviation, shipping, chemical industry and healthcare [4]. Bow-tie was created by combining two existing risk analysis tools. These are the fault tree, which describes the probability that several faults will lead to a single failure, and the event tree, which describes the various consequences that can be predicted as a result of a single event. A relational diagram is built, which gives a visual representation of the relationship between causes (defects or failures) and effects [5]. BowTie method is a risk assessment method that can be used to demonstrate and analyze cause-and-effect relationships in high-risk scenarios. The method gets its name from the shape of the resulting diagram, which resembles a butterfly when created. The risk event is in the center of the bow tie diagram [6]. The article describes the identification of risk factors in public transport vehicles operating in the Southern regions of the Republic of Azerbaijan, as well as measures for their prevention and management. A survey of 420 respondents was conducted regarding the implementation of the Urban Mobility Plan in Masalli,Lenkoran,Bilasuvar and Jalilabad districts. During the analysis, risk factors were identified based on the respondents' opinions, the analysis was carried out using the "bow tie" method.

The "bow tie" method is widely used in risk management for visualization and systematic analysis of cause-and-effect relationships. The advantage of the method is that it allows for a comprehensive risk assessment by combining in one diagram both the initial factors that led to the event (left side) and the consequences that may occur after the event (right side) [7].

A review of the literature shows that the "bow tie" analysis has previously been used in the oil and gas industry, and more recently in healthcare, aviation and public transport, and has demonstrated high efficiency [5,6]. The "bow tie" method also helps to identify protective measures to prevent risk factors and mitigate their consequences, which plays an important role in improving the safety of public transport passengers. As a result of surveys conducted in Masalli and other southern cities, key risk factors such as the technical condition of public transport, driver behavior, road infrastructure, and parking conditions were identified. The bow tie method allowed us to systematically show both the causes and potential consequences of each of these risk factors and propose specific risk management measures [3,8]. Therefore, in this study, the bow tie method was chosen as the main basic tool of the methodology.

Factors Affecting Public Transport Use and Passenger Satisfaction

Understanding the factors that drive the use of existing public transport services is crucial to attract passengers to new public transport services, especially in small and

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medium-sized cities. User satisfaction plays a decisive role in their decision to use a service or not. Therefore, it is important to identify the key aspects that influence the perception of high service quality, how these aspects affect customer satisfaction, and how these aspects affect a person's willingness to use the service and recommend it to others. Here, data on user satisfaction and dissatisfaction, as well as the factors that influence their decision to use public transport services, are presented.

Chen et al. (2019) found that service hours have a significant impact on overall satisfaction. Service hours cover the time when public transport services are available to users and standard routes are running. [9]

Redman et al. (2013) emphasized the importance of punctuality and frequency of public transport services, stating that punctuality or "punctuality" directly influences customers' perceptions of reliability. This, in turn, influences passenger satisfaction levels with the transport service. Public transport is often perceived as a convenient and comfortable way to travel, so price is an important factor. Lower fares may encourage people to use public transport instead of driving [10]. According to Stewart et al. (2000), travel time or speed is at least as important as frequency. They also found that customer satisfaction is related to users' perceptions of the costs associated with public transport services.[11]

The travel time between an origin and destination reflects the convenience of a service, especially when compared to other modes of transport. The proximity of stops to an origin or destination reflects the accessibility of a service and is considered an important factor in the decision to use public transport.

Eboli and Mazullah (2010) suggested that good communication and route information are critical to the convenience of passengers using public transport.[12,13]

Accessible information and accurate, up-to-date information about routes and travel times can make it easier for people to plan their trips and make informed decisions about which mode of transport to use. In addition, access to real-time information about the location and status of buses can reduce the stress and uncertainty associated with waiting for a bus, leading to an improved experience and higher levels of satisfaction with the service. [14]

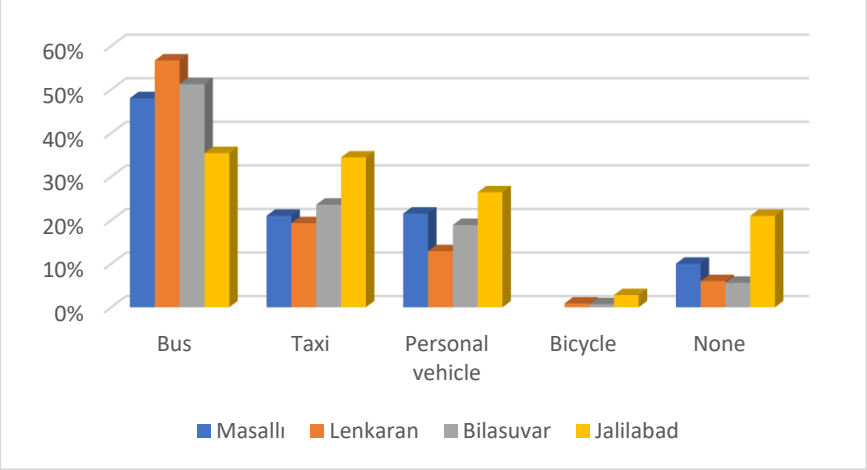
Tirinopoulos and Antoniou (2008) found that both distance to stop and waiting time affected overall satisfaction[15]. The ease of switching between different modes of transport allows users to reach their destination quickly and efficiently. The ease of boarding and disembarking from a vehicle affects user comfort and satisfaction [16]. Personal space in a vehicle is directly related to user comfort. If the personal space inside the vehicle is narrow and cramped, it can cause discomfort and anxiety, which can lead to user dissatisfaction. Tirinopoulos and Antoniou (2012) found that crowding was the factor that most deterred respondents from using public transport[15]. De Oña (2013) believed that the temperature inside the vehicle is important for passenger satisfaction [17].

Analysis of the level of public transport use by passengers and the problems arising from it

Increasing the use of public transport is a long-term sustainable solution for urban networks, while reducing the impact of related problems such as urban pollution [18]. The focus should be on customer satisfaction [19] in the divestment process. Most studies carried out internationally show that factors such as quality of services, availability, price and affordability have a wider impact on satisfaction levels[20].

It is important to identify and attract and retain a wide range of users across age groups[21]. There are very few studies of this kind in the field of public transport, so the aim of this study is to identify the main characteristics that influence the satisfaction of users of public transport.

As bus is the most popular and widely used public transport mode in the country, a survey was carried out in several cities and regions of Azerbaijan under the guidelines of the Cabinet of Ministers of the Republic of Azerbaijan for the preparation of the Intra-urban Mobility Plan [22]. The districts covered by the urban mobility plan include Larkaran,Masalli,Bilasuvar and Jalilabad.



Graph 1. Daily trips on transport used by the population of southern cities of Azerbaijan

The level of motor vehicle use in the southern cities was determined on the basis of the survey carried out. The charts show that the population of southern cities is predominantly dependent on public transport. In Masalli, respondents use buses most often (48 percent) for daily journeys. The proportion of respondents using taxis and private cars for daily journeys is 21.5 percent and 21.8 percent respectively.

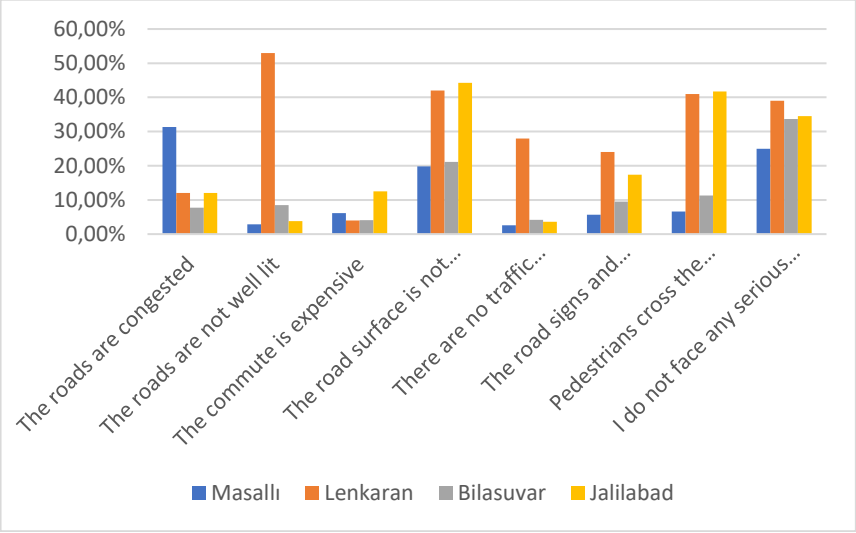
56.65 percent of Lankaran's population travel by bus, 12.88 percent by car and 0.86 percent by bicycle.

Respondents using taxi services represent 19.31 percent of the total.

In Bilasuvar, respondents to the survey were most likely to use buses for daily commuting to work (51.21%). 23.56 percent of the respondents use taxis, 18.90 percent use private cars and 0.71 percent use bicycles for their daily commute. In the Jalilabad district, 35.4 percent of respondents use buses, 26.4 percent use personal vehicles, 34.4 percent use taxis, and 2.8 percent use bicycles.

Problems faced by the population when traveling by transport

In surveys in southern cities, the majority of people use personal cars to reach their destinations, in addition to public transport. A survey of the population revealed the most common problems encountered by the population when travelling. The graph below shows the most frequent problems encountered by passengers travelling by car in southern cities (Graph 3).

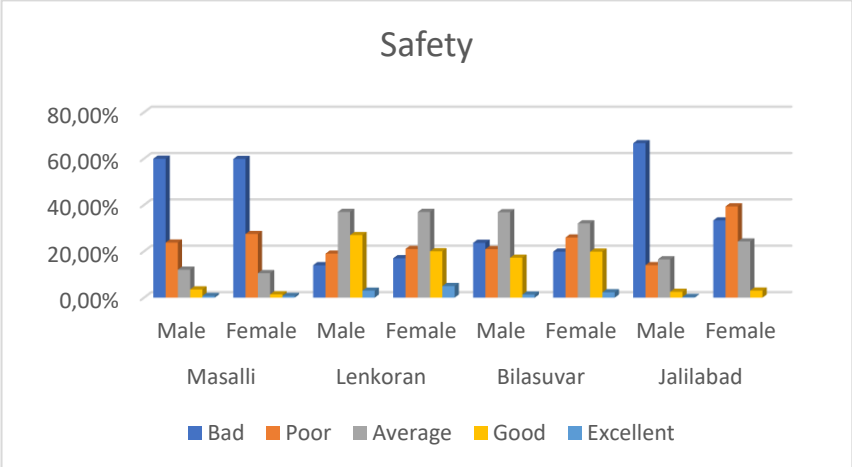


Graph 3. Problems faced by the population when traveling by transport in the southern cities of Azerbaijan

Problems encountered when travelling by car in southern cities vary from one extreme to another. The main problems in Masalli are traffic congestion (31.37%), poor road conditions (19.81%) and not following the rules (6.60%). In the Lankaran, the main complaint was poor road lighting (53%), 42 percent of respondents complained about the state of road surface and 41 percent complained about irregular pedestrian traffic. Bilasuvar's main problems are poor road conditions (21.09%), other problems include illegal pedestrian crossings (11.27%) and the lack of road signs (9.56%). In Jalilabad, the main concerns are poor road conditions (44.25%), irregular pedestrian crossings (41.69%) and the lack of road signs (17.39%). Overall, the main problems faced by the transport system in the Southern cities of Azerbaijan are the road infrastructure and the lack of pedestrian protection.

Evaluation of existing bus routes on a 5-point scale

It is important to consider different factors when assessing bus safety in the risk matrix. These factors include factors such as the technical state of buses, the professional competence of drivers, road conditions, passenger behaviour and the presence of security measures. This risk assessment plays an important role in the development of safety programmes for public transport authorities [23]. The results of the assessment of the most frequently selected issues by survey respondents on the reliability indicators of bus lines in southern cities on a five-point scale are shown in the graphs below.



Graph 4. Assessment of bus safety on a 5-point scale

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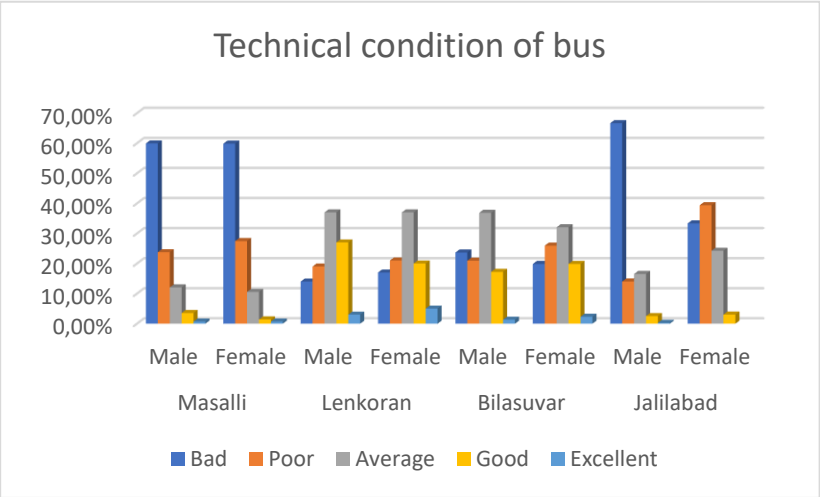
Respondents rated the safety and comfort levels of buses in southern cities in different ways. In Masalli, 22.88 percent of respondents rated bus safety as good or very good, while 4.93 percent of female rated bus safety as good (3 point) or very good (4point). In Lenkaran, 37 percent of male respondents and 20 percent of female rating the buses as good and 5 percent as very good. In Bilasuvar, 40.05 percent of respondents rated bus safety as average, 32.06 as good and 2.29 as excellent. In Jalilabad, 29.74 percent of respondents rated bus safety as good (3 points), 36.92 percent of female respondents rated it as good, and 1 point of respondents rated it as poor.

Overall, although most respondents rated bus safety as average, attitudes of women about buses differ from city to city. While female respondents in Masalli and Lankaran rated bus safety relatively low, opinions differed in Bilasuvar and Jalilabad.

A study by Xuan Long Nguyen et al. (2023) investigated the impact of bus service quality factors on passenger satisfaction in Ho Chi Minh City. A total of 3,913 samples were collected from 25 bus routes in Ho Chi Minh City in 2019–2020. The impact of different service aspects on passenger satisfaction was analyzed using the SEM model. 64.9% of passengers were satisfied with the bus service, but respondents wanted the bus schedule to be optimized, information systems to be improved, and drivers and dispatchers to be trained.[24]

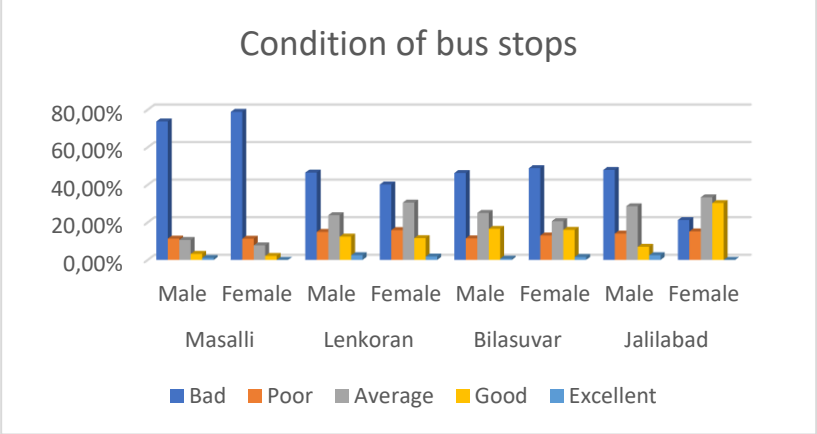


Graph 5. Assessment of the technical condition of bus routes on a 5-point scale

Respondents generally rated the technical state of the buses in southern cities as poor. In the Masalli survey, 59.91 percent of respondents considered the technical state of the buses to be poor (1 point), 25.8 percent as satisfactory, 11.56 percent as average and only 0.71 percent as very good. In the case of Lenkaran, 37 percent rated the technical state as average (3 points), 24 percent as good (4 points), 20 percent as satisfactory and 15 percent as poor.

In Bilasuvar, 35.36 percent of the respondents rated the technical state of the roads as average, 18.03 percent as good, 22.48 percent as satisfactory and 1 point each as poor. In Jalilabad, the situation is even more critical - 63.85 percent consider bus technical conditions to be poor, 16.15 percent satisfactory, 17.18 percent average and only 0.26 percent very good.

The technical state of the buses in Jalilabad and Masalli is generally considered to be low, while the situation in Bilasuvar and Lankaran is considered to be relatively satisfactory.



Graph 6. Assessment of the condition of bus stops on a 5-point scale

The current status of bus stops in southern cities of Azerbaijan was generally rated negatively by respondents. In Masalli, 3.19 percent of mate respondents rated the parking lots as good, 10.64 percent as average, and 78.87 percent of female respondents rated the parking lots as poor. In Lenkaran, 8.7 percent consider bus stop conditions good, 15.2 percent average, and 40 percent of female respondends consider bus stop conditions poor. Although the condition of the Bilasuvar parking lot appears to be somewhat improved, the overall assessment was negative. 16.55 percent of male respondents rated it as good, 25 percent as average and 46.28 percent as bad. 48.85 percent of women classified the interrogation as traumatic. In Jalilabad, 7 percent of male respondents considered parking to be good, 28.57 percent to be bad, and 47.9 percent to be poor. 21.21 percent of women are unhappy with the state of the bus stops.

Overall, the condition of bus stops in all cities was assessed as poor, with the vast majority of female respondents being particularly dissatisfied with the stops

Analysis of the technical condition of buses using the "bow-tie" method. The following risk factors have been identified and evaluated as a result of the research and monitoring carried out in the southern cities.

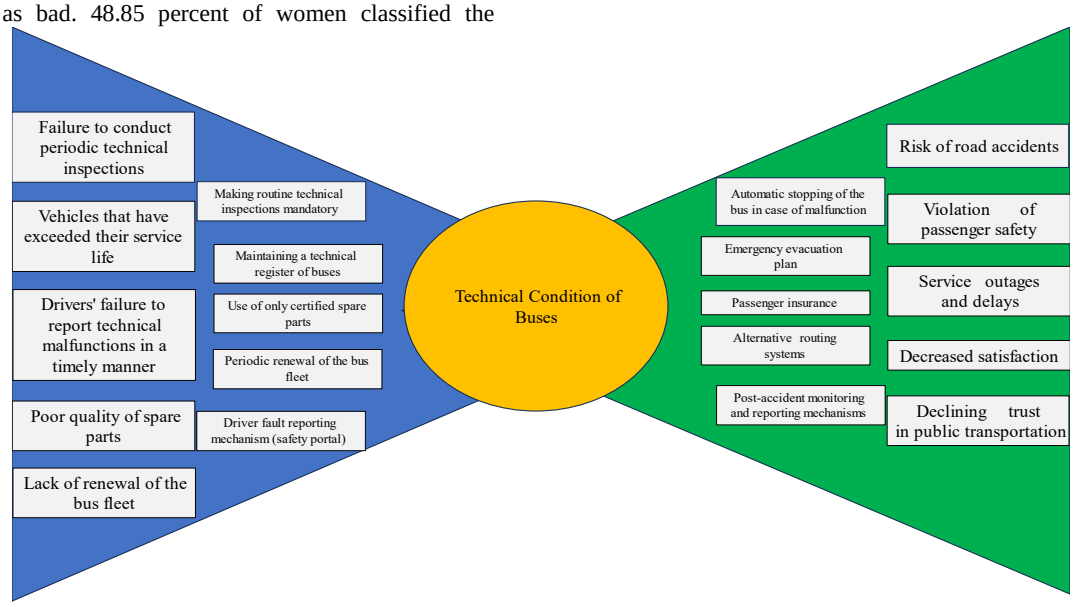


Figure 1. Assessment of the technical condition of buses using the "bow tie" method

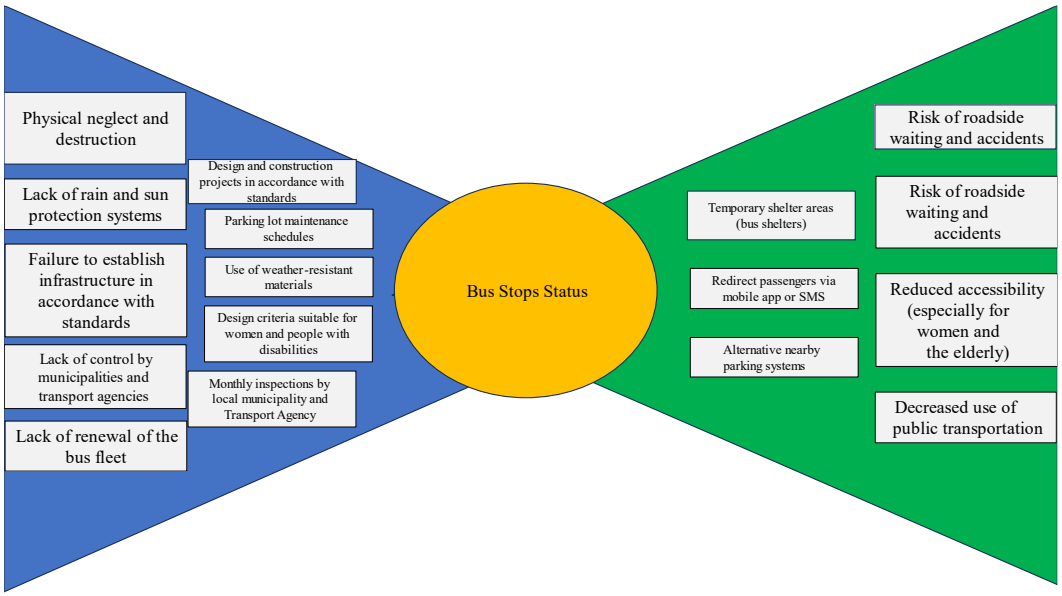


Figure 2. Assessing the condition of bus stops using the bow tie method

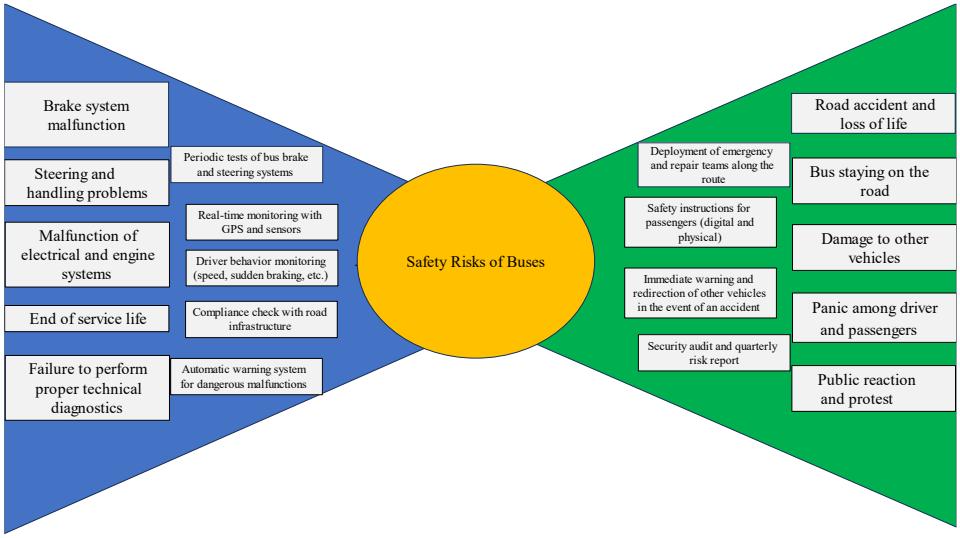


Figure 3. Bus safety assessment using the bow tie method

To eliminate the above risk factors, control measures, preventive causes, and mitigating measures to reduce consequences are proposed.

3. Discussion

The results of the study showed that technical faults of buses and poor condition of bus stops prevail among the main risk factors affecting the level of public transport safety in the southern cities. The level of technical risk in Masalli and Jalilabad districts was assessed as very high (risk score 25), which indicates that buses pose a serious threat to passenger safety during operation. In Bilasuvar and Lankaran districts, technical risks were observed at medium and low levels.

Risk analysis conducted at bus stops yielded similar results. The poor condition of bus stops, especially in Masalli and Jalilabad, negatively affects the comfort and safety of passengers. Risk levels (P×S) are in the high risk zone in these cities. The bow tie analysis identified the key measures to prevent threats as:

- Regular technical inspection of buses,
- Monitoring and training driver behaviour,
- Upgrading bus stops and using weather-resistant materials,
- Including improving urban mobility plans to suit local conditions.

The obtained results are consistent with international studies [25]. In addition, some differences were also found; for example, higher levels of complaints about traffic violations by pedestrians in the regions (lack of pedestrian crossings, road safety issues) are observed in Azerbaijan more often than in other countries.

Among the limitations of the study:

- Based on subjective assessments of respondents,
- Not taking into account the results of real technical inspections,
- It can be noted that modeling methods are not used.

It is recommended that future studies include realistic technical indicators, expand risk models using traffic modeling programs such as PTV, and conduct regional comparisons.

4. Conclusion

The study shows that the current problems of public transport in southern cities are mainly related to the technical condition of buses, the condition of bus stops and safety on buses. Using the bow tie method, these problems were systematically assessed and preventive and corrective measures were proposed to solve them.

These measures include regular technical inspections, periodic renewal of the bus fleet, the introduction of a mechanism to warn drivers about faults (safety portal), the use of weather-resistant materials at bus stops, monthly inspections by the local municipality and the Transport Agency, and periodic testing of the braking systems and steering of buses. The implementation of the proposed measures will not only improve the safety of urban transport, but also create more comfortable and accessible conditions for passengers.

Further research should focus on measuring the effectiveness of these measures, conducting additional statistical analyses and conducting a more in-depth assessment of intra-city transport flows. For the sustainable development of public transport, both infrastructure and transport policies need to be strategically formulated.

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