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Pedestrian Safety: Improving Pedestrian Safety Factor

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A B S T R A C T

Pedestrian safety is a critical issue for achieving sustainable cities. Rapid urbanization brings various impacts, including pressure on pedestrian safety in urban environments. Inadequate infrastructure, poor visibility, unsafe behavior, and weak law enforcement contribute to the high number of pedestrian accidents. Therefore, building a safe and inclusive pedestrian-friendly environment is an urgent need. This study aims to explore technological and engineering solutions to improve pedestrian safety in developing cities. The solutions offered include intelligent traffic signal systems, pedestrian-friendly navigation applications, wider sidewalks, and safe road crossings. The Narrative Literature Review (NLR) method is used to integrate findings from various current literature sources and formulate effective solutions to create a safe and pedestrian-friendly urban environment. This study is expected to contribute to addressing pedestrian safety issues in urban environments and promoting sustainable urban development.

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1. INTRODUCTION

Rapid urbanization has become a global phenomenon in recent decades (Fox & Goodfellow, 2022); (Helbling & Meierrieks, 2023); (Kuddus et al., 2020). Rapid urban growth can put pressure on the environment, including issues of pollution, land use, and population density, as well as driving changes in the social and economic structures of communities (Villani & Talamini, 2023). Along with urban growth, infrastructure and transportation systems also experience rapid development, ultimately influencing the development of transportation systems, which in turn shape the city's structure (PUPR, 2018b). The development of automobiles and highways during the 19th century has significantly influenced modern cities, with infrastructure built to support this faster movement. The consequences of planning strategies focused on automobiles and economic growth are evident in many cities, where mobility infrastructure systems erode quality of life (Freudendal-pedersen, 2020).

Urban growth demands the creation of safe and livable environments with affordable and equitable access to urban services, including transportation, that support human resource development and human dignity (Rizkiya et al., 2021). Therefore, a systemic and integrative approach encompassing spatial planning, transportation, and the environment is needed to support effective and sustainable urban mobility (PUPR, 2018b). In this regard, the role of stakeholders is crucial to realizing sustainable urban transportation and mobility (PUPR, 2018b).

However, behind this progress, there are worrying consequences for pedestrian safety (Hess & Moudon, n.d.); (Kristensen et al., 2023); (PUPR, 2018a); (Alonso et al., 2021); (Nikolaou et al., 2023); (Fatmawati, 2022). They are highly vulnerable road users due to their lack of speed, mass, and protection compared to motorized vehicles (Nikolaou et al., 2023). Based on data from the Indonesian National Police Traffic Corps (Korlantas Polri), approximately 10,428 pedestrians have been victims of traffic accidents throughout Indonesia by 2023. The most risky behavior is jaywalking, which reached 54.84% of the total number of victims (Pusiknas.polri.go.id, 2023).

Another factor contributing to the high number of accidents involving pedestrians is urban growth that is not accompanied by adequate access to public transportation, which can force pedestrians to use more dangerous routes (Kristensen et al., 2023); (PUPR, 2018a); (Alonso et al., 2021). In poorly planned urban growth, pedestrian infrastructure such as sidewalks and crosswalks is often inadequate, reducing pedestrian safety. Furthermore, urban sprawl, often unaccompanied by adequate pedestrian infrastructure development, increases the risk for pedestrians who must walk longer distances to reach their destinations (Fatmawati, 2022). Therefore, adequate infrastructure, such as wider sidewalks, safe crossings, and traffic signs, is needed to protect pedestrians from potential road hazards (PUPR, 2018a); (Alonso et al., 2021); (Nikolaou et al., 2023).

A positive example is the city of Copenhagen, which demonstrates a shift in planning approaches. In this case, urban space is redistributed to provide more space for pedestrians, bicycles, and buses, while reducing space for cars and parking. This signals a shift in everyday mobility practices and a redistribution of urban space (Freudendal-pedersen, 2020).

In this study, the discussion focuses solely on pedestrian areas in the context of "Pedestrian Safety from Motor Vehicle Hazards." This study aims to explore the factors that influence pedestrian safety and solutions that can be implemented to improve pedestrian safety in urban environments. This research will focus on two main aspects:

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Technological solutions: How technology can be used to improve pedestrian safety, such as intelligent traffic signal systems, pedestrian-friendly navigation apps, and pedestrian detection technology.

Engineering solutions: How urban infrastructure can be designed and built to be more pedestrian-friendly, such as wider sidewalks, dedicated pedestrian lanes, and safer street crossings.

This research will use the Narrative Literature Review (NLR) method to objectively review literature relevant to the research topic. NLR was chosen because it allows researchers to tell a coherent and comprehensive story about the research topic by integrating findings from various literature sources. Data selection prioritizes recent scientific literature published between 2018 and early 2024. This is done to ensure that this research is based on the most recent and relevant information. Additionally, older scientific literature from nationally and internationally accredited journals, as well as related manuals, will also be reviewed to provide broader context and perspective.

This research is expected to make a significant contribution to the existing knowledge on pedestrian safety, and can help in formulating effective solutions to create a safe and friendly urban environment for all, especially for pedestrians.

2. LITERATURE REVIEW

2.1 Walkable Environment

Walking is a critical element of urban accessibility at the local level and has been an essential part of urban planning since ancient times (Cui, 2021). The design and planning of safe, comfortable, and accessible pedestrian networks are crucial to promoting walking as a mode of transportation (Cui, 2021). In developing cities, the majority of trips are made by walking, yet pedestrian infrastructure is often overlooked in city planning and budgeting, which often leads to negative consequences such as fatal accidents and injuries (Krambeck, 2006). This contrasts sharply with the concept of walkability, as the variable “safe environment” is one of the most important indicators of walkability (Katarína & Sládeková, 2020). A walkable environment is a measure of the extent to which an environment supports walking by providing safe, comfortable, and connected pedestrian paths and other supporting facilities (Suminar & Anjar Sari, 2021); (Saputri & Tantyo, 2024). As one example, “walkable neighborhoods in Hong Kong” are characterized by multi-level pedestrian accessibility encompassing public and semi-public spaces, as seen in the Taikoo Place development in Quarry Bay (Choi et al., 2023). In this case, walkable neighborhoods involve the concept of “servicescape,” which refers to the physical and environmental settings that influence perception (Woo et al., 2023). By definition, walkable is derived from the word walkability, which is a measure of how friendly an area or environment is to pedestrians, with the aim of creating comfortable, safe pedestrian facilities that can reduce air pollution levels (PUPR, 2023). Another perspective related to walkable neighborhoods is the extent to which the built environment has the potential to support various forms of walking (Garau et al., 2020). Based on the concepts of ability and affordance, walkability is conceptualized as the effect of affordances integrated into the built environment on an individual's propensity to walk to various destinations (Garau et al., 2020). The quality of pedestrian facilities, road conditions, land use patterns, and security are essential components of walkability. A walkable environment must be “proximity” (short distances between origins and destinations), “barrier-free” (accessible to everyone), and “safe” (free from crime and vehicles). Planning a walkable environment also requires alignment between “residents’ desires and expectations for destination types, their willingness to walk certain distances, and the quality of the

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required paths" (Wood, 2024). Therefore, creating a walkable environment requires comprehensive planning from initial planning through construction to periodic maintenance, taking into account principles such as comfort, safety, and accessibility (Suminar & Anjar Sari, 2021).

Facilities needed to support the concept of walkability include wide and well-maintained pedestrian paths, safe crossings, traffic signs, adequate lighting, and facilities for people with disabilities (Suminar & Anjar Sari, 2021); (Saputri & Tantyo, 2024). The size, texture, and articulation of physical elements that are appropriate to human size and proportion, as well as walking speed, are also considered to be able to increase walkability (Singh, 2016). In addition, factors such as closure, block length, and edge conditions are very important in creating the perception of a walkable environment (Singh, 2016). Therefore, what is expected from a walkable environment is that it can have an impact on sustainable cities. Through efforts to improve the walkability index, it is hoped that it can reduce the environmental burden, which means it can contribute to the achievement of the Sustainable Development Goals (SDGs) (Kato, 2020).

2.2 Pedestrian Safety

Emphasizing safety issues can shift transportation modal distribution to benefit vulnerable road users, improve urban sustainability, and improve residents' quality of life (Galanis et al., 2017). Pedestrians are among the most vulnerable road users to injury. They face significant challenges in navigating the complex and sometimes hostile traffic conditions of modern cities (Thorson, 2012). Pedestrians are often at risk of road accidents, with factors such as vehicle speed, lack of pedestrian facilities, and poor visibility contributing to accidents (PUPR, 2018b). Furthermore, pedestrian walking behavior differs across road types, with the highest legal behavior on major arterials and the lowest on local roads, which also impact pedestrian safety (Galanis et al., 2017).

In line with this statement, it is crucial to provide infrastructure that supports pedestrians, such as safe and comfortable sidewalks, street lighting, and other adequate facilities (PUPR, 2018b). Furthermore, other sources state that pedestrian safety (especially in crossing areas) is influenced by infrastructure characteristics, as well as vehicle and pedestrian traffic levels (Galanis et al., 2017). In his article, Botzoris emphasized the importance of understanding and evaluating various aspects of pedestrian crossings to create safer urban environments for pedestrians (Galanis et al., 2017). Furthermore, it is also necessary to emphasize developing pedestrian-friendly environments that consider safety in the built environment to maximize the health benefits of walkability, while reducing the risk of pedestrian/bicycle fatalities (Wali & Frank, 2024).

In line with the principles of the New Urban Agenda in realizing safe and sustainable urban mobility, there are at least 3 (three) approaches that can be taken to improve pedestrian safety (PUPR, 2018b), namely :

- Engineering: This approach involves designing and building safe road infrastructure, including features such as adequate lighting, clear road markings, and intersection designs that reduce the risk of accidents.
- Education: The education aspect includes programs to increase public awareness about the importance of road safety, such as the use of seat belts, helmets, and safe driving behavior.
- Enforcement: Strict enforcement of traffic violations is an important part of this approach. This includes imposing penalties on traffic violators to ensure compliance and reduce accidents.

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Based on the three approaches above, in accordance with the topic of pedestrian safety, the engineering approach and the enforcement approach are very suitable to be implemented.

Furthermore, there are differences in perceptions of walking safety from a gender perspective (Katarína & Sládeková, 2020)*;* (Mazzulla et al., 2024); (Bittencourt et al., 2018). Men and women have different perceptions regarding this. Men tend to pay more attention to the continuity of pedestrian paths, road surface conditions, and disruptions caused by vehicle traffic (Katarína & Sládeková, 2020); (Mazzulla et al., 2024). Meanwhile, women are more sensitive to important aspects such as personal safety from robbery or theft, environmental cleanliness, and the presence of furniture along pedestrian paths (Mazzulla et al., 2024). Other data indicate that concerns about accidents, harassment, and theft are higher at night than during the day (Alkheder et al., 2022). For girls in particular, adequate street lighting can encourage them to walk. Places such as narrow alleys, parks, and areas with few people become more intimidating when poorly lit, especially at night (Katarína & Sládeková, 2020). Other findings also indicate that the exclusive presence of men in public spaces makes women feel unsafe and changes their paths, highlighting issues of women's safety and autonomy in public spaces (Bittencourt et al., 2018). Therefore, planning pedestrian routes should also consider aspects considered important by both user categories and aspects that contribute to inequalities between men and women, such as safety for women, to encourage pedestrian mobility (Mazzulla et al., 2024); (Bittencourt et al., 2018).

2.3 Factors Affecting Pedestrian Safety

a) Pedestrian Infrastructure

Although intended to improve traffic flow, road widening often has negative consequences for pedestrians and cyclists. Road widening generally involves the removal of sidewalks, parks, and other public spaces previously used by pedestrians and cyclists. This results in a reduction in safe and comfortable public spaces for them to move around (PUPR, 2018b). This situation stands in stark contrast to the New Urban Agenda (NUA), which emphasizes that pedestrians must be a priority in city transportation planning, by providing adequate paths and facilities (PUPR, 2018b). Therefore, a “sustainable and environmentally friendly” approach needs to be implemented, with a focus on the development of efficient public transportation, “safe infrastructure for pedestrians” and cyclists, and the creation of welcoming and comfortable public spaces for all (PUPR, 2018b). So specifically related to pedestrian infrastructure, the principle is to emphasize the smoothness, security, safety, and comfort of pedestrians, including the connectivity of these facilities (Dirjen Binamarga, 2023).

The main problem related to pedestrian infrastructure (especially in Indonesia) is related to the issue of continuity. From several scientific literature collected, points are always one of the main factors in assessing the walkability index (Kashef, 2022); (Suminar & Anjar Sari, 2021); (Koo et al., 2022); (Saputri & Tantyo, 2024); (Mirzaee, 2020); (Browne & Flower, 2023); (Rizal & Basuki, 2013); (Nugroho, 2022). Especially what happens in several big cities in Indonesia, the low pedestrian connectivity as referred to is generally caused by the lack of adequate infrastructure for pedestrians, such as damaged sidewalks, lack of pedestrian crossings, and so on (Saputri & Tantyo, 2024); (Rizal & Basuki, 2013); (Suminar & Anjar Sari, 2021); (Nugroho, 2022), as well as the lack of road signs to direct pedestrians (Banger et al., 2024); (Papadimitriou et al., 2017); (Saputri & Tantyo, 2024).

b) Pedestrian Inclusivity

The concept of an inclusive city aims to create an environment that is equally accessible to all city residents, including people with disabilities. People with disabilities experience

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barriers to accessibility to city infrastructure services, particularly pedestrian paths that are not yet friendly to them (Rizkiya et al., 2021)**.** Pedestrian paths must consider accessibility for people with disabilities. This involves designing them to take physical barriers into account and include disability-friendly infrastructure. In other words, every pedestrian path plan must ensure that pedestrian facilities meet the elements of inclusivity for vulnerable groups, people with disabilities, the elderly, children, and women (Dirjen Binamarga, 2023), and include facilities such as wide sidewalks, ramps, zebra crossings, and safe crossings (PUPR, 2018b). In some situations (particularly in large cities in Indonesia), many pedestrian paths still lack supporting facilities for people with disabilities, ultimately contributing to the assessment of "Not Walkable" or unfriendly to pedestrians (Nugroho, 2022). A common problem is that people with disabilities experience difficulty in accessing pedestrian paths due to physical obstructions such as trees in the middle of the path, obstructing vehicle parking, and so on (Saputri & Tantyo, 2024); (Rizal & Basuki, 2013); (Suminar & Anjar Sari, 2021); (Nugroho, 2022); (Rizkiya et al., 2021); (Eisenberg et al., 2024).

Furthermore, pedestrian paths are not yet fully integrated with the city's main activity centers, making it difficult for people with disabilities to participate in daily activities (Rizkiya et al., 2021). Based on these conditions, the application of universal design in transportation infrastructure, including pedestrian paths, still needs to be improved to create more inclusive and friendly urban spaces for all users, including people with disabilities (Rizkiya et al., 2021). Therefore, in such conditions, more attention is needed to support the concept of comfortable and safe walkability for all users (Suminar & Anjar Sari, 2021).

c) Application of Technology & Engineering That Can Improve Pedestrian Safety

In an effort to improve pedestrian safety, numerous efforts have been made, including research, planning, and implementation by relevant stakeholders. In this section, researchers will explore various forms of technology and engineering implementation based on numerous scientific articles.

1) Application of Technology on Pedestrian Paths

a. Application of Technology in The Planning Process

The use of technology to support pedestrian safety begins at the planning stage. Several studies have used various types of "simulation models" to plan pedestrian routes that take pedestrian safety into account. Some of these simulation models include:

- ***The Cellular Automata (CA)*** floor field model is a microscopic model for simulating human (pedestrian) movement. This means that the model focuses on the behavior of individual pedestrians (Feliciani et al., 2019). The CA floor field model utilizes a grid or small squares to represent an area. Each pedestrian is represented by a square. The model then calculates the movement of these pedestrians from one square to another. There are two main components in the CA floor field model:

➢ ***Static field***: This component shows the distance between the current tile and the destination (e.g. exit)

➢ ***Dynamic field***: This component shows the footprints left by pedestrians within the plot. These footprints will decrease in value over time (dispersion effect)

The floor field CA model has several advantages, such as ease of implementation and the ability to model the movement of many pedestrians simultaneously. However, its weakness is that it cannot fully account for pedestrians' physical characteristics, such as body size and shape. This can affect simulation accuracy, particularly in terms of density and potential collisions between pedestrians.

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- **Virtual Reality (VR);** VR technology such as the HTC Vive or Oculus Quest is being used to study pedestrian safety behavior and perceptions in a safer and more efficient manner. This allows for understanding and evaluating pedestrian safety and perceptions at crosswalks, and allows for comparisons between pedestrian crossing behavior in virtual environments and real-world behavior (Valentine et al., 2023). VR technology allows users to interact with a simulated computer-generated environment, giving the user the feeling of being inside that environment. VR typically uses a special headset that displays stereoscopic (3D) images and is sometimes equipped with gloves or other devices to track user movements and enable interaction with the virtual environment. Experimental results have shown that VR simulations are effective in replicating naturalistic pedestrian crossing behavior in virtual environments modeled after real locations (Valentine et al., 2023).

b. Application of Technology in the Field

The rapid development of technology encompasses various aspects, including technology to improve pedestrian safety. This technology can take the form of hardware, software, or systems designed to assist in completing specific tasks. Some types of technology already applied in the field to improve pedestrian safety include:

- ***Video-Based Safety (*CCTV which is equipped with YOLOv8x and BOT-SORT);** is a "video analysis" based technology to improve pedestrian safety at road crossings. (Hnoohom et al., 2024). This type of technology is used to track pedestrians and vehicles with high accuracy (mAP: 0.861, precision: 0.899, recall: 0.785). Based on the tracking data, Time-to-Collision (TTC) and Post-encroachment time (PET) are calculated to measure the risk and recovery time of a potential collision. Analysis of 30 near-miss scenarios demonstrated the effectiveness of this method in identifying high-risk situations (TTC accuracy of 90%). Furthermore, 18 scenarios had PETs greater than 1.0 seconds, indicating sufficient reaction time to avoid a collision (Hnoohom et al., 2024). These results suggest that video analysis is a promising tool for improving the safety of street crossings and contributing to safer urban environments for pedestrians (Hnoohom et al., 2024). YOLOv8x and BOT-SORT It is a combination of two artificial intelligence (AI) technologies. YOLOv8x is a deep learning algorithm that functions to track and recognize objects (pedestrians and vehicles) in CCTV video footage, while BOT-SORT is a tracking algorithm that works in conjunction with YOLOv8x to track the movement of individual objects (pedestrians and specific vehicles) through time in video footage (Hnoohom et al., 2024).

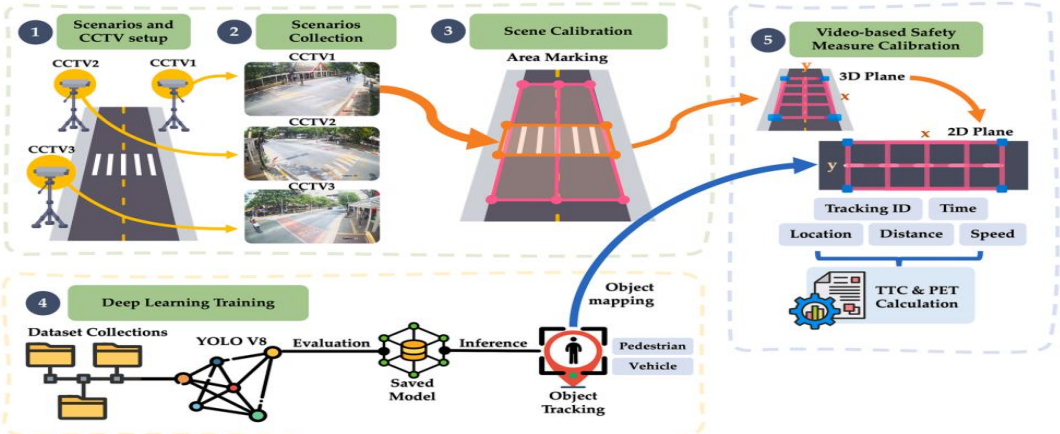

Figure 1. Video-based safety action development process (Hnoohom et al., 2024)

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- ***Intelligent Transport Systems*** **(ITS)** : Proper implementation of ITS can significantly improve road safety. Combining various ITS technologies, such as LED lighting, can help create a safer road environment for all road users (Hussain et al., 2023). The application of innovative technologies to sidewalk and road infrastructure can play a significant role in improving pedestrian and driver safety. The use of LED lights on sidewalks can improve pedestrian visibility, especially at night or in adverse weather conditions, thereby reducing the risk of accidents. Furthermore, Variable Message Boards (ITS_VMS) can display up-to-date traffic information, such as speed limits, accident warnings, and directions to avoid congestion. This helps drivers make better decisions and improves road safety (Hussain et al., 2023).

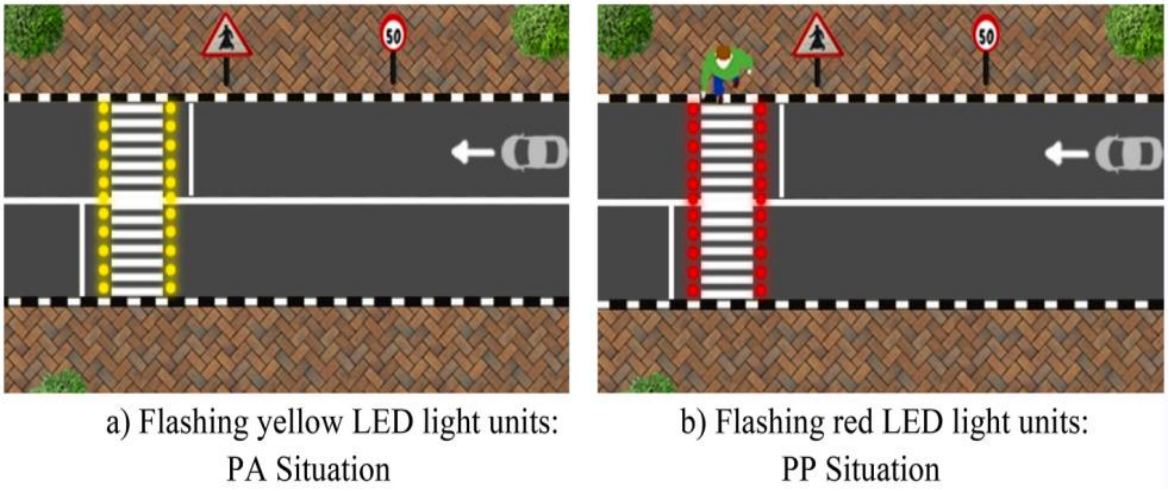

Figure 2. Simulation of the Application of ITS Technology - LED Lights at Level Crossings (Hussain et al., 2023).

The implementation of this innovative technology demonstrates a commitment to improving the safety of road users, both pedestrians and drivers. By continuously developing and implementing new technologies, it is hoped that this will create a safer and more comfortable traffic environment for all.

2) Upaya Rekayasa Pada Jalur Pejalan Kaki

As an effort to improve pedestrian safety on the road, in general (in Indonesia) the form of engineering (standards) has been regulated by provisions (Technical Planning Guidelines for Pedestrian Facilities). Based on these guidelines, pedestrian infrastructure is essentially a basic effort that must be provided to improve pedestrian safety, such as "Dimensional Adjustment, Inclusive Facilities, and Supporting Facilities" (Dirjen Binamarga, 2023). Other sources emphasize that improving pedestrian safety involves creating dedicated spaces for pedestrians, such as sidewalks, bicycle lanes, and pedestrian overpasses. This is intended to minimize interference (vehicles, etc.) with pedestrians (Guide, 2021). Furthermore, a focus on lighting infrastructure is also crucial for improving nighttime visibility for all road users (Guide, 2021).

Another form of engineering to improve pedestrian access is through physical road narrowing. Physical road narrowing has proven to be the most effective in reducing average vehicle speeds and increasing driver compliance (Hussain et al., 2023). In Indonesia, this form of engineering has been implemented in DKI Jakarta (2017-2022), which was emphasized by the issuance of the DKI Jakarta Gubernatorial Regulation concerning the Integrated Development and Improvement of Sidewalks and their Facilities. The regulation included efforts to improve pedestrian safety through "Rightsizing," which is an effort to optimize

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vehicle lanes to improve pedestrian safety, but it was not continued during the change of leadership in the subsequent period (news.republika.co.id, 2023).

Furthermore, one way to improve pedestrian safety is to build a "pedestrian platform." This is a pedestrian path in the form of a level crossing facility with a surface raised above the road surface. The goal is to provide sufficient visibility to ensure pedestrians are visible to those around them, especially at night.

Figure 3. Pedestrian Platform Application (viastrada.nz, 2021).

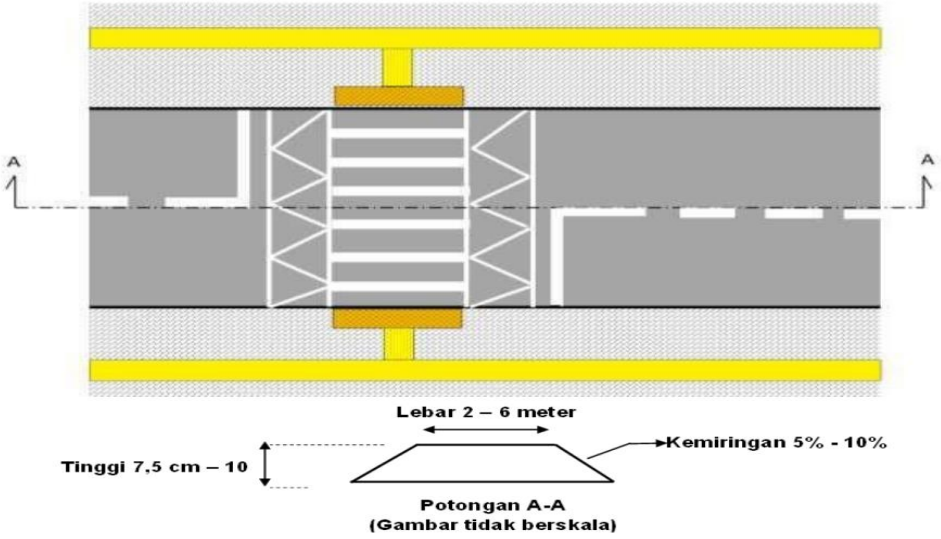

Figure 4. Typical Dimensions of Pedestrian Platforms (Dirjen Binamarga, 2023).

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Next, is the implementation of "Innovative Road Markings", as an effort to create a safer road environment for all road users (Hussain et al., 2023). Innovative road markings such as yellow zigzag lines and narrowing road markings with the word "SLOW" in the center can warn drivers to reduce speed and increase alertness in high-risk areas, such as near schools or pedestrian zones. These innovative road markings have proven effective in changing driving behavior and reducing traffic violations, thus contributing to a safer traffic environment (Hussain et al., 2023).

Figure 5. Simulation of the Use of Innovative Road Markings (Hussain et al., 2023).

3. RESULT AND DISSCUSSION

A. Pedestrian Friendly Environment

Walkable environment A walkable environment is defined as an environment that supports walking by providing safe, comfortable, and connected infrastructure and other supporting facilities. The primary goal of a walkable environment is to improve accessibility and encourage the use of walking, which has health, environmental, and economic benefits. Essential components of a walkable environment include:

1) Adequate pedestrian infrastructure: wide, level, and well-maintained sidewalks; safe street crossings; clear traffic signs; adequate lighting; and facilities for the disabled.
2) Comfort and aesthetics: shaded and leafy walking paths; seating and rest areas; attractive landscape elements; and aesthetic design.
3) Accessibility: connectivity between roads and public areas; short distances between origin and destination; and ease of access for everyone.
4) Safety: free from danger of accidents and crime; adequate lighting at night; and adequate supervision.

B. Pedestrian Safety

Pedestrians are the most vulnerable road users to accidents. High vehicle speeds, lack of adequate pedestrian infrastructure, poor road visibility, unsafe pedestrian behavior, and lack of law enforcement against traffic violations are factors that increase the risk of pedestrian accidents. Pedestrian safety is a critical issue for public health and sustainable development. Traffic accidents involving pedestrians are a leading cause of death and injury worldwide. Therefore, comprehensive efforts are needed to improve pedestrian safety. An example of

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an effort that can be adopted from Copenhagen is the "Re-distribution of Space," namely creating more space for pedestrians, bicycles, and buses by reducing space for cars and parking (Freudendal-pedersen, 2020).

Walking is the most natural form of mobility and must be taken into account in the development of transportation systems (Thorson, 2012). Various indices have been developed to measure built environment characteristics that support walking behavior, ranging from neighborhood-level urban form factors to street-level urban design factors. Street-level factors are often more closely related to higher-order needs such as safety, comfort, and enjoyment of walking (Koo et al., 2022). Furthermore, in an effort to improve pedestrian safety, it is important to understand the risk perceptions and concerns of pedestrians themselves (Alkheder et al., 2022).

Based on this description, efforts are needed to improve pedestrian safety, which can be done through three approaches, namely the Engineering Approach, the Education Approach, and the Enforcement Approach.

C. Factors Affecting Pedestrian Safety

Pedestrian safety is a crucial issue in sustainable urban planning and development. Adequate and inclusive pedestrian infrastructure is key to achieving this. Research shows that pedestrian infrastructure that is fragmented, damaged, or obstructed by illegal parking, as well as a lack of facilities such as crosswalks and signs, significantly increases the risk of pedestrian accidents. Lack of accessibility for people with disabilities, such as narrow sidewalks and the absence of ramps, further exacerbates the situation. Universal design in transportation infrastructure, including pedestrian paths, is a solution to creating inclusive and welcoming urban spaces for all users. The integration of pedestrian paths with major city activity centers also needs to be improved to facilitate access for people with disabilities.
To improve pedestrian safety and inclusiveness, the following efforts are needed:

1) **Building sustainable and environmentally friendly pedestrian infrastructure:** Focus on developing efficient public transportation, safe infrastructure for pedestrians and cyclists, and creating public spaces that are friendly and comfortable for all.
2) **Improving the continuity of pedestrian infrastructure:** Ensure sidewalks are well connected and free of obstructions, and provide safe and accessible road crossing facilities.
3) **Creating pedestrian infrastructure that is friendly to people with disabilities:** Provide supporting facilities such as ramps, zebra crossings, and safe crossings, and design infrastructure that takes into account the needs of people with disabilities.
4) **Integrating pedestrian paths with activity centers:** Building pedestrian paths that are well connected to the city's main activity centers, thus facilitating access for all users.
5) **Applying universal design to transportation infrastructure:** Designing transportation infrastructure with the needs of all users, including people with disabilities, in mind.

By implementing these solutions, it is hoped that pedestrian safety and inclusivity can be improved, thus creating a more comfortable and safe urban environment (especially for pedestrians). The implementation of these solutions also needs to be accompanied by law enforcement and public education, which is expected to improve pedestrian safety and inclusivity.

D. Application of Technology & Engineering That Can Improve Pedestrian Safety

Efforts to improve pedestrian safety continue through various approaches, including the application of technology and engineering. This technology and engineering are applied at various stages, from planning to implementation in the field.

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At the planning stage, Simulation models such as Floor Field Cellular Automata (CA) and Virtual Reality (VR) are used to plan safe pedestrian paths. CA models consider pedestrian density and potential collisions, while VR allows users to interact with a virtual environment to understand pedestrian behavior and safety perceptions at crosswalks.

In the field, Technologies such as Video-Based Safety (CCTV with YOLOv8x and BOT-SORT) and Intelligent Transport Systems (ITS) are used to improve safety. Video-Based Safety tracks pedestrians and vehicles with high accuracy, identifying high-risk situations, while ITS helps improve road safety by using LED lights to increase pedestrian visibility and variable message boards (ITS_VMS) to display up-to-date traffic information.

Engineering efforts Pedestrian paths are also being developed to improve safety. This includes basic infrastructure such as dimensional adjustments, inclusive facilities, and supporting facilities, as well as other efforts such as physical road narrowing, pedestrian platforms, and innovative road markings. Physical road narrowing has been proven effective in reducing average vehicle speeds and increasing driver compliance, while pedestrian platforms increase pedestrian visibility, and innovative road markings warn drivers and increase awareness in high-risk areas.

4. CONCLUSION

Pedestrian safety is a crucial issue in sustainable urban planning and development, as pedestrians are the most vulnerable road users. Factors such as inadequate infrastructure, poor visibility, unsafe behavior, and weak law enforcement contribute to high rates of pedestrian accidents. Therefore, creating a safe and inclusive pedestrian-friendly environment is an urgent need. Achieving a safe and inclusive pedestrian-friendly environment requires comprehensive and sustained efforts involving various stakeholders. These efforts should include the development of adequate and inclusive infrastructure, the implementation of appropriate technology and engineering, public education and awareness, and strict law enforcement. This is expected to create a safe and comfortable environment for pedestrians, as well as encourage healthier and more sustainable lifestyles. The application of technology and engineering also plays a crucial role in improving pedestrian safety. Simulation models such as Floor Field Cellular Automata (CA) and Virtual Reality (VR) can be used to plan safe pedestrian paths, while technologies such as Video-Based Safety (CCTV with YOLOv8x and BOT-SORT) and Intelligent Transport Systems (ITS) can help improve safety on the ground. Pedestrian path engineering efforts, such as physical road narrowing, pedestrian platforms, and innovative road markings, have also proven effective in improving pedestrian safety.

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