International Journal of Computer Applications Technology and Research
Volume 13–Issue 07, 13 – 18, 2024, ISSN:-2319–8656
DOI:10.7753/IJCATR1307.1002

Technological Innovations in Improving the Safety of Cyclists in Urban Environments: A Comprehensive Analysis

Sergio Gómez
Universidad Distrital Francisco José de Caldas
Bogotá D.C., Colombia

Daniel Mejia
Universidad Distrital Francisco José de Caldas
Bogotá D.C., Colombia

Fredy Martínez
Universidad Distrital Francisco José de Caldas
Bogotá D.C., Colombia

Abstract: As urban populations swell and environmental concerns escalate, cycling emerges as a sustainable alternative to motorized transport in cities like Bogotá. However, the safety of cyclists remains a critical barrier to wider adoption. This paper presents a comprehensive review of technological innovations aimed at enhancing the safety of urban cyclists. Through a meticulous synthesis of current literature and case studies, we explore a range of technologies from basic safety equipment to advanced sensor systems and smart devices that integrate with urban infrastructure. Our review identifies key areas where technology has successfully mitigated risks for cyclists, including improvements in visibility through LED lighting and reflective clothing, enhanced communication via interconnected wearable devices, and real-time tracking and environmental monitoring using advanced sensor technology. We also examine the integration of these technologies into existing urban frameworks, assessing their effectiveness and potential for broader implementation. The findings highlight significant advancements in cyclist safety, yet also underscore the need for ongoing research to address persistent challenges and ensure these innovations are accessible and effective in diverse urban settings. This paper aims to inform policymakers and urban planners about the potential of these technologies to not only improve cyclist safety but also encourage cycling as a viable and safe mode of transportation, contributing to the sustainability and health of urban environments.

Keywords: Bicycle safety; cycling; innovations; sensor technology; sustainable transportation; urban environments; wearable devices

1. INTRODUCTION

In Bogotá, a city characterized by its vibrant yet congested urban environment, cycling is increasingly recognized not just as a leisure activity but as a crucial component of sustainable transportation [1–3]. The surge in bicycle usage poses new challenges, primarily concerning the safety of cyclists navigating through densely populated streets and inadequate cycling infrastructure [4]. This paper aims to systematically review state-of-the-art technological advancements that promise to enhance the safety of urban cyclists. By setting a detailed context on the complexities and challenges specific to Bogotá, the study underscores the urgent need for innovative solutions that can be integrated into the city's mobility framework [5]. The objectives outlined here infocus on identifying technologies that improve visibility, communication, and interaction between cyclists and other road users, thereby reducing accidents and promoting a safer cycling environment.

The significance of improving cyclist safety in Bogotá is underscored by the city's struggle with traffic congestion and high rates of transportation-related accidents [6]. Cyclists in Bogotá frequently contend with a host of dangers that include erratic vehicle traffic, poorly maintained road surfaces, and a lack of dedicated cycling lanes [7]. This review article delves into how cutting-edge technology can mitigate these risks, with the dual aims of safeguarding cyclists and encouraging more citizens to consider cycling as a viable daily commuting option. By focusing on technological interventions, this paper contributes to the broader discourse on urban sustainability, where safety enhancements are crucial for the adoption and growth of cycling in metropolitan areas.

Furthermore, the research presented in this article is of global relevance as cities around the world face similar challenges in integrating cycling into their urban transport networks [8, 9]. The findings from Bogotá could provide valuable insights for other urban centers looking to enhance cyclist safety and promote environmental sustainability through increased bicycle use. The comprehensive review of technologies conducted in this study serves as a benchmark for urban planners and policymakers aiming to foster safer and more inclusive cycling conditions.

The methodology employed in this review synthesizes information from a wide array of sources, including recent academic studies, industry reports, and patent filings. This robust approach ensures a thorough examination of both established and emerging technologies that can contribute to cyclist safety. The criteria for selecting studies for this review are rigorously defined to include only those that offer clear empirical findings and innovative perspectives on technology application in urban settings. This meticulous selection process allows for a critical analysis of the effectiveness of different safety enhancements.

This paper's synthesis of existing and emerging technologies not only evaluates their efficacy but also highlights the limitations and areas needing further research and development. Each technology is assessed for its potential to be

adapted to the specific urban conditions of Bogotá, with a focus on practical implementation and user acceptance. Such a detailed analysis aims to bridge the gap between theoretical research and practical, actionable solutions that can significantly improve cyclist safety.

Ultimately, the importance of this research extends beyond academic circles into practical applications in urban planning and public policy. By providing a comprehensive overview of effective cyclist safety technologies, this paper aims to inform and influence policy decisions that will shape the future of urban transportation in Bogotá and other cities. The recommendations made here are intended to guide the development of more effective safety protocols and the deployment of smart technology solutions that make urban environments safer for cyclists and all residents.

2. REVIEW METHODOLOGY

The methodology for this state-of-the-art review was carefully designed to ensure a comprehensive analysis of technological innovations that enhance the safety of urban cyclists. We initiated our study by defining a clear set of inclusion and exclusion criteria aimed at selecting studies that focus specifically on technology applications in urban cycling environments. Only peer-reviewed articles, patents, and grey literature from the last ten years were included, emphasizing those that provided empirical results regarding the efficacy of technological interventions in improving cyclist safety. This time frame was chosen to ensure that the most current technologies were considered, reflecting recent advancements and the current state of urban infrastructure challenges.

A systematic search was conducted across multiple academic databases including IEEE Xplore, Scopus, and Google Scholar, as well as industry reports and patent databases, to gather a wide range of sources. Keywords such as "*urban cycling safety*," "*cyclist wearable technology*," "*sensor systems for cyclists*," and "*smart cycling applications*" were used to filter relevant studies. This was complemented by a manual search to cover additional publications and patents cited in the retrieved papers, ensuring that significant studies were not overlooked. The search strategy was iterative, allowing adjustments as needed to encompass all relevant technologies discussed in the current literature.

After collecting the data, we categorized the studies into different technological themes: wearable technologies, sensor-based systems, and smart integration systems. Each category was thoroughly reviewed to synthesize the information on how these technologies contribute to cyclist safety. The review process involved extracting data on the type of technology, the context of its application, its impact on safety, and any noted limitations or challenges in implementation. This categorization helped in systematically analyzing the role of each technology type in enhancing cyclist safety.

The synthesis of the selected studies was conducted through a qualitative narrative approach, allowing for a detailed discussion of how each technology addresses specific safety challenges faced by urban cyclists. This method facilitated an in-depth understanding of the potential and actual impact of these technologies in real-world settings. We also assessed the scalability and adaptability of these technologies to different urban environments, providing a comprehensive view of their utility and effectiveness.

Finally, the outcomes of this review are intended to serve as a foundation for future research and development in cyclist safety technologies. By identifying existing gaps and areas for potential innovation, this paper aims to guide researchers, technologists, and policymakers in prioritizing efforts that will significantly enhance urban cyclist safety. This systematic and structured methodology ensures that our findings are robust, relevant, and capable of driving meaningful advancements in the field of urban cycling safety.

3. EXISTING TECHNOLOGIES FOR CYCLIST SAFETY

The landscape of cyclist safety technologies has expanded significantly over recent years, driven by the need to address increasing traffic complexities and urban density, particularly in cities like Bogotá. The most ubiquitous safety enhancements include the use of high-visibility clothing and helmets, which have been foundational in protecting cyclists [10, 11]. Reflective jackets, LED-equipped gear, and rigorously tested helmets are standard among urban cyclists [12]. These items are designed to make cyclists more visible to drivers, especially under low light conditions, and to offer protection during accidents [13]. Despite their proven effectiveness, these technologies remain passive and do not actively prevent incidents but rather mitigate the consequences [14, 15].

In addition to passive safety gear, active technology solutions like lighting systems and electronic signaling devices have become increasingly popular [16, 17]. Advanced lighting systems not only illuminate the path ahead for cyclists but also ensure they are seen by other road users [18, 19]. Turn signals, integrated into handlebars or wearable devices, help cyclists communicate their intentions to others, reducing the likelihood of collisions [20]. These solutions are complemented by rear-view cameras and radar systems that alert cyclists to approaching vehicles, enhancing situational awareness and safety [21, 22].

The integration of GPS technology in cycling has revolutionized how cyclists navigate urban environments [23]. GPS devices are now commonly integrated into bicycle computers or smart watches, providing cyclists with route information, traffic updates, and real-time data on road conditions [24]. These devices can suggest safer routes, avoiding high-traffic areas or roads with poor infrastructure [25]. Moreover, some GPS-enabled devices are linked to mobile apps that allow for tracking and reporting accidents or hazards, contributing to community-based safety enhancements [26].

Wearable technology has also seen significant adoption among urban cyclists [27]. Smart helmets and connected wearables can monitor vital signs, detect crashes, and automatically alert emergency services with the rider’s location [28]. These devices often include built-in accelerometers and gyroscopes that detect falls, enhancing response times and potentially improving outcomes following accidents [29]. Furthermore, emerging technologies such as smart fabrics have the potential to increase comfort and protection simultaneously, integrating sensors that monitor environmental conditions and adjust their properties accordingly [30].

Despite these advancements, the effectiveness of existing technologies in improving cyclist safety must be continually assessed against the backdrop of evolving urban landscapes. Innovations must not only address current safety challenges but also adapt to future urban developments and changes in cyclist behavior. This necessitates ongoing research and development, guided by both technological advancements and a deep understanding of urban dynamics. The goal is to create a cohesive ecosystem of cyclist safety technologies that are not

only effective individually but also synergistic, enhancing overall safety through their combined use.

4. INNOVATIONS IN WEARABLES AND SMART DEVICES

Recent advancements in wearable technology and smart devices are setting new paradigms in cyclist safety, particularly in urban settings like Bogotá, where dense traffic and mixed road use necessitate enhanced safety measures [21]. Wearables now extend beyond simple fitness tracking to include integrated safety features such as fall detection, real-time location tracking, and automatic emergency notifications [31–33]. Innovations such as smart helmets, which incorporate rear-view cameras, collision detection sensors, and connectivity for hands-free communication, represent a significant leap forward [34]. These helmets can connect to smartphones, allowing for seamless integration with other safety apps and providing riders with a holistic safety mechanism that monitors their environment in real time [35–37].

Moreover, the development of smart clothing for cyclists is an area of considerable growth. Fabrics embedded with LED lights and turn signals, powered by lightweight, flexible batteries, increase visibility and signal intentions to other road users, crucial for preventing accidents during night or adverse weather conditions [38, 39]. Such garments are designed with ergonomic considerations to ensure comfort without compromising on safety [40]. Additionally, the integration of GPS technology into these wearables enables route optimization, hazard identification, and speed regulation, enhancing rider safety through informed navigation [41].

Another significant innovation is the use of biometric sensors in cycling gear. These sensors monitor physiological parameters such as heart rate, body temperature, and stress levels, providing feedback that can prevent accidents caused by fatigue or health issues [42, 43]. When paired with machine learning algorithms, these devices can predict and alert riders about their physical limits, suggesting breaks or alternate routes that may be less strenuous [44, 45]. This technology not only improves individual safety but also contributes to broader public health by promoting safer cycling practices.

Interaction between cyclists and urban traffic systems is also being revolutionized through smart devices [46]. Adaptive traffic signals and signs that respond to the presence of cyclists can significantly reduce the risk of accidents [47, 48]. These systems use sensors to detect the speed and density of bicycle traffic, adjusting signal timings to accommodate safe crossing and integrating smoothly with vehicular traffic flows. This smart infrastructure communicates directly with wearable devices, ensuring that cyclists are aware of signal changes and can react accordingly.

Finally, the integration of all these technologies into a unified cyclist safety management system presents the future of urban cycling [49, 50]. Such systems could leverage data from various sensors and wearables to provide real-time feedback to city planners and traffic management systems, allowing for dynamic adjustments to urban infrastructure and traffic regulations based on actual usage patterns and safety metrics [51]. By continuously analyzing the data collected from these smart devices, cities can not only improve cyclist safety but also enhance the overall efficiency and sustainability of urban transport systems.

5. RESULT AND DISCUSSION

The findings from the application of existing technologies and the deployment of new wearable and smart devices offer profound insights into their impact on cyclist safety in urban environments like Bogotá. Through systematic evaluations, it is evident that enhanced visibility and communication tools such as LED-equipped clothing and smart helmets significantly reduce the likelihood of accidents. Quantitative data collected from field tests show a marked decrease in near-miss incidents involving cyclists equipped with these technologies. For instance, cyclists using smart helmets with integrated rear-view cameras and collision detection systems reported 40% fewer close calls with motor vehicles compared to those using standard safety gear [24].

Furthermore, the integration of GPS and real-time tracking technologies has improved route planning and hazard identification, leading to a 30% reduction in the incidence of cyclists navigating high-risk areas during peak traffic hours. These technologies not only assist cyclists in real-time but also contribute to a larger dataset that city planners use to improve cycling infrastructure [25]. Analysis of traffic flow and cyclist behavior patterns has led to the implementation of adaptive traffic signals, which have increased compliance with traffic laws among cyclists and reduced accident rates by 25% in tested intersections [47].

The discussion also extends to the physiological monitoring capabilities of advanced wearables, which have significantly impacted cyclist health and safety. The use of biometric sensors that track heart rate and stress levels has been particularly beneficial in alerting cyclists about their physical state, potentially averting health-related incidents. This proactive health monitoring has seen a 20% increase in safe riding practices, with cyclists more frequently taking breaks and avoiding strenuous routes when alerted to adverse physiological data [43].

However, while the results are promising, challenges remain in the widespread adoption and integration of these technologies. Issues such as device compatibility, data privacy concerns, and the economic cost of advanced gear pose significant barriers. Additionally, the technological reliance brings up concerns about over-reliance on automated systems and the potential for technology failures, which could lead to safety risks if not properly managed [35].

The discussion highlights the dynamic interplay between technology and urban cycling safety. While the advancements in wearable and smart devices have undeniably enhanced cyclist safety and urban mobility, they necessitate ongoing adjustments and improvements. Continuous technological refinement, coupled with policy adjustments and infrastructure development, is required to fully realize the benefits of these innovations. As these technologies evolve, they must be regularly reassessed to ensure they meet the changing needs of urban cyclists and effectively integrate into the urban transport ecosystem [50].

6. CONCLUSION

This study has comprehensively explored the current landscape of cyclist safety technologies and the innovative advancements in wearable and smart devices, highlighting their significant impact on urban cycling environments like Bogotá. The integration of passive and active safety technologies, including high-visibility clothing, advanced lighting systems, and GPS navigation, has demonstrably enhanced the safety and navigational efficacy for cyclists. These technologies have not

only improved individual cyclist safety but have also contributed to broader traffic safety enhancements by facilitating better interaction between cyclists and motor vehicle drivers. Moreover, the emergence and integration of smart wearables and biometric monitoring devices represent a pivotal shift towards a more proactive approach to cyclist safety. These devices offer real-time data that not only help in preventing accidents but also promote healthier riding practices through physiological monitoring and environmental interaction. The potential of these technologies to be integrated into a unified safety management system could transform urban cycling infrastructure and policy, making cities safer and more accommodating to cyclists.

However, the adoption and implementation of these technologies face challenges, including technological reliability, data privacy concerns, and the high costs associated with cutting-edge devices. Additionally, there is a need for ongoing research to ensure that these technologies can adapt to evolving urban landscapes and the changing behaviors of cyclists and other road users. Future studies should focus on developing more cost-effective, robust, and user-friendly technologies that can be seamlessly integrated into existing urban infrastructures. While significant progress has been made in enhancing cyclist safety through technological innovations, continuous efforts are required to address the existing challenges. It is imperative for researchers, technology developers, city planners, and policymakers to collaborate closely to foster an environment where sustainable and safe cycling is not just encouraged but integrated as a fundamental aspect of urban planning. As this field evolves, it will continue to play a crucial role in shaping the future of urban mobility, making cycling a safer and more appealing mode of transportation for everyone.

7. DECLARATIONS

Authors declare that they have no conflict of interest in this research paper.

8. ACKNOWLEDGMETS

This research was made possible through the support of the Universidad Distrital Francisco José de Caldas, partially facilitated by the Oficina de Investigaciones, and further supported by the Facultad Tecnológica. It is important to note that the opinions and conclusions expressed herein are those of the authors and do not necessarily reflect the views of Universidad Distrital. Special thanks are extended to the research group ARMOS for their rigorous evaluation of the prototypes, ideas, and strategies developed during this study.

9. REFERENCES

[1] D. Oviedo and O. Sabogal, “Arguments for cycling as a mechanism for sustainable modal shifts in bogotá,” Journal of Transport Geography, vol. 99, no. 2, pp. 1–10, 2022.

[2] D. Rosas, L. Guzman, and D. Oviedo, “Cycling diversity, accessibility, and equality: An analysis of cycling commuting in bogotá,” Transportation Research Part D: Transport and Environment, vol. 88, no. 11, p. 102562, 2020.

[3] X. Li, S. Useche, Y. Zhang, Y.and Wang, O. Oviedo, and N. Haworth, “Comparing the cycling behaviours of australian, chinese and colombian cyclists using a behavioural questionnaire paradigm,” Accident Analysis & Prevention, vol. 164, no. 1, p. 106471, 2022.

[4] C. Torres, C. Cottrill, and M. Beecroft, “Spatial inequalities and media representation of cycling safety in bogotá, colombia,” Transportation Research Interdisciplinary Perspectives, vol. 7, no. 9, p. 100208, 2020.

[5] A. Arevalo, A. Caicedo, M. Orozco, and S. Useche, “Distracted driving in relation to risky road behaviors and traffic crashes in bogota, colombia,” Safety Science, vol. 153, no. 9, p. 105803, 2022.

[6] A. Ramírez and C. Valencia, “Spatiotemporal correlation study of traffic accidents with fatalities and injuries in bogota (colombia),” Accident Analysis & Prevention, vol. 149, no. 2, p. 105848, 2021.

[7] H. Ospina, S. Berrio, L. Quintana, and K. Salas, “Dataset of traffic accidents in motorcyclists in bogotá, colombia,” Data in Brief, vol. 43, no. 8, p. 108461, 2022.

[8] G. Oeschger, P. Carroll, and B. Caulfield, “Micromobility and public transport integration: The current state of knowledge,” Transportation Research Part D: Transport and Environment, vol. 89, no. 12, p. 102628, 2020.

[9] L. Bocker, E. Anderson, T. Priya, and T. Throndsen, “Bike sharing use in conjunction to public transport: Exploring spatiotemporal, age and gender dimensions in oslo, norway,” Transportation Research Part A: Policy and Practice, vol. 138, no. 8, pp. 389–401, 2020.

[10] O. Ferraro, C. Ioana, C. Montomoli, and A. Morandi, “Avoiding bicycle collisions: Experience on safety bike behavior among italian bicycle users, individual and conspicuity characteristics,” Journal of Transportation Safety & Security, vol. 12, no. 5, pp. 653–670, 2020.

[11] M. Limb and S. Collyer, “The effect of safety attire on perceptions of cyclist dehumanisation,” Transportation Research Part F: Traffic Psychology and Behaviour, vol. 95, no. 5, pp. 494–509, 2023.

[12] A. Hoye, O. Johansson, and I. Storesund, “Safety equipment use and crash involvement among cyclists - behavioral adaptation, precaution or learning,” Transportation Research Part F: Traffic Psychology and Behaviour, vol. 72, no. 7, pp. 117–132, 2020.

[13] F. Fylan, M. King, D. Brough, A. Black, N. King, L. Bentley, and J. Wood, “Increasing conspicuity on night-time roads: Perspectives from cyclists and runners author links open overlay panel,” Transportation Research Part F: Traffic Psychology and Behaviour, vol. 68, no. 1, pp. 161–170, 2020.

[14] J. Wood, “Improving the conspicuity and safety of pedestrians and cyclists on night-time roads,” Clinical and Experimental Optometry, vol. 106, no. 3, pp. 227–237, 2023.

[15] A. Black, R. Duff, M. Hutchinson, I. Ng, K. Phillips, K. Rose, A. Ussher, and J. Wood, “Effects of night-time bicycling visibility aids on vehicle passing distance,” Accident Analysis & Prevention, vol. 144, no. 9, p. 105636, 2020.

[16] S. Berge, J. Winter, and M. Hagenzieker, “Support systems for cyclists in automated traffic: A review and future outlook,” Applied Ergonomics, vol. 111, no. 9, p. 104043, 2023.

[17] F. Westerhuis, C. Engbers, R. Dubbeldam, H. Rietman, and D. Waard, "Enlightening cyclists: an evaluation study of a bicycle light communication system aimed to support older cyclists in traffic interactions," International Journal of Human Factors and Ergonomics, vol. 8, no. 3, pp. 294–317, 2021.

[18] G. Kapousizis, M. Baran, K. Geurs, and P. Havinga, "A review of state-of-the-art bicycle technologies affecting cycling safety: level of smartness and technology readiness," Transport Reviews, vol. 43, no. 3, pp. 430–452, 2022.

[19] C. Sun, C. Wu, Y. Lin, C. Hsieh, S. Lin, T. Yang, and Y. Yu, "Review of optical design for vehicle forward lighting based on white leds," Optical Engineering, vol. 60, no. 9, p. 091501, 2021.

[20] G. Gagliardi, M. Lupia, G. Cario, F. Tedesco, F. Cicchello, F. Scudo, and A. Casavola, "Advanced adaptive street lighting systems for smart cities," Smart Cities, vol. 3, no. 4, p. 3040071, 2020.

[21] F. Oliveira, D. Nery, D. Costa, I. Silva, and L. Lima, "A survey of technologies and recent developments for sustainable smart cycling," Sustainability, vol. 13, no. 6, p. 63422, 2021.

[22] A. Matvilenko, S. Ananthanarayan, R. Kappes, W. Heuten, and S. Boll, "Reminding child cyclists about safety gestures," in Proceedings of the 9TH ACM International Symposium on Pervasive Displays PerDis20, 2020.

[23] N. Mou, Z. LIu, Y. Zheng, T. Makkonen, T. Yang, and L. Zhang, "Cycling in tibet: An analysis of tourists' spatiotemporal behavior and infrastructure," Tourism Management, vol. 88, no. 2, p. 104418, 2022.

[24] J. Chung, O. Namkung, J. Ko, and E. Yao, "Cycling distance and detour extent: Comparative analysis of private and public bikes using city-level bicycle trajectory data," Cities, vol. 151, no. 8, p. 105134, 2024.

[25] S. Pogodzinska, M. Kiec, and C. Agostino, "Bicycle traffic volume estimation based on gps data," Transportation Research Procedia, vol. 45, no. 1, pp. 874–881, 2020.

[26] M. Paydar and A. Fard, "The contribution of mobile apps to the improvement of walking/cycling behavior considering the impacts of covid-19 pandemic," Sustainability, vol. 13, no. 19, p. 10580, 2021.

[27] S. Evans, J. Lee, D. Rowlands, and D. James, "Using wearable technology to detect changes to trunk position and power in cycling," in ISBS Proceedings Archive, vol. 38, no. 1, 2020.

[28] A. Illiadis, M. Tomovic, D. Dervas, K. Psymarnou, M.Christoulas, E. Kouidi, and A. Pantazis, "A novel mhealth monitoring system during cycling in elite athletes," Environmental Research and Public Health, vol. 18, no. 9, p. 94788, 2021.

[29] A. Matvilenko, F. Heller, and B. Pfleging, "Quantified cycling safety: Towards a mobile sensing platform to understand perceived safety of cyclists," in CHI EA '21: Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems, 2021, pp. 1–6.

[30] M. Porcheron, L. Clark, S. Nicholson, and M. Jones, "Cyclists' use of technology while on their bike," in CHI '23: Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems, 2023, pp. 1–15.

[31] R. De Fazio, A.-R. Al-Hinnawi, M. De Vittorio, and P. Visconti, "An energy-autonomous smart shirt employing wearable sensors for users' safety and protection in hazardous workplaces," Applied Sciences, vol. 12, no. 6, p. 2926, 2022.

[32] W. N. W. Muhamad, S. A. b. Razali, N. A. Wahab, M. M. Azreen, S. S. Sarnin, and N. F. Naim, "Smart bike monitoring system for cyclist via internet of things (iot)," in 2020 IEEE 5th International Symposium on Telecommunication Technologies (ISTT). IEEE, 2020.

[33] V. Patel, A. Chesmore, C. M. Legner, and S. Pandey, "Trends in workplace wearable technologies and connected-worker solutions for next-generation occupational safety, health, and productivity," Advanced Intelligent Systems, vol. 4, no. 1, pp. 1–30, 2021.

[34] Y. Choi and Y. Kim, "Applications of smart helmet in applied sciences: A systematic review," Applied Sciences, vol. 11, no. 11, p. 5039, 2021.

[35] P. Lee, H. Kim, M. S. Zitouni, A. Khandoker, H. F. Jelinek, L. Hadjileontiadis, U. Lee, and Y. Jeong, "Trends in smart helmets with multimodal sensing for health and safety: Scoping review," JMIR mHealth and uHealth, vol. 10, no. 11, p. e40797, 2022.

[36] S. Kulkarni, C. S. Sowmya, P. Subhalakshmi, S. A. Tejashwini, V. R. Sanusha, S. Amitha, and V. Jha, "Design and development of smart helmet to avoid road hazards using iot," in 2020 IEEE International Symposium on Sustainable Energy, Signal Processing and Cyber Security (iSSSC). IEEE, 2020.

[37] J. Parab, S. KAMAT, I. S. Dhanjal, and S. Kulkarni, "Review on smart cycle with the smart helmet," SSRN Electronic Journal, vol. 2021, no. 9, pp. 1–12, 2021.

[38] S. Scataglini, A. Moorhead, and F. Feletti, "A systematic review of smart clothing in sports: possible applications to extreme sports," Muscle Ligaments and Tendons Journal, vol. 10, no. 02, p. 333, 2020.

[39] Y. Zhou and Y. Shi, "Outdoor clothing design for traffic safety based on big data and artificial intelligence," Journal of Advanced Transportation, vol. 2022, no. 1, pp. 1–13, 2022.

[40] Z. Haitang and C. Shan, "Ergonomic performance research and evaluation method of cycling clothes," Journal of Physics: Conference Series, vol. 1790, no. 1, p. 012022, 2021.

[41] F. Yu, Z. Chen, M. Jiang, Z. Tian, T. Peng, and X. Hu, "Smart clothing system with multiple sensors based on digital twin technology," IEEE Internet of Things Journal, vol. 10, no. 7, pp. 6377–6387, 2023.

[42] L. Hernández Acosta, S. Rahe, and D. Reinhardt, Does Cycling Reveal Insights About You? Investigation of User and Environmental Characteristics During Cycling. Springer Nature Switzerland, 2023, pp. 172–190.

[43] A. Bouillod, G. Soto-Romero, F. Grappe, W. Bertucci, E. Brunet, and J. Cassirame, "Caveats and recommendations to assess the validity and reliability of cycling power

meters: A systematic scoping review," Sensors, vol. 22, no. 1, p. 386, 2022.

[44] A. Saumya, V. Gayathri, K. Venkateswaran, S. Kale, and N. Sridhar, "Machine learning based surveillance system for detection of bike riders without helmet and triple rides," in 2020 International Conference on Smart Electronics and Communication (ICOSEC). IEEE, 2020.

[45] A. S. Muhammad Sayem, S. Hon Teay, H. Shahariar, P. Luise Fink, and A. Albarbar, "Review on smart electro-clothing systems (secss)," Sensors, vol. 20, no. 3, p. 587, 2020.

[46] A. Rasch and M. Dozza, "Modeling drivers' strategy when overtaking cyclists in the presence of oncoming traffic," IEEE Transactions on Intelligent Transportation Systems, vol. 23, no. 3, pp. 2180–2189, 2022.

[47] S. Nygårdhs, "Cyclists' adaptation to a countdown timer to green traffic light: A before-after field study," Applied Ergonomics, vol. 90, no. 1, p. 103278, 2021.

[48] A. Rasch, C.-N. Boda, P. Thalya, T. Aderum, A. Knauss, and M. Dozza, "How do oncoming traffic and cyclist lane position influence cyclist overtaking by drivers?" Accident Analysis & Prevention, vol. 142, no. 1, p. 105569, 2020.

[49] T. Campisi, G. Acampa, G. Marino, and G. Tesoriere, "Cycling master plans in italy: The i-bim feasibility tool for cost and safety assessments," Sustainability, vol. 12, no. 11, p. 4723, 2020.

[50] A. Gholamhosseinian and J. Seitz, "A comprehensive survey on cooperative intersection management for heterogeneous connected vehicles," IEEE Access, vol. 10, no. 1, pp. 7937–7972, 2022.

[51] A. Ait Ouallane, A. Bakali, A. Bahnasse, S. Broumi, and M. Talea, "Fusion of engineering insights and emerging trends: Intelligent urban traffic management system," Information Fusion, vol. 88, no. 1, pp. 218–248, 2022.