Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 9, No. 6, 118-134
2025
Publisher: Learning Gate
DOI: 10.55214/25768484.v9i6.7759

Design of people movement trackers application in determining public transportation corridors for sustainable smart city transportation systems

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Abstract: The development of a sustainable smart city transportation system in Makassar requires accurate data on people's movement patterns to support the effective planning of public transportation corridors. This study aims to design a people movement tracker application as a data-driven tool for public transport route planning. The application was developed using the Waterfall software development method, which includes the stages of requirement analysis, system design, implementation, testing, and maintenance. The application integrates GPS tracking, user behavior analysis, and spatial data processing. A total of 23 participants who installed the application provided training data on their mobility within Makassar. The results show that real-time mobility tracking can effectively identify movement patterns and areas with high population density, which can be used to determine more responsive public transportation corridors. The application offers practical contributions to transport policy and infrastructure planning based on actual user needs. This study concludes that combining a structured software engineering approach with digital mobility tracking technology is essential for building a sustainable and adaptive urban mobility system in the era of smart cities.

Keywords: *Apps, Makassar city, People movement, Public transportation, Smart cities, Trackers, Transportation corridors.*

1. Introduction

Urbanization has driven the growing need for sustainable urban development, where the concept of the smart city is positioned as a strategic framework to address environmental, economic, and social challenges [1]. In Indonesia, congestion problems do not only occur in DKI Jakarta but also in the buffer area, which is the main mobility point to the capital. In response to these conditions, the government initiated the development of integrated urban areas in the Greater Jakarta area to improve the connectivity and efficiency of mobility between the regions, according to Syafruddin [2] stated that to achieve an ideal public transportation system, at least 72.8% of people's movements should be facilitated by public transportation [2]. A sustainable transportation system is one that can provide mobility solutions economically without cause in, or only causing minimal damage to the environment [3]. In the context of road transportation, public buses are seen as the most efficient and sustainable mode of transportation because they can transport many passengers economically and reduce the burden of individual costs. Nevertheless, the complexity of urban mobility requires a data-driven approach that considers a variety of criteria, such as traffic patterns, cost-effectiveness, and environmental impact, to design an efficient transportation route system [4]. However, challenges to service sustainability still often arise. In Makassar, two Teman Bus service corridors were stopped from operation as of January 1, 2025 due to the limited subsidy budget from the Ministry of Transportation [5]. Corridors 1 and 2 of the Teman Bus service in Makassar will cease operations as of January 1,

History: Received: 6 March 2025; Revised: 7 May 2025; Accepted: 12 May 2025; Published: 2 June 2025
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2025. Now, Teman Bus Makassar only serves corridor 5, namely the Unhas Tamalanrea Campus-Faculty of Engineering Unhas Gowa route. Currently, only corridor 5 is still operating, serving the Unhas Tamalanrea Campus – Faculty of Engineering Unhas Gowa route [6]. Currently, only corridor 5 is still operating, serving the Unhas Tamalanrea Campus – Faculty of Engineering Unhas Gowa route. In Yogyakarta, line 7 Trans Jogja will also be stopped starting February 1, 2025, even though the line previously served the Giwangan–Babarsari Terminal route [7]. Based on these various problems, this study proposes the development of a people movement tracker application as a strategic tool in planning adaptive and sustainable public transportation corridors in the context of smart cities. The initial trial was conducted in Makassar City by involving 23 user respondents who had the application installed on their mobile devices to record their daily movement patterns.

Overview of the Development of Public Transportation Technology in Smart Cities The development of information systems in the public transportation sector continues to make rapid progress in line with the adoption of advanced technology in smart city infrastructure [8] proposed a new dynamic spatial approach based on Geographic Information Systems (GIS) and artificial intelligence (AI) techniques, to predict travel time according to spatiotemporal fluctuations. Research Alam, et al. [9] the system integrates IoT devices, such as sensors, cameras, and GPS trackers, with data analytics and advanced communication networks to create a connected and intelligent transportation infrastructure. Research Chen, et al. [10] large language models (LLMs) have potential in interpreting and processing multi-modal urban data, but issues such as model instability, computational inefficiencies, and concerns about reliability hinder their implementation. In fact, viable LLM application scenarios critically evaluate existing challenges and highlight avenues to advance LLM-based mobility systems through multi-mode data integration and developing robust, lightweight models. From various studies related to the development of public transportation in smart city systems, including IoT, 5G, blockchain, and AI, this research develops IoT networks in building people mobility tracker applications to help corridor networks in public transportation to serve passengers [11]. The quiet use of public transportation in big cities is due to the static corridor system, so a tracking application is needed for prospective passengers based on the pattern of people movement, which is a guide for the corridor system in public transportation. The increasing traffic congestion in Surabaya has made people in the city consider switching from private vehicles to public vehicles. However, the problem that arises is the lack of information about public transportation in Surabaya, making it quite difficult for people who want to use public transportation [12]. In this context, the use of innovative technologies is indispensable to minimize risks, improve mobility efficiency, and create safer and more inclusive urban environments [13]. Therefore, this study focused on the development of a person-movement tracking application to analyse and compile public transportation corridors based on user needs. The analysis was carried out using a participatory approach based on user data obtained directly from the developed application.

In software development, detailed design includes the internal implementation of the module, the design of the data structure, the selection of algorithms, and the coding process in the appropriate programming language [14]. Software engineering is a structured approach that aims to produce high-quality software efficiently and cost-effectively. Software development methodology refers to the systematic framework used to design, plan, and control the entire system development process [15]. In this study, the development method used is the Waterfall model, which is a sequential development model that divides the process into several phases that are linearly connected to each other. Each phase from needs analysis, system design, implementation, testing, and maintenance must be completed before proceeding to the next phase [15]. This model was chosen because of its systematic structure and is suitable for projects with clearly defined needs from the outset. In the next section, this article will describe in detail the stages of system design, implementation results, analysis, and the discussion of the findings, as well as conclusions from the conducted research.

2. Literature Review

The concept of smart cities and sustainable transportation has emerged as a strategic response to the increasing challenges of urbanization, environmental degradation, and the growing mobility needs of urban areas. Local governments in Estonia have the authority to set mobility and transportation financing policies. The findings of the study indicate a substantial degree of local autonomy in decentralized transportation governance systems, which is reflected in the allocation of approximately 60% of the local government budget to the transportation sector [16]. Urban sustainability is a conceptual approach that emphasizes the importance of urban development that is able to meet the needs of the current generation without reducing the capacity of future generations to meet their needs. This approach requires the planning, development, and management of urban areas that are holistic, integrated, and sustainable [17].

The following section reviews previous studies related to mobility tracking and public transportation route planning based on 36 articles published between 2020 and 2024, after extracting 11 articles that matched the keywords. These studies leverage a variety of advanced technologies, such as the Internet of Things (IoT), artificial intelligence (AI), and spatial-temporal data, to improve the efficiency and sustainability of urban transportation systems.

Table 1.
Related journals by research topic, methods used and key findings.

No	Author & Year	Research Topics	Methods Used	Key Findings
1	Ribeiro, et al. [18]	Passive mobility monitoring on public transport	Passive Wi-Fi, motion data analysis	Develop a Wi-Fi-based system to analyse passenger movement patterns on Madeira Island.
2	Huang, et al. [19]	Use of mobile and Bluetooth app data for mobility analysis	Mobile ticketing app, Bluetooth beacon	Analyse multi-modal mobility in Helsinki with GPS and Bluetooth data for transportation service planning.
3	Mukai and Ikeda [20]	Mobility evaluation using GPS data	GPS data, temporal network	Using GPS data to build a temporal network in planning routes taking into account time changes.
4	Luo, et al. [21]	Multi-modal trip planning based on user preferences	Massive search algorithms, travel optimization	Integrating public transport and micro-mobility to plan efficient routes based on preferences.
5	Arhipova, et al. [22]	Transportation route planning based on mobility and emissions budgets	Mobility budget analysis, route planning	Devising sustainable transport routes by taking into account carbon emissions and resource distribution.
6	Rachmanie, et al. [23]	Implementation of autonomous trams in Surakarta	Case studies, mobility pattern analysis	Analysis of the potential use of autonomous trams in Surakarta based on the movement patterns of existing users and buses.
7	Alam, et al. [9]	The use of IoT to monitor people's movements in smart cities	Sensor IoT, camera, GPS	Integrating sensors and GPS in transportation infrastructure to create an intelligent transportation system.
8	Chen, et al. [10]	The potential of large language models in urban mobility data analysis	Large language model (LLM), multi-modal data integration	Evaluate the potential of LLMs in processing multi-modal urban data for more efficient transportation planning.
9	Xiao, et al. [4]	Incorporation of criteria for efficient transportation route planning	Criteria merging techniques, traffic data analysis	Designing a transportation route planning system based on traffic patterns, costs, and environmental impacts.
10	Fenghour, et al. [8]	Dynamic spatial approach in transport route planning	Geographic Information Systems (GIS), artificial intelligence	Apply GIS and AI to predict travel time based on spatiotemporal fluctuations.

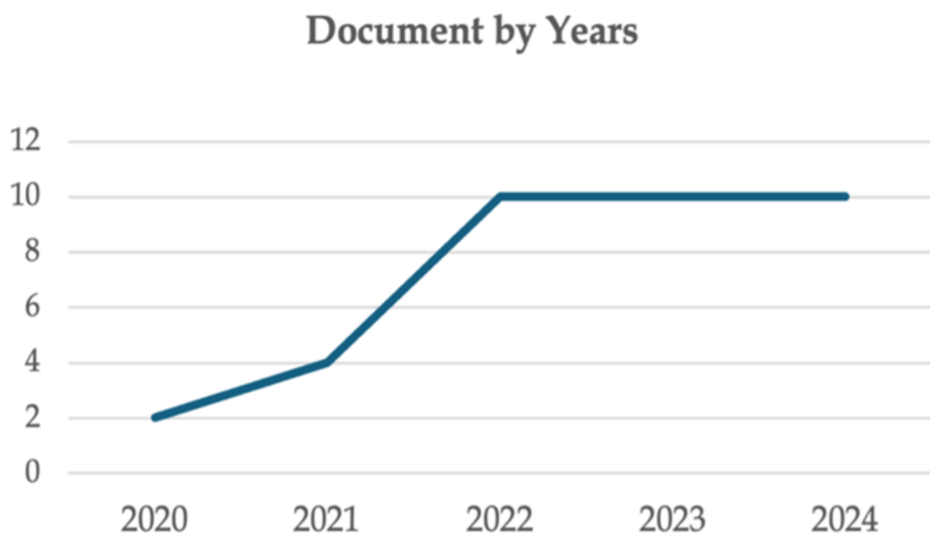


Figure 1.
Number of publication documents related to the tracking of people's movements and route planning based on Scopus. com.

Table 2.
Number of research documents in the last 5 years.

Year	Number of Document
2024	10
2023	10
2022	10
2021	4
2020	2

The development of GPS-based tracking technologies, Internet of Things (IoT), and Geographic Information Systems (GIS) in public transportation systems has been the main focus of various studies in the last decade, with significant contributions to improving route efficiency, mobility monitoring, and the development of data-driven intelligent transportation systems [8, 9]. How ever, most research is still limited to fleet or vehicle monitoring, rather than user-based individual mobility tracking that can represent the dynamics of people's movements in a more granular manner. In addition, the direct integration of data on the movement of people and public transportation corridor planning has not been widely developed in the form of operational systems that can support evidence-based policies at the local level. Another weakness identified was the lack of predictive and adaptive approaches capable of responding to real-time mobility patterns. On the other hand, the lack of contextual research in developing countries such as Indonesia, especially in medium-sized cities such as Makassar, illustrates the gap in the use of tracking technology to support inclusive and responsive public-transport planning to local characteristics. Therefore, this study aims to address this gap by designing and testing a mobile-based people-movement tracker application that is integrated with a spatial analysis system, in order to produce a map of public-transportation corridor needs based on the actual mobility behaviour of the community. This approach is expected to contribute to the development of a sustainable smart city transportation system that is based on user data and adaptive to changing urban dynamics.

3. Method

This research adopts the Waterfall approach in software design and development process. The Waterfall model is one of the oldest and most widely used paradigms in software engineering. Also known as the classical life cycle model or linear sequential model, this approach emphasizes a systematic and structured development process, where each stage is completed sequentially and must be completed before proceeding to the next stage. This model was first formally introduced by Royce [24]. At that time, he proposed improvements to the engine through iterations as follows [25] . The clarity of stages in the Waterfall model makes it suitable for projects with well-defined needs from the outset, such as in the development of the IoT-based movement tracking system examined in this study.

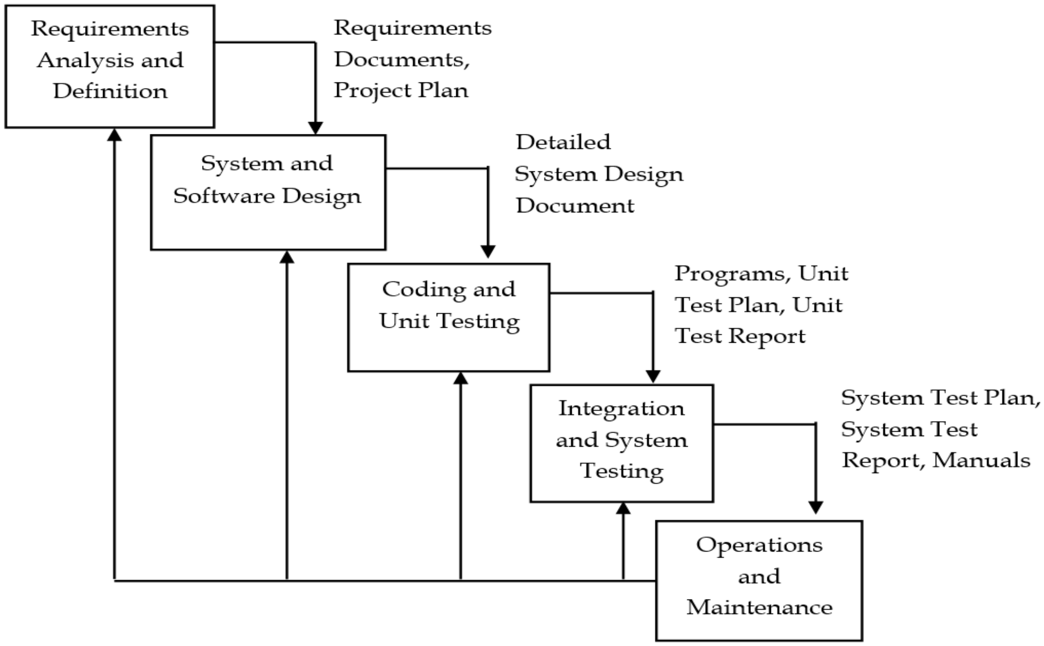


Figure 2.
Waterfall Model [25].

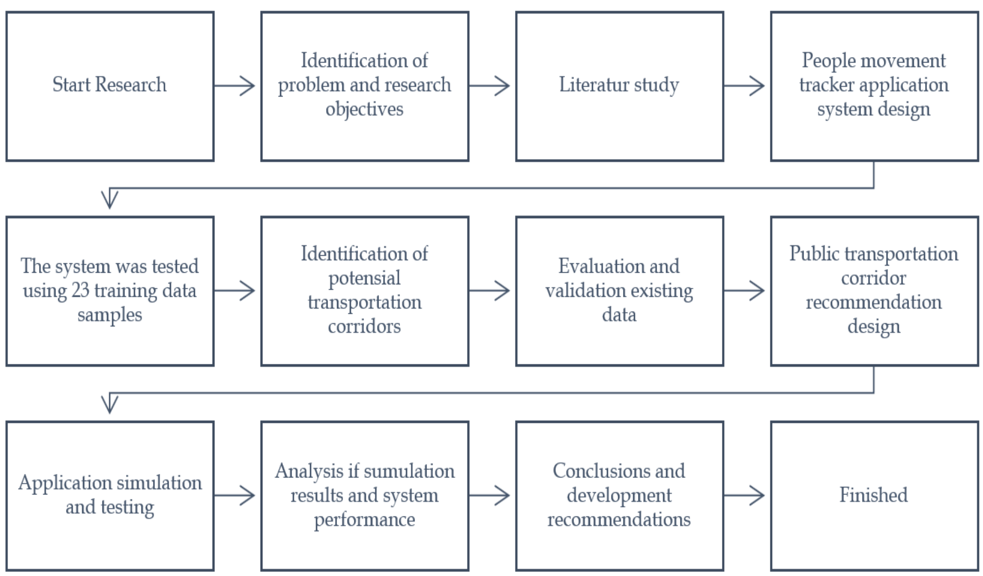


Figure 3.
Research Flow.

To create a use case of the "People Movement Trackers" application in the context of a sustainable smart city transportation system, we will identify the key actors and use cases involved.

Table 3.
Actor user and description.

Actor User	
User	**(Login)**
User	(View User Data)
User	(View Recommended Routes)
(Login)	(Collect Movement Data)
(Collect Movement Data)	(Analyze Data)
(Analyze Data)	(Generate Report)
(Generate Report)	(View Recommended Routes)
GPS	(Collect Movement Data)
App	(Collect Movement Data)
User	(Provide Feedback)
(Provide Feedback)	(Improve System)

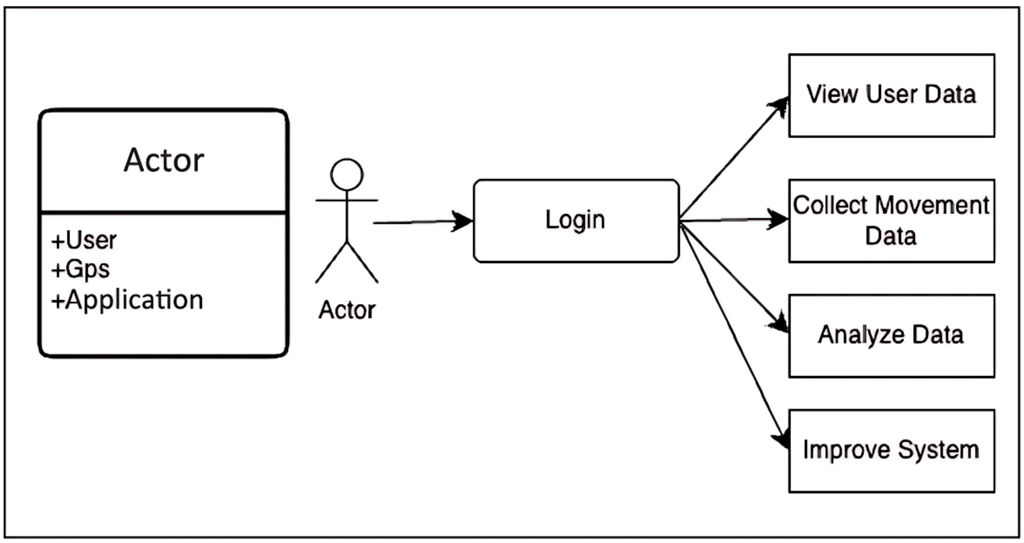


Figure 4.
Use case actor user.

Table 4.
Actor and use case.

Actor	
User	An individual who uses the app for movement tracking.
GPS	A source of location data that provides real-time position information.
App	An app that users use to interact.
Use Cases	
Login	The user is logged in to the app to be able to access features.
View User Data	Users can view their movement data and statistics.
Collect Movement Data	The system collects movement data from GPS and apps.
Improve System	Use user feedback for system improvement.

This diagram illustrates the interaction between users and systems in motion tracking applications, with the main goal of improving the utilization of public-transport corridors in sustainable smart cities.

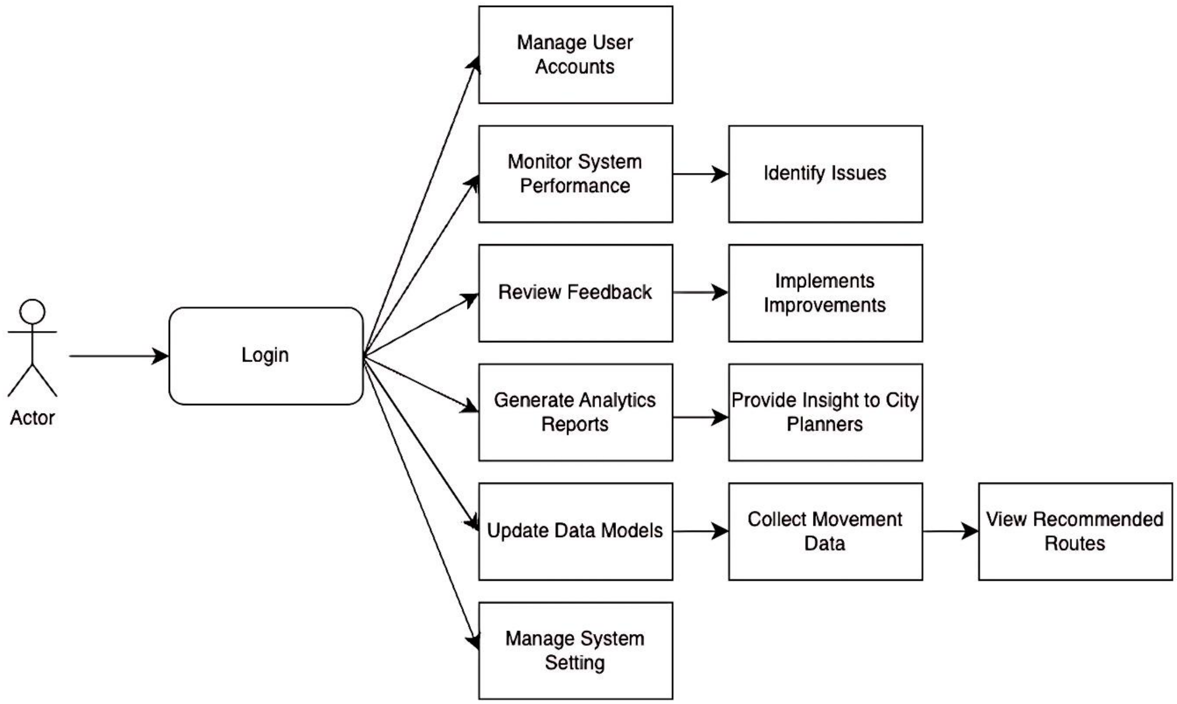


Figure 5.
Use case actor admin.

Table 5.
Use case diagram and actor admin.

Use Case Diagram	
Actor Admin	
Admin	(Login)
Admin	(Manage User Accounts)
Admin	(Monitor System Performance)
Admin	(Review Feedback)
Admin	(Generate Analytics Reports)
Admin	(Update Data Models)
Admin	(Manage System Settings)
(Monitor System Performance)	(Identify Issues)
(Review Feedback)	(Implement Improvements)
(Generate Analytics Reports)	(Provide Insights to City Planners)

Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 9, No. 6: 118-134, 2025
DOI: 10.55214/25768484.v9i6.7759

Table 6.
Actor and use cases.

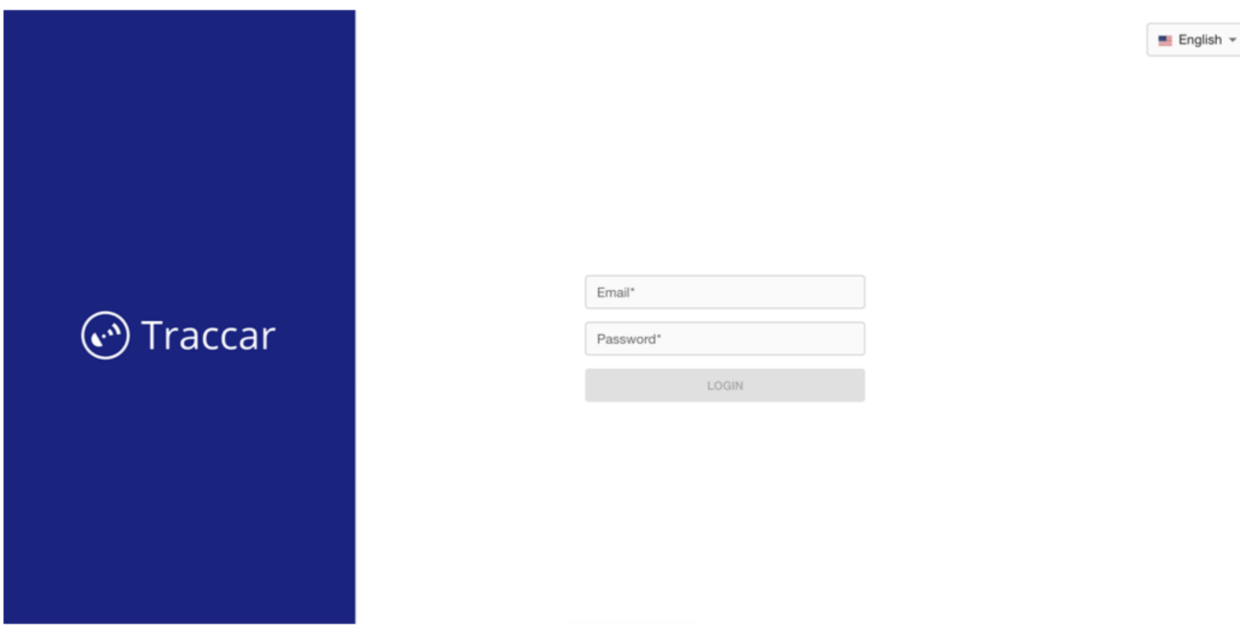
Actor	
Admin	The individual responsible for managing and maintaining the app.
Use cases	
Login	Admins log in to the app to gain access to administrative features.
Manage User Accounts	Manage user accounts, including addition, deletion, and update user information.
System Performance Monitor	Monitors system performance to ensure applications run smoothly.
Review Feedback	Review feedback from users to improve services.
Generate Analytics Reports	Create analytics reports from the collected data to provide further insights.
Update Data Models	Update the data models used in the analysis to improve accuracy.
Manage System Settings	Manage system settings to customize the operation of the application.
Identify Issues	Identify and address issues in system performance.
Implement Improvements	Make improvements based on user feedback.
Provide Insights to City Planners	Provide recommendations and insights to city planners for better public transportation development.

This diagram illustrates the roles and responsibilities of the Administrator in the management of applications that aim to support a sustainable smart city transportation system.

4. Results and Discussion

4.1 Implementation

The following is the interface of the information system of the person-movement tracking application for admins.



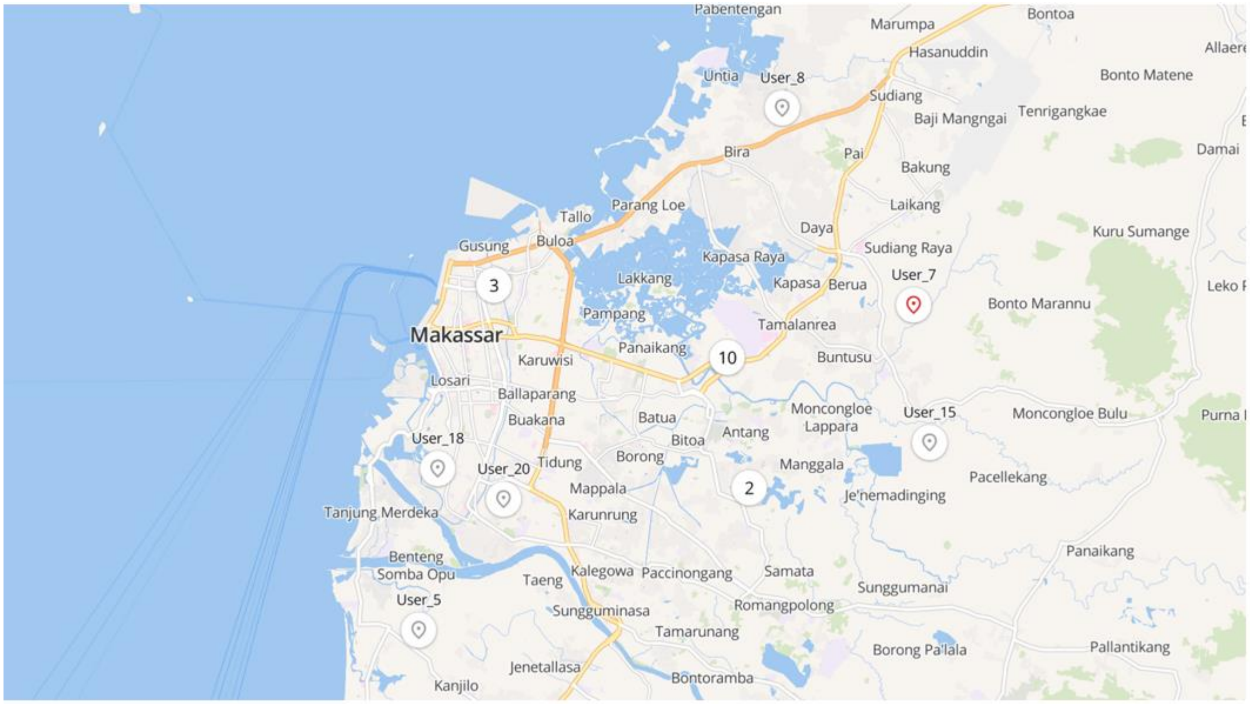


Figure 6.
Admin login view and admin page after login

After user login, the application displays maps showing the distribution of connected users. The admin page can access the map types that will be displayed, one of which is dark mode, reports consisting of combined routes from to each user, events, trips, stops, charts, and trip statistics.

Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 9, No. 6: 118-134, 2025
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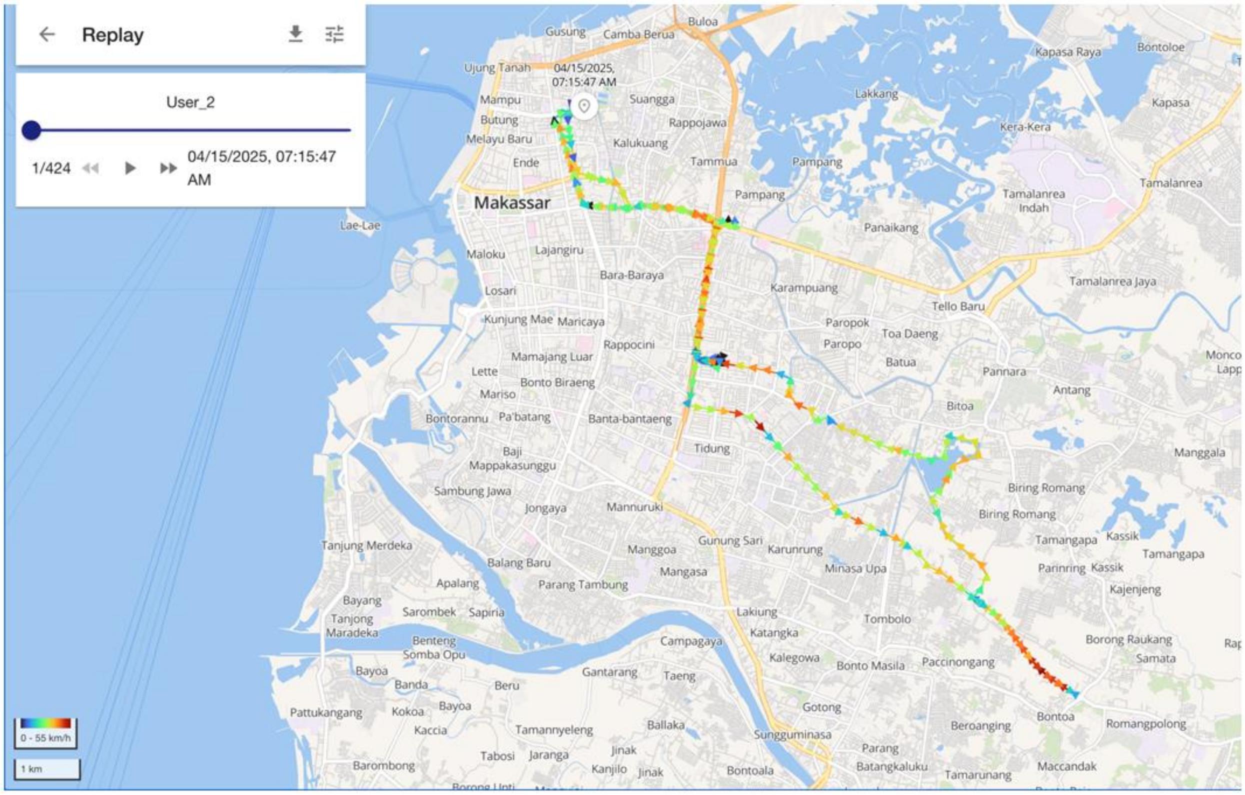
Replay
User_2
1/424
04/15/2025, 07:15:47 AM
04/15/2025, 07:15:47 AM
0 - 55 km/h
1 km
Makassar

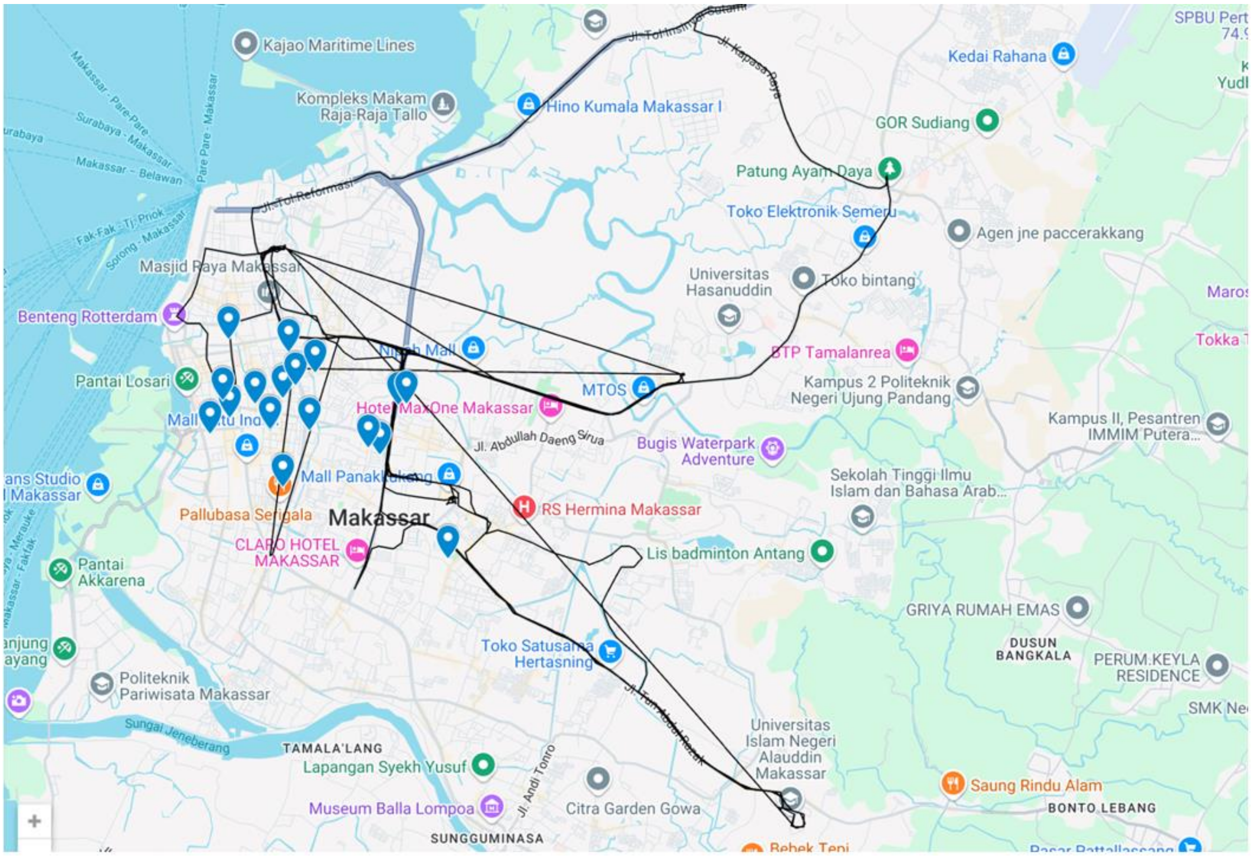

Figure 7.
Report the user's journey in a day and Monthly travel map network of each user.

Admins can monitor the user's journey in a day, from start to finish, and vice versa. Daily travel tracking over a month can be used as a reference when planning public transportation corridors. Daily data recap can be exported to an Excel file, as shown in Figure 7.

Table 7.
User journey recapitulation.

Report type:	**Route**						
Device:	**User_2**						
Group:							
Period:	2025-04-15 00:00:00 - 2025-04-15 23:59:59						
Valid	**Time**	**Latitude**	**Longitude**	**Altitude**	**Speed**	**Address**	**Attributes**
TRUE	15/04/2025 07.15.47	-5,121441	119,422093	6 m	0.0 km/h	-5.121441°, 119.422093°	batteryLevel=64 distance=20.372673690869476 totalDistance=291494.90410950343 motion=false
TRUE	15/04/2025 07.15.56	-5,121488	119,422080	6 m	0.0 km/h	-5.121488°, 119.422080°	event=u batteryLevel=64 distance=5.426928838470671 totalDistance=291500.3310383419 motion=false
TRUE	15/04/2025 07.19.05	-5,121600	119,422004	6 m	0.0 km/h	-5.121600°, 119.422004°	event=t batteryLevel=64 distance=15.048308391166136 totalDistance=291515.3793467331 motion=false
TRUE	15/04/2025 07.22.05	-5,121816	119,421662	7 m	5.0 km/h	-5.121816°, 119.421662°	event=t batteryLevel=64 distance=44.900253093592994 totalDistance=291560.27959982667 motion=true
TRUE	15/04/2025 07.23.11	-5,121388	119,420283	8 m	3.0 km/h	-5.121388°, 119.420283°	batteryLevel=64 distance=160.1481143483756 totalDistance=291720.427714175 motion=true
TRUE	15/04/2025 07.24.05	-5,123186	119,419971	9 m	16.0 km/h	-5.123186°, 119.419971°	batteryLevel=64 distance=203.119853982967 totalDistance=291923.547568158 motion=true
TRUE	15/04/2025 07.24.47	-5,125003	119,420114	8 m	23.0 km/h	-5.125003°, 119.420114°	batteryLevel=64 distance=202.88797590214037 totalDistance=292126.43554406014 motion=true
TRUE	15/04/2025 07.25.05	-5,125994	119,420277	7 m	21.0 km/h	-5.125994°, 119.420277°	event=t batteryLevel=64 distance=111.78815823240433 totalDistance=292238.22370229254 motion=true
TRUE	15/04/2025 07.25.27	-5,126827	119,420414	8 m	15.0 km/h	-5.126827°, 119.420414°	batteryLevel=64 distance=93.96500226503352 totalDistance=292332.1887045576 motion=true
TRUE	15/04/2025 07.26.35	-5,128603	119,420786	7 m	6.0 km/h	-5.128603°, 119.420786°	batteryLevel=64 distance=201.95989866339136 totalDistance=292534.148603221 motion=true

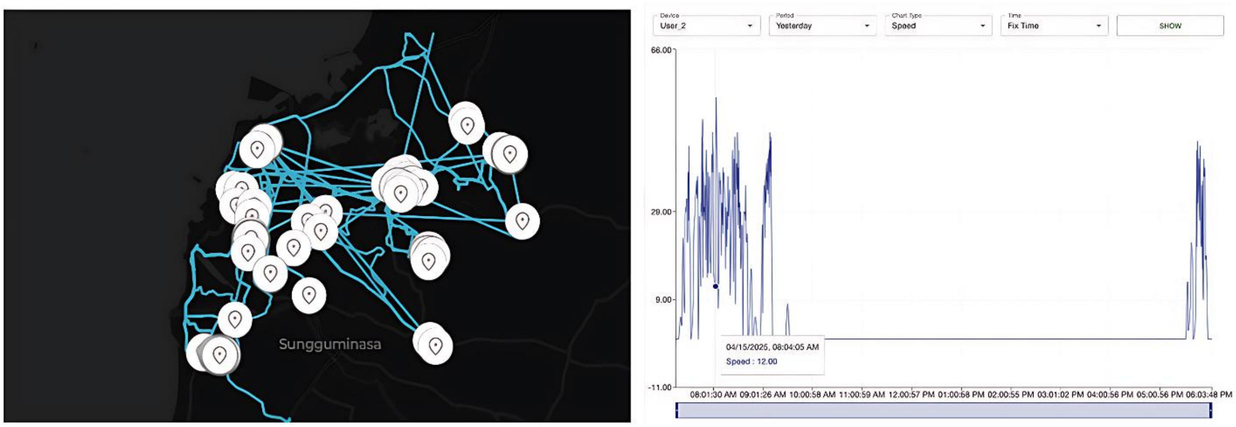

Figure 8.
Map of the travel network of all users and chart of each user's driving speed

Table 8.
Start and stop each user.

Report type:	**Trips**							
Device:	User_22							
Group:								
Period:	2025-03-01 00:00:00 - 2025-03-31 23:59:59							
Start	**Start Address**	**Start Odometer**	**End**	**End Address**	**End Odometer**	**Duration**	**Length**	**Average speed**
2025-03-19 16:47:28	Tamalanrea Indah, South Sulawesi, ID	7.2 km	2025-03-19 20:08:40	Tamalanrea Indah, South Sulawesi, ID	49.1 km	3 h 21 min 12 s	42.0 km	12.5 km/h
2025-03-19 22:25:46	-5.140691°, 119.488868°	54.3 km	2025-03-19 23:23:37	Tamalanrea Indah, South Sulawesi, ID	60.1 km	0 h 57 min 51 s	5.8 km	6.0 km/h
2025-03-20 02:36:34	Jalan Perintis Kemerdekaan, Tamalanrea, South Sulawesi, ID	73.2 km	2025-03-20 03:53:54	-5.139523°, 119.487655°	84.5 km	1 h 17 min 20 s	11.3 km	8.8 km/h
2025-03-20 14:04:55	Jalan Perintis Kemerdekaan, Tamalanrea, South Sulawesi, ID	127.3 km	2025-03-20 16:30:20	Tamalanrea Indah, South Sulawesi, ID	150.9 km	2 h 25 min 25 s	23.6 km	9.8 km/h

ISSN: 2576-8484
Vol. 9, No. 6: 118-134, 2025
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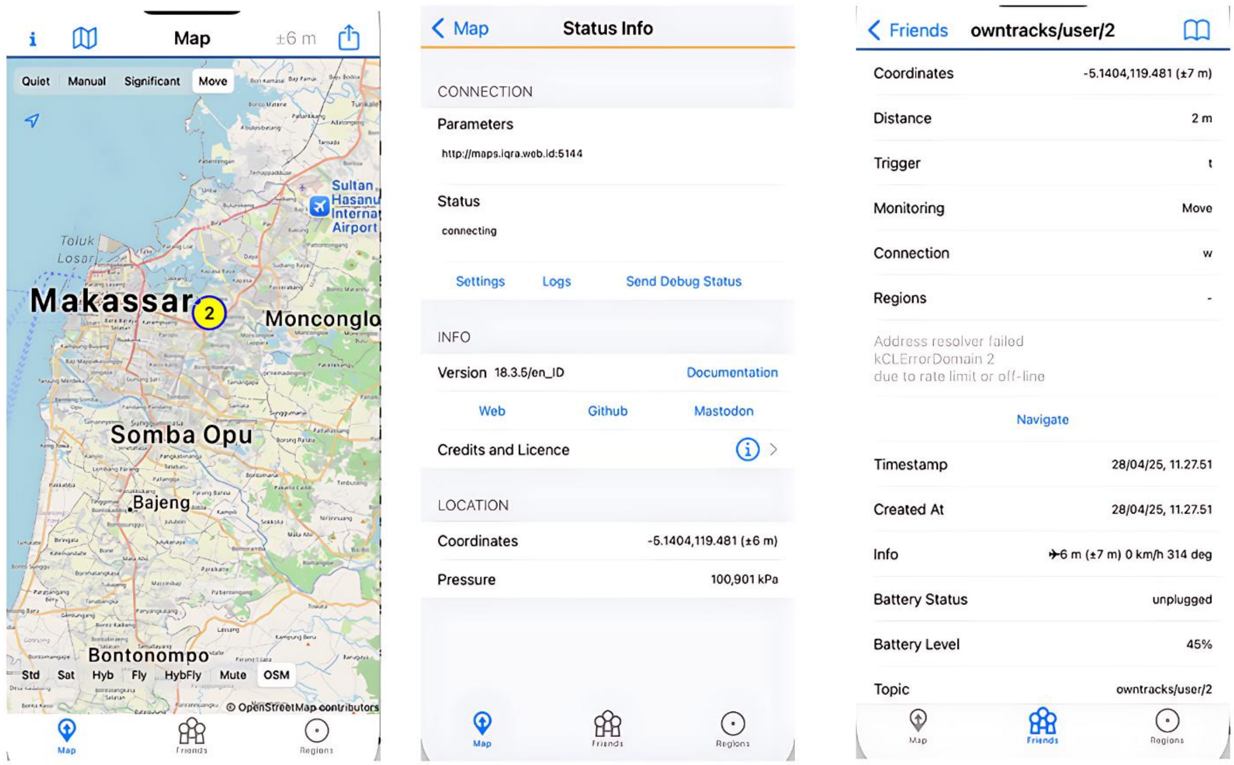

Figure 9.
UI on the user's phone.

5. Discussion

The People Movement Trackers app has great potential for reducing emissions and improving smart city transportation system efficiency. By collecting real-time data on the movement patterns of road users and public transportation, the app enables more efficient transportation corridor design, reduces congestion, and minimizes travel time, which in turn reduces greenhouse gas emissions and air pollution. In addition, the application supports a more precise distribution of public vehicles, thereby reducing dependence on private vehicles and optimizing energy use. With more efficient traffic flow and more optimal use of public transportation, these applications contribute to the reduction of carbon emissions and support the transition to a more environmentally friendly and sustainable transportation system.

Research Contributions: This research makes a significant contribution to the development of sustainable smart city transportation systems through the design of the People Movement Trackers application that identifies more efficient public transportation corridors. By utilizing IoT-based tracking technology, sensors, and GPS, the application is able to collect real-time data on the movement patterns of road users, including pedestrians and public transportation users, which is then used to design optimal public transportation routes. This system helps to reduce congestion, improve route efficiency, and minimize carbon emissions by optimizing traffic flow and public vehicle use. In addition, this application supports transportation planning that is more responsive to changes in people's mobility patterns, as well as contributing to urban transportation system sustainability.

System Limitations: Although the People Movement Trackers app shows promising results, there are some limitations to be aware of. First, the success of these systems relies heavily on the availability of supporting infrastructure, such as sensor networks and stable IoT connectivity across urban areas. Second, the accuracy of the collected data can be affected by external factors, such as signal interference or varying sensor quality. Third, these applications require large-scale data processing, which requires efficient computing capacity and data management. In addition, implementation in cities with high geographic complexity and population density may require further adjustments in terms of sensor coverage and distribution.

The future development of the People Movement Trackers application can be directed at the integration of artificial intelligence (AI) and machine learning technologies to improve the prediction of long-term movement patterns as well as respond to real-time changes such as weather or traffic disturbances. In addition, the application can be extended with the interoperability of other transportation systems, such as smart parking and autonomous vehicles, to create more efficient multimodal solutions. Increased sensor capacity and the use of 5G technology will allow for more accurate tracking, especially in congested areas, while the application of big data analytics can dig deeper into insights to design more adaptive and sustainable transportation policies. The development of cloud-based platforms can also support the collaboration of relevant agencies for faster and more transparent data distribution. As such, the app can become a key component in smart, efficient, responsive, and environmentally friendly transportation systems.

6. Conclusion

The results of tests or simulations using the People Movement Trackers application show that this system is effective in mapping the movement patterns of people in urban areas and in determining more efficient public transportation corridors in a sustainable smart city transportation system. By using sensor-based and IoT-based tracking technology, the app provides accurate real-time data on the density of road users, including pedestrians and public transportation users. This allows for the identification of optimal routes, as well as the adjustment of the frequency and capacity of public-transport services according to actual needs. Simulations also show that these applications can reduce congestion, improve travel efficiency, and support the reduction of environmental impact through more environmentally friendly corridor design. Overall, the results of the trial prove that People Movement Trackers are an effective tool for supporting more sustainable transportation planning, optimizing the use of resources, and improving the quality of life of people in smart cities.

The People Movement Trackers app offers a more sophisticated and dynamic approach to identifying transportation corridors than conventional methods, which generally rely on manual surveys, visual observations, or historical data from existing transportation systems. Conventional approaches often collect data periodically and rely on reports from drivers or field officers who are prone to bias and inaccuracies. Instead, the app leverages IoT, sensors, and GPS technology to collect data automatically and in real-time, providing a more accurate picture of the movement patterns and density of road users. With more granular and dynamic data, the application enables more efficient and responsive determination of transportation corridors to changing mobility patterns. In addition, the app can identify trends that are not visible in conventional approaches, such as movements affected by time, weather, or special events, as well as provide more optimal corridor design recommendations to reduce congestion and minimize travel time. Overall, while conventional approaches remain useful, the People Movement Trackers app offers advantages in terms of data accuracy, real-time analysis, and adaptability to change, all of which are critical in smart and sustainable urban transportation planning.

The People Movement Trackers app has great potential for reducing emissions and improving smart city transportation system efficiency. By collecting real-time data on the movement patterns of road users and public transportation, the app enables more efficient transportation corridor design, reduces congestion, and minimizes travel time, which in turn reduces greenhouse gas emissions and air pollution. In addition, the application supports a more precise distribution of public vehicles, thereby reducing dependence on private vehicles and optimizing energy use. With more efficient traffic flow and more optimal use of public transportation, these applications contribute to the reduction of carbon emissions and support the transition to a more environmentally friendly and sustainable transportation system.

Transparency:
The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

Authors' Contributions:
The authors collectively contributed to the conception and design of the study, development of the application, data collection and analysis, interpretation of the results, drafting of the manuscript, and final approval of the version to be published.

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