Enhancing traffic management through Digital Twin BIM: A case study in Dili city Timor-Leste

Elfrido Elias Tita [1,2], Humbelina M.S. Viegas [3], Gakuho Watanabe [1*]

[1] *Department of Civil and Environmental Engineering, Yamaguchi University, Japan*
[2] *Department of Civil Engineering, Instituto Politecnico de Betano, Same, Timor-Leste*
[3]*Department of Civil Engineering, Universidade Nacional Timor Lorosa'e, Timor-Leste*
[*]*Corresponding author. Email: gakuho.w@yamaguchi-u.ac.jp*

ABSTRACT

Urban traffic issues have widespread economic and environmental implications. This is exemplified in Dili, Timor-Leste's capital, where rapid urbanization has led to traffic-related economic losses and declining air quality. To tackle this, the integration of digital twin technologies, merging building information modeling and geographic information, is gaining attention. This strategy offers a foundation for evidence-based policy-making (EBPM) in transportation economics, transcending mere traffic predictions. This study applied digital twin and real traffic data to assess traffic patterns, congestion points, and CO_2, NOx, and PM10 emissions in two busy Dili areas. Notably, it accurately identified peak congestion periods and locations, aligning with actual survey results. Surprisingly, motorcycles' contribution to air pollutants couldn't be dismissed compared to heavy-duty vehicles, attributed to their prominence and reduced mobility during congestion. This underscores the future necessity of dedicated motorcycle lanes.

Keywords: *Traffic management, Digital Twin, BIM, EBPM, Environmental effects.*

1. INTRODUCTION

Population growth driven by rapid urban development leads to increased traffic volumes and severe traffic congestion, causing economic losses and deteriorating air quality[1,2,3]. Thus, effective traffic management has become a crucial policy concern globally[4]. Neglecting the implementation of traffic policies and the management of traffic congestion, without considering forecasts and analyzing transportation capacity, can result in economic losses due to decreased productivity and air pollution from heightened emissions[5]. Hence, proper traffic management is a significant concern in numerous cities worldwide, including Dili, the capital of Timor-Leste, where the authors are located. Despite various measures taken by our government to address the issue, budget, and resource constraints have prevented a fundamental solution from being reached. It is anticipated that more suitable transportation policies will be formulated by simulating traffic congestion and dynamics through traffic volume surveys and forecasts based on new transportation infrastructure. To address these challenges, a novel approach to traffic management based on Digital Twin (DT) technology has gained attention[6,7]. DT technology serves as a digital representation of Building Information Modeling (BIM) and geographic information in the virtual realm[8]. By integrating real-time data with simulation technology, it becomes feasible to assess present and future conditions. By developing DTs for cities and transportation facilities, it becomes possible to analyze traffic dynamics, identify congestion points, predict traffic volumes, and estimate air pollutant emissions like CO_2 using real-time traffic data. This analytical approach is expected to offer quantitative and reliable data for various traffic management assessments and contribute significantly to evidence-based policy-making (EBPM) in transportation management.

The purpose of this study is the implementation of Digital-Twin technology for two specific high-traffic areas in Dili city in order to identify traffic management challenges by assessing traffic dynamics, congestion spots, and emissions of CO_2, NOx, and PM10 based on actual traffic volume data for the traffic evidence-based policymaking (EBPM). Therefore, Digital Twin- BIM technology is suitable for solving traffic problems in Dili city.

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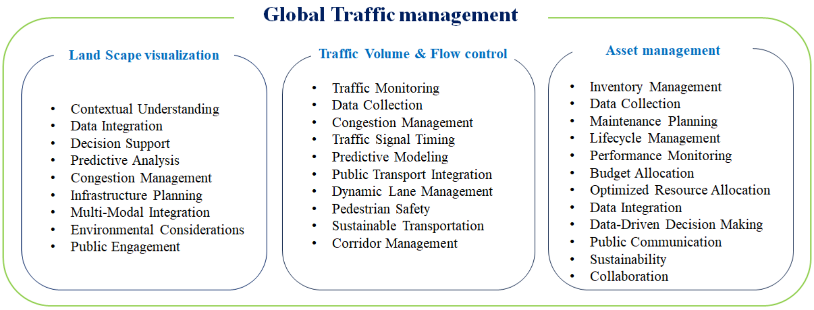


Figure 1. Global traffic management

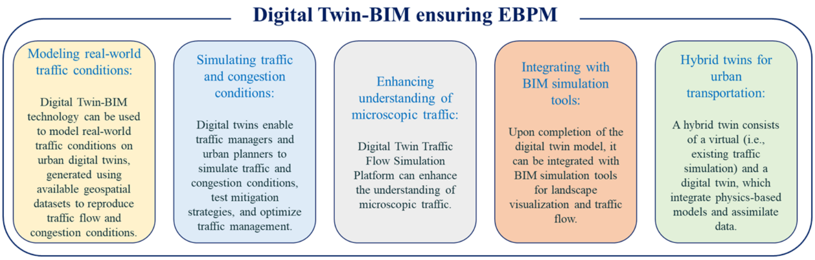


Figure 2. Digital twin-BIM for Ensuring EBPM Traffic management.

2. DIGITAL TWIN-BIM STRATEGY FOR TRAFFIC MANAGEMENT

2.1. Global traffic management

The global Traffic management policy making is composed of Traffic volume control, Landscape design, and Asset Management transportation facilities as shown in **Figure 1**. In the actual operations, each work of three components has been conducted by the specific sections, respectively. All projects for traffic management should be done with an appropriate balance and based on factual evidence (EBPM). Therefore, simulating the actual condition and predicting future conditions is necessary to be carried out.

2.2. Digital Twin Traffic Simulation for EBPM Traffic Management.

Digital Twin is a technology that can ensure evidence-based policy making in traffic management. This technology can be used to model real-world traffic conditions, simulate traffic and congestion conditions, and enhance the understanding of microscopic traffic. By integrating with BIM simulation tools and using hybrid twins for urban transportation, Digital-Twin for traffic simulation can be used to optimize traffic management in cities as can be seen in **Figure 2**. Digital Twin-BIM Traffic Simulation has the potential to revolutionize traffic policy by providing evidence-based insights and enabling proactive measures. By simulating traffic flow and congestion conditions, testing mitigation strategies, and optimizing traffic management, cities can enhance traffic flow, reduce congestion, and improve the overall quality of life for residents.

2.3. Traffic management collaboration

For achieving good traffic management in a city, it is important to collaborate with all related stakeholders that work for traffic management. Therefore, in order to implement Digital twin-BIM technology to ensure evidence-based policy making, we need to collaborate with all stakeholders as shown in **Figure 3**. Stakeholders vary widely from project to project and span a variety of disciplines, including government agencies and municipalities, transportation and urban

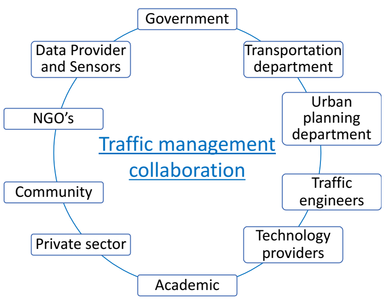


Figure 3. Traffic Management Collaboration

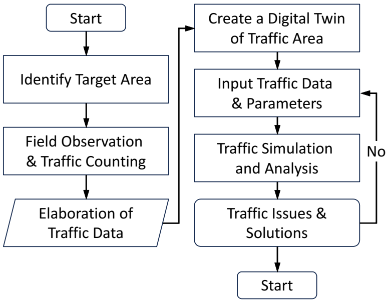


Figure 4. Digital Twin-BIM workflow

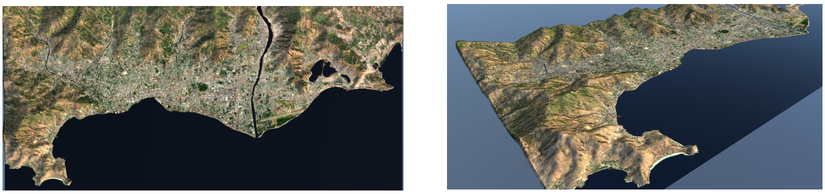


Figure 5. Dili city area

planning agencies, traffic engineers and planners, technology providers and consultants, academic and research institutions, private sector and industry partners, and communities.

3. DEVELOPMENT OF DIGITAL TWIN FOR TRAFFIC MANAGEMENT

The development of a Digital Twin for traffic management follows the workflow as shown in **Figure 4**. In this chapter, an overview of the target city, the development of the Digital Twin model, the preparation of data for traffic simulation, and the simulation methodology are described as follows.

3.1. Overview of Dili City

Dili is the capital city of Timor-Leste and the center of economy, administration, and education. Since its independence from Indonesia in 2002, this city played an especially significant role in the country and the population is explosively increasing year by year [9]. In addition, the concentration of population in urban areas has become more pronounced. According to the Timor-Leste Population and Housing Census, 2022, the total population of Dili city is 324,269 people out of 1,340,434 people of the total Timor-Leste population. It indicates that the population of Dili occupied 24.2 % of the entire population. Timor-Leste's population is 1.34 million and its area is 14,954 square kilometers. It has a population density of around 90 persons per square kilometer. This value of the population density shows a comparatively substantial number among the other east-south Asian countries. Moreover, **Figure 5** is a satellite photo of Dili city, which clearly shows that urbanization is concentrated in the limited plains of Dili. The population density of Dili is 1,177 persons per square kilometer and has become extremely high among others in Timor-Leste. Such rapid growth of urbanization and the population of Dili causes significant challenges of traffic congestion. As mentioned earlier, traffic congestion not only reduces transportation mobility, but also reduces logistics productivity, economic losses, and even air pollution, so it is expected that a new approach utilizing Digital Twin technology will be introduced to optimize traffic management.

3.2. Target research zone

In this study, we have identified two specific zones in Dili city to conduct traffic simulation and analysis, as depicted in **Figure 6**. These zones are the Villa Verde-Cathedral zone and Delta-Elemloi zone. These two zones were selected based on field observations and documentation of significant traffic congestion and delays, which are visually depicted in **Photo 1**. These zones were prioritized as focus areas that require special attention and intervention to address the existing traffic problems, so that traffic problems can be resolved, and smooth vehicle mobilization can be achieved.

3.3. Field Traffic Observation and Daily Traffic Data

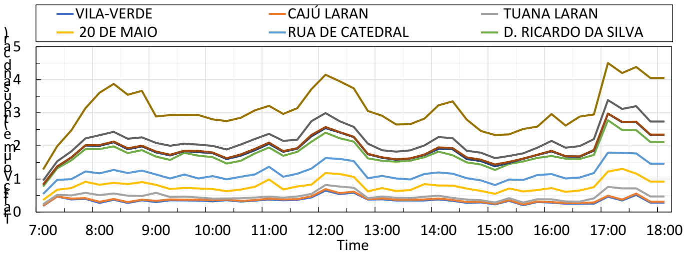
Photo 1 shows the targeted research zone which faces serious traffic congestion in downtown Dili. Traffic surveys need to be conducted to collect traffic data at specific times, hours, and days. Then, the data can be elaborated and input into BIM for simulation and analysis. The total daily vehicle volume in the Villa-Verde zone and Delta-Elemloi zone is presented in **Figure 7**. The vehicle volume data can then be used for the next process, which is the simulation and analysis process.

Figure 6. Target research zone

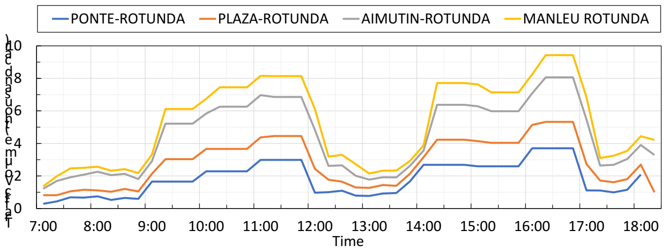
(a) at Delta Elemloi zone.

(b) at Villa Verde- Cathedral zone.

Photo 1. Field traffic observation at actual condition



(a) Villa Verde- Cathedral zone



(a) Delta Elemloi zone

Figure 7. Total daily traffic volume

Table 1. Peak hour data at Villa Verde-Cathedral zone

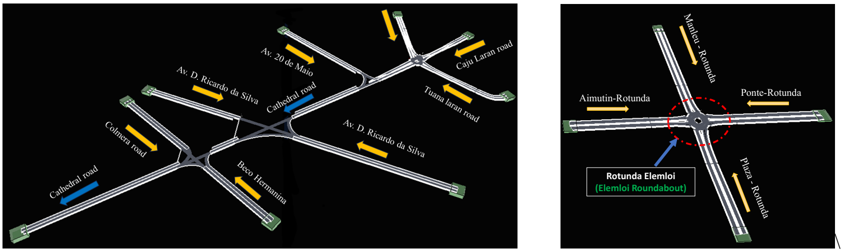
No	Traffic Sources	Morning	Afternoon		Evening
		07:30-08:30	12:00-13:00	13:30-14:30	17:00-18:00
1	Av. Vila Verde	1418	2144	1410	1606
2	Rua Caju Laran	104	119	112	130
3	Rua Tuana Laran	621	472	274	918
4	Av. 20 de maio	1194	1278	1309	1954
6	Av. D.Ricardo da Silva (1)	409	570	387	881
7	Av. D.Ricardo da Silva(2)	2696	2582	2262	3028
8	Av. de Colmera	976	1359	1122	1663
9	Beco Hermanina	65	68	114	49
10	Rua Cathedral	4285	4518	3680	4705

Table 2. Peak hour data at Delta -Elemloi zone

No	Traffic Sources	Morning	Afternoon		Evening
		07:30-08:30	12:00-13:00	13:00-14:00	17:00-18:00
1	Rua Ponte- Rotunda	2612	3847	4300	4346
2	Rua Aimutin-Rotunda	4030	3086	1875	4434
3	Rua Plaza-Rotunda	1906	2317	1911	2504
4	Rua Manleu-Rotunda	1291	2308	1447	2060

(a). Villa Verde- Cathedral zone **(b)**. Delta -Elemloi zone

Figure 8. DT model developed for Traffic Simulations



(a). Villa Verde-Cathedral zone **(b)**. Delta -Elemloi zone

Figure 9. Analytical Model for Traffic Simulation

3.4. Traffic Simulation based on the Observed Traffic Data

Real-time traffic simulation is essential to understand the traffic problems in a city. In this study, the city of Dili is taken as an example to evaluate traffic problems. In particular, at the Villa Verde-Cathedral zone and Delta-Elemloi zone. The goal is to accurately replicate the actual field traffic conditions. However, before we start the simulation and analysis process. It is important to know the working hours of an area so that we can determine the busy hours. For example, in Timor-Leste, all daily activities such as offices, schools, and others start operating from 8:00 a.m. to 12:00 p.m. And in the afternoon, from 2:00 p.m. to 5:00 p.m. That means one day is 8 hours of work. Usually from 12:00 pm to 2:00 pm is the break time, where people have lunch, and many people go back to their homes to rest. Therefore, usually during these hours, there are long traffic jams because many people mobilize. So, we determine the busy hours for both zones as shown in **Tables 1 and 2**. The purpose of determining the busy hours is to identify the traffic congestion that occurs so that it can be evaluated. However, in this study, we limit the simulation and analysis. As in the Villa Verde - Cathedral zone, we only simulate the morning peak hour, starting from 7:30 a.m. to 8:30 a.m. Because it is during these hours that people start going to work, school, and all other activities. For the Delta-Elemloi zone, we chose to simulate the afternoon rush hour, which is from 5:00 p.m. to 6:00 p.m.

Once we knew the working hours in Timor-Leste and were able to determine the simulated peak hours, we then began to develop the Digital Twin model in Building Information Modeling (BIM). This model will be used for simulation and analysis. In this research, we developed two study sites in Dili city, namely Vila Verde-Cathedral zone and

Table 3. Origin – Destination (O/D) matrices of Villa Verde-Cathedral zone.

Morning Peak hour : 07:30 - 8:30												
No	O/D	1	2	3	4	5	6	7	8	9	Total	%
		RUA DE TUANA LARAN	RUA DE CAJÚ LARAN	AVENIDA VILA-VERDE	AVENIDA 20 DE MAIO	AVENIDA D. RICARDO DA SILVA 1	AVE. D. RICARDO DA SILVA 2	BECO DE HERMANINA	RUA DE COLMERA	RUA DE CATEDRA L 2		
1	RUA DE TUANA LARAN		5	75	63	22	175	3	52	226	621	5.3%
2	RUA DE CAJÚ LARAN	5		13	11	4	25	1	9	38	104	0.9%
3	AV. VILA-VERDE	75	13		144	49	485	19	118	516	1418	12.0%
4	AV. 20 DE MAIO	63	11	144		41	395	7	99	435	1194	10.1%
5	AV. D. RICARDO DA SILVA 1	22	4	49	41		108	2	34	149	409	3.5%
6	AV. D. RICARDO DA SILVA 2	142	24	325	274	94		15	224	1600	2696	22.9%
7	BECO DE HERMANINA	3	1	8	7	2	15		5	24	65	0.6%
8	RUA DE COLMERA	52	9	118	99	34	224	5		436	976	8.3%
9	RUA DE CATEDRAL 2	226	38	516	435	149	982	24	355		4285	36.4%

Table 4. Origin-Destination (O/D) matrices of Delta-Elamloi zone.

Origin - Destination(O/D) matrices						
Zone	1	2	3	4	Total	%
1		2152	1169	1025	4346	32.6%
2	2181		1200	1053	4434	33.2%
3	1003	1020		481	2504	18.8%
4	798	812	450		2060	15.4%
Total					13344	

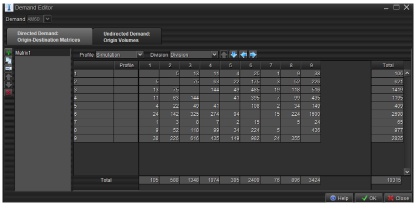


Figure 10. Traffic Demand Editor

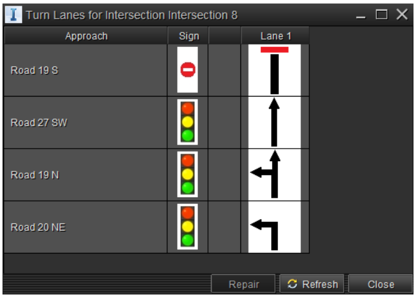


Figure 11. Signalization and Intersection

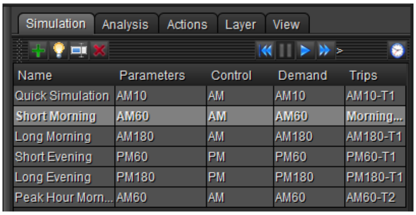


Figure 12. Traffic Simulation panel

Delta-Elemloi zone as depicted in **Figure 8**. In addition, **Figure 9** displays the analytical models designed for traffic simulation in both zones. These models provide a comprehensive overview of the characteristics of each road section, including interconnections and intersections. Clear labels indicating the road name and direction of traffic flow have been provided for easy understanding.

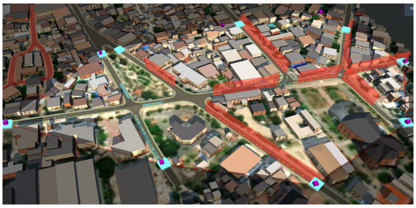
Furthermore, **Tables 3 and 4** contain the Origin-Destination (O/D) matrix which is important for traffic simulation. The O/D matrix represents the distribution of vehicles coming from the source (Origin) and going to the destination (Destination) [10]. To create this matrix, peak hour data is used as specified. For the Villa Verde-Cathedral zone, the morning peak hour of 7:30 a.m. to 8:30 a.m. will be used, while for the Delta-Elemloi zone, the afternoon peak hour of 5:00 p.m. to 6:00 p.m. will be used.

After creating the O/D matrix, the next step is to input the data into the O/D Traffic Demand Editor of the BIM tool, as illustrated in **Figure 10**. After that, we can configure the traffic simulation parameters, including turn lanes for intersections, roundabouts, traffic signs, traffic timing, and traffic lights, as shown in **Figure 11**. Next, we can start the traffic simulation by using the simulation panel as shown in **Figure 12**. During the simulation process, the BIM tool engine will simultaneously analyze the traffic problems such as congestion, queue length, and gas emissions generated by vehicles. Once the analysis is complete, we can check the output data and assess the traffic issues based on the real-time data collected on the field.

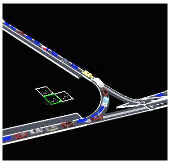
4. SIMULATION AND ANALYSIS RESULT

4.1. Result of Villa Verde – Cathedral zone

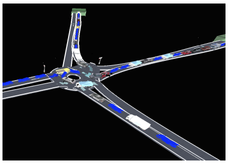
After we simulated and analyzed the morning peak hour traffic using Digital Twin-BIM from 7:30 a.m. to 8:30 a.m., the results for the Villa Verde-Cathedral zone are presented in **Figure 13 and Table 5**. The findings show that seven out of ten road sections in Villa Verde-Cathedral are congested, and only three road sections have smooth traffic flow. On the congested sections, the delay time exceeds the set threshold, resulting in long queues. The root causes of this traffic congestion can be attributed to the high volume of traffic passing through the area, the lack of adequate transportation facilities, and the lack of traffic management. As a result, the Villa Verde-Cathedral zone grapples with severe traffic problems that have far-reaching consequences, including disruption to economic activities, increased traffic accidents, and adverse environmental impacts.



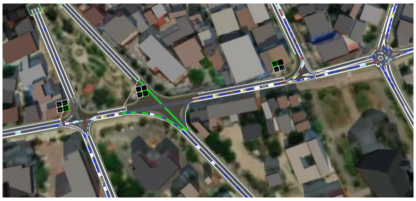
(a) Vila Verde -Cathedral zone



(b) Roundabouts in front of Dili Cathedral.



(c) Intersection between Av. 20 de Maio and Rua de Cathedral.



(d) Traffic Simulation and issues occurrence

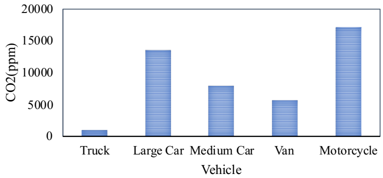
Figure 13. Result of traffic simulation

Table 5. Traffic Simulation and analysis result

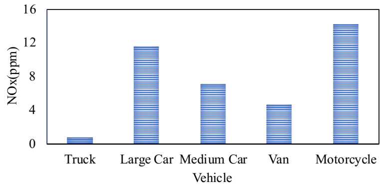
Traffic Sources	Average Delay (second)	Queue(m)	Delay Theshold	Result	
AV. Villa Verde	74	95.7	55	Yes	Congested
Rua de Caju Laran	108	90.5	55	Yes	Congested
Rua de Tuana Laran	182	111.1	55	Yes	Congested
Av. 20 de maio	197	120	55	Yes	Congested
Rua de Cathedral	82	95	55	Yes	Congested
Av. D. Ricardo da Silva.	81	100	55	Yes	Congested
Av. D. Ricardo da Silva.	168	168	55	Yes	Congested
Beco Hermanina	21	61	55	No	Not Congested
Rua de Colmera	46	100	55	No	Not Congested
Rua de Cathedral	20	86	55	No	Not Congested

Table 6. Impact of traffic congestion on environment of Villa Verde- Cathedral zone.

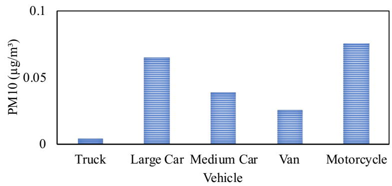
No	Car Type	Distance(kM)	CO2(ppm)	NOx(ppm)	PM10(µg/m³)
1	Truck	2.462	1063.919	0.773218	0.004355
2	Large Car	37.843	13476.943	11.603178	0.06461
3	Medium Car	23.4	7897.661	7.122403	0.038934
4	Van	15.287	5622.621	4.702144	0.025696
5	Motorcycle	46.375	17057.764	14.263163	0.075804
Total		125.367	45118.908	38.464106	0.209399



(a) Cabon dioxide (CO_2)



(b) Nitrogen Oxide (NOx)



(c) PM10

Figure 14. *Impact of traffic congestion on the Environment of Villa Verde-Cathedral zone.*

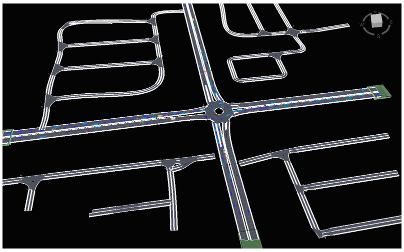
4.2. Impact of traffic congestion on the Environment at Villa Verde-Cathedral zone.

Once the simulation and analysis in BIM are completed, we can assess the environmental impact of traffic congestion, focusing on air pollutants such as carbon dioxide (CO2), nitrogen oxides (NOx), and particulate matter 10 micrometers or less in diameter (PM10), as shown in **Table 6** and **Figure 14**. The results show that motorcycles emit much higher levels of exhaust emissions into the air compared to other types of vehicles. This is because motorcycles are the dominant mode of transportation in the city of Dili. Therefore, it is important to develop a motorcycle lane in the future to reduce traffic congestion and gas emissions. Because these emissions can affect public health and contribute to climate change.

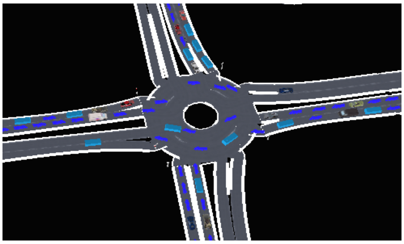
4.3. Result of Delta-Elemloi zone

Figure 15 and **Table 7** show the results of the evening peak hour traffic simulation and analysis using Digital Twin BIM from 17:00 to 18:00 for the Delta-Elemloi zone. These results show that four road segments in the Delta-Elemloi zone are congested. The delay time exceeds the threshold value, resulting in long queues in the congested sections.

The high volume of traffic passing through the area and the lack of adequate transportation facilities and traffic management are the main causes of this congestion. The implementation of effective traffic management systems, the improvement of road infrastructure, including pedestrian and bicycle paths, and the expansion of parking facilities are essential to address the problems in the Delta-Elemloi zone.



(a) Traffic simulation at Delta-Elemloi zone.



(a) Traffic movement at the roundabout.

(b) Traffic simulation and issues occurrence

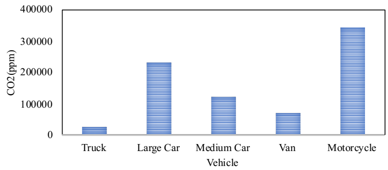
Figure 15. Result of traffic simulation of Delta-Elemloi zone.

Table 7. Traffic Simulation and Analysis Result of Delta-Elemloi zone.

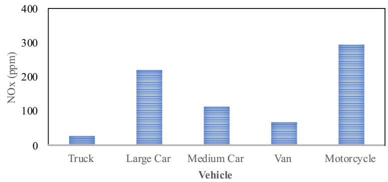
Traffic Sources	Average Delay (second)	Queue(m)	Delay Theshold (second)	Obvervation	Status
Rua Ponte- Rotunda	154	240.2	55	Yes	Congested
Rua Aimutin-Rotunda	150	196.8	55	Yes	Congested
Rua Plaza-Rotunda	166	140.5	55	Yes	Congested
Rua Manleu-Rotunda	198	199	55	Yes	Congested

Table 8. Result of traffic simulation

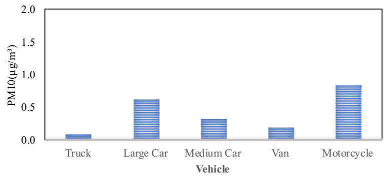
No	Car Type	Distance(kM)	CO2(ppm)	NOx(ppm)	PM10(µg/m³)
1	Truck	82.88	26326.67	27.61	0.08
2	Large Car	668.46	231310.48	221.13	0.62
3	Medium Car	342.57	121654.33	112.63	0.32
4	Van	207.80	70221.75	68.89	0.19
5	Motorcycle	905.45	344448.06	294.67	0.84
Total		2207.15	793961.29	724.93	2.05



(a) Carbon dioxide (CO_2)



(b) Nitrogen Oxide (NOx)



(c) MP10

Figure 16. *Impact of traffic congestion on the Environment of Delta-Elemloi zone*

4.4. Impact of traffic congestion on the Environment of Delta-Elemloi zone.

The assessment of the environmental impact of traffic congestion can be effectively evaluated through simulation and analysis within a digital twin BIM framework, as shown in **Table 8** and illustrated in **Figure 16**. The results show that vehicle emissions of gases such as CO2, NOx, and PM10 have increased as a result of congestion and delays. In particular, motorcycles are the main source of these emissions. This is due to their higher usage compared to other vehicle types. Therefore, it is crucial to prioritize the provision of infrastructure for motorcycles in the future in order to mitigate the impact on the environment. These emissions can have adverse effects on public health and be a contributor to climate change. Therefore, it is imperative to implement an evidence-based traffic management system in Dili City, firmly grounded in Evidence-Based Policy Making (EBPM).

5. DISCUSSIONS

Results of the case study "Enhancing Traffic Management through Digital Twin-BIM in Dili City Timor-Leste" can be discussed:

(a) The use of Building Information Modeling (BIM) to create a Digital Twin (DT) can accurately replicate the traffic infrastructure of Dili City, with a particular focus on the Vila Verde-Cathedral zone and the Delta-Elemloi zone. This replica will serve as a basis for conducting traffic simulations and analysis and will allow for the identification of traffic-related problems.

(b) The use of real-time data for traffic simulation and analysis within a digital twin BIM framework can provide substantial evidence for evidence-based policy making (EBPM) in traffic management systems.

(c) The results of the traffic simulation and analysis conducted within the Digital Twin-BIM framework for the two specified zones are the following. In the Vila Verde-Cathedral zone, out of the 10 road segments, seven experienced congestions, while the remaining three remained uncongested. Conversely, in the Delta-Elemloi zone, all road segments were affected by congestion.

(d) Traffic congestion leads to the release of harmful gas emissions such as CO_2, NOx, and PM10 into the atmosphere, posing significant risks to public health and contributing to climate change. Among these gas emissions, the number of motorcycles is a major contributor. For Timor-Leste, motorbikes are the primary means of transportation for many people. Therefore, in order to reduce traffic congestion and mitigate the environmental impacts associated with increased motorcycle use, it is critical to consider the development of dedicated motorcycle lanes in future planning.

6. CONCLUSION

The case study "Improving Traffic Management through Digital Twin-BIM in Dili City, Timor-Leste" highlights the significant potential of integrating Digital Twin (DT) with Building Information Modeling (BIM) technology to revolutionize traffic management practices while addressing environmental concerns and promoting evidence-based policy making (EBPM), as summarized below:

1. Advances in traffic management: The implementation of Digital Twin BIM in Dili City has shown great progress in traffic management. By creating a virtual replica of the city's transportation infrastructure, authorities can monitor traffic flow in real-time, identify congestion points, and optimize traffic signal timing more effectively. This has resulted in reduced traffic congestion, shorter travel times, and improved overall traffic safety.

2. Digital Twin-BIM Synergy: The synergy between Digital Twin and BIM provides an invaluable tool for urban planners and traffic management authorities. BIM models serve as the basis for developing an accurate Digital Twin, ensuring that real-world and simulated data are closely aligned. This integration enables better decision-making and more efficient resource allocation for traffic management projects.

3. Evidence-Based Policy Making (EBPM): The use of Digital Twin BIM supports Evidence-Based Policy Making (EBPM) by providing data-driven information on traffic patterns, accident locations, and infrastructure performance. Decision-makers can rely on this comprehensive information to formulate and implement effective policies that meet the specific needs of Dili City.

4. Environmental Impact Mitigation: One of the most important aspects of this case study is the environmental benefits. By optimizing traffic flow and reducing congestion, the city can expect significant reductions in CO2, NOx, and PM10 emissions. This not only contributes to cleaner air quality but is also in line with global efforts to combat climate change.

In summary, the use of Digital Twin BIM technology in traffic management in Dili City, Timor-Leste, is an example of a progressive approach to urban development. Technology leverages data-driven decision-making, improves traffic efficiency, and plays an important role in reducing environmental impact.

AUTHORS' CONTRIBUTIONS

ELFRIDO ELIAS TITA. IN THIS PAPER THE AUTHOR CONTRIBUTED TO CONCEPTUALIZATION, METHODOLOGY, ANALYSIS, DATA CURATION, RESULTS, AND PAPER WRITING.

HUMBELINA M.S. VIEGAS. THE AUTHOR MAINLY CONTRIBUTED TO CONCEPTUALIZATION AND DATA COLLECTION IN THE FIELD.

GAKUHO WATANABE. THE AUTHOR CONTRIBUTED TO CONCEPTUALIZATION, METHODOLOGY, ANALYSIS, RESULT, PAPER WRITING AND SUPERVISING THE RESEARCH PROCESS.

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