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Modelling Heterogeneous Traffic Performance During Non-Recurrent Congestion (NRC): A Case Study of Tugu Bundaran Sweta Intersection

Ahmad Muharror[1], Wardati Hashim[2]*, Noor Azreena Kamaluddin[2], Nor Izzah Zainuddin[2], Nur Ilya Farhana Md Noh[2] and Ekarizan Shaffie[3]

[1]*Transport Agency of West Nusa Tenggara, Mataram, 83125, Indonesia*
[2]*School of Civil Engineering, College of Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia*
[3]*Institute for Infrastructure Engineering and Sustainable Management, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia*

ABSTRACT

This research delves into the intricate dynamics of traffic performance during non-recurrent congestion (NRC), specifically focusing on the Lebaran Topat festival in Lombok. Utilising sophisticated transport modelling software, namely PTV Vissim, the study systematically models real-world traffic scenarios and calibrates and validates the simulation model's accuracy. The calibration of driver behaviour parameters, guided by the Wiedemann 74 model, is pivotal in comprehending nuanced vehicle interactions. Data collected from field observation was analysed in preparation for the calibration process, which employed maximum queue length as the parameter and an innovative trial and error method for optimisation. Specific values were assigned for each vehicle type during this calibration, exemplified by an average standstill distance. The validation of the NRC traffic performance model using the chi-square test stands as a testament to its reliability, boasting a chi-square value of 0.12, lower than the critical value of 0.18, at a significance level of 98%. Field assessment shows that during Lebaran Topat, the Level of Service (LOS) for signalised intersections based on the field maximum queue length is F, improved to D after simulated through PTV Vissim.

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E-mail addresses:
ahmadmuharror1@gmail.com (Ahmad Muharror)
wardati@uitm.edu.my (Wardati Hashim)
azreena@uitm.edu.my (Noor Azreena Kamaluddin)
norizzah@uitm.edu.my (Nor Izzah Zainuddin)
nurilya@uitm.edu.my (Nur Ilya Farhana Md Noh)
eka@uitm.edu.my (Ekarizan Shaffie)
* Corresponding author

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INTRODUCTION

Non-Recurrent Congestion (NRC) presents a significant challenge in transportation research, characterised by abrupt and unforeseeable traffic disruptions triggered by various factors like holidays, festivals,

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or accidents. These disruptions escalate traffic volume, posing considerable challenges to traffic performance. An illustrative example is evident during the Lebaran Topat celebration in Lombok, West Nusa Tenggara (NTB), Indonesia, a week after Eid al-Fitr. During this time, a substantial influx of visitors flocked to regional tourist destinations, notably increasing traffic volume (Rianti et al., 2018). Additionally, individuals from middle to low-income groups, predominantly engaged in manual occupations such as farming, labour, and fishing, use this opportunity to visit beaches, parks, and other recreational areas. Due to their affordability and versatility, pick-up vehicles become the primary mode of transportation during this period, further contributing to the heterogeneous traffic composition.

This highlights the need to comprehensively understand traffic behaviour and performance during NRC. Addressing the complexities of NRC requires accurate simulation and modelling of traffic conditions. Advanced traffic simulation tools like PTV Vissim are crucial in achieving this. PTV Vissim offers a robust platform to replicate real-world traffic scenarios by simulating heterogeneous vehicle interactions and assessing traffic performance under varying conditions. Hence, PTV Vissim is hypothetically expected to be able to simulate NRC's traffic performance.

This study focuses on understanding traffic behaviour during NRC through rigorous model calibration in PTV Vissim. Previous studies emphasise the importance of accurate calibration in traffic simulation models to reflect realistic traffic conditions. Building upon this foundation, questions arise about how traffic performance during NRC can be calibrated and validated using the PTV Visim. By calibrating driver behaviour parameters for diverse vehicle types, including pick-ups, motorcycles, and heavy vehicles, this research aims to provide insights into traffic performance during the Lebaran Topat festival and serve as a foundation for formulating effective traffic management strategies with the main objective to develop a reliable and validated traffic simulation model.

The influx of visitors and heightened traffic volume during the festive celebration of Lebaran Topat in Lombok precipitates NRC, exerting profound impacts on traffic performance and causing diverse traffic disruptions. Modelling this heterogeneous traffic and evaluating its performance during NRC is crucial for understanding the challenges of such events and formulating effective traffic management strategies. Previous studies underscore the significance of addressing NRC and advocate for research focusing on traffic performance in this context. This research endeavours to contribute to this area by employing the software PTV Vissim to model and analyse heterogeneous traffic performance during NRC to enhance traffic management during similar events.

BACKGROUND OF RESEARCH

NRC Analysis

A study by Boonserm and Wiwatwattana (2021) examined road traffic crashes during New Year festivals in Thailand. The findings revealed a significant increase in crash rates during the festive period. The congestion and higher vehicle volumes led to an elevated risk of collisions and reduced overall traffic safety.

Furthermore, a study by Lin and Yan (2011) investigated the impact of major events on traffic performance. The results showed a substantial decrease in intersection capacity and increased queue lengths and delays. These findings emphasised the adverse effects of non-recurrent congestion during the festive season, highlighting the need for effective traffic management strategies.

Another study by Isa et al. (2018) reviewed the impact of non-recurrent traffic congestion on traffic flow and traffic density. The study revealed a significant decrease in traffic performance and proposed several approaches to handle NRC. One of the findings underscored that adjusting the traffic signal time could mitigate drivers' challenges.

This study would like to evaluate how Lebaran Topat compares to other festive celebrations in terms of traffic performance. It would provide insights into Lebaran Topat's unique characteristics and identify specific challenges that need to be addressed.

Makarova et al. (2020) found that simulation modelling emerges as the most effective means of exploring and discovering the optimal solutions within the domain of traffic safety. By creating virtual representations of real-world traffic scenarios, simulation modelling empowers transportation professionals and researchers to delve into various factors and variables under controlled conditions. This approach allows for a comprehensive understanding of the intricate dynamics within traffic systems, enabling the assessment of different safety measures and identifying the most efficient strategies to enhance overall traffic safety. With the ability to replicate real-world scenarios, modify variables, and analyse complex interactions, simulation modelling provides a safe, cost-effective, and versatile platform to test and refine safety interventions, ultimately paving the way for improved traffic safety outcomes.

In the PTV Vissim manual, three essential parameters are introduced for fine-tuning driver behaviour within the context of the Wiedemann 74 car-following model. These parameters play a pivotal role in shaping the dynamics of vehicle interactions and influencing the distances between vehicles during traffic simulations. The key parameters include the Average Standstill Distance (referred to as w74ax), the Additive Part of Safety Distance (w74bxAdd), and the Multiplicative Part of Safety Distance (w74bxMult).

Calibration Practice

Researchers employ diverse parameter calibration criteria to tailor Vissim models to real-world conditions, as shown in Table 1 below:

The selection of parameter calibration in this study is based on the chi-square test, reflecting a statistical approach to parameter determination. The optimisation procedure involves trial and error, systematically exploring parameter values. The chosen Measure

Table 1
Calibration methods from researchers

Source	Selection of parameter calibration	Optimisation procedure	MOE of Calibration
Zhou & Huang (2013)	MAPE	Trial and error	Traffic conflict
Manjunatha et al. (2013)	2-way Annova	Genetic algorithm	Delay
Siddharth & Ramadurai (2013)	Annova	Genetic algorithm	Flow
Mehar et al. (2014)	Literature review, 2-way Annova	Trial and error	Capacity
Prabhu & Sarkar (2016)	2-way Annova	Manual adjustment	Vehicle flow, pedestrian flow
Salgado et al. (2016)	Coefficient of determination (R^2)	Manual adjustment	Turning movement
Karakikes et al. (2017)	GEH	Genetic algorithm	Travel time
Yu & Fan (2017)	GRE, PMAE, PMRE	Genetic algorithm, Tabu Search	Flow
Gallelli et al. (2019)	RMSE	Genetic algorithm	Speed
Bhattacharyya et al. (2020)	Kolmogorov– Smirnov test (K–S test) Smirnov test (K–S	Genetic algorithm	Travel time
Arafat et al. (2020)	Kolmogorov– test), Shapiro-Wilk test	Non-inbuilt attribute	Saturation headway, saturation flow
Maheshwary et al. (2020)	One-way Annova	Genetic algorithm	Vehicle class
Preston & Pulugurtha (2021)	Ensure a minimum error (≤15%)	Trial and error	Speed
Mistry et al. (2022)	MAPE	Manual adjustment	Traffic volume, Travel time
Jehad et al. (2022)	MAPE	Paired t-test	Traffic flow
Severino et al. (2022)	GEH	Trial and error	Traffic flow
Kvašňovská et al. (2023)	Deviation percentage	Trial and error	Average travel time
This Study	Chi Square Test	Trial and error	Max queue length

of Effectiveness (MOE) for calibration is the maximum queue length, underscoring the significance of accurately representing and managing queue lengths in Vissim simulations. This unique combination of parameter selection, optimisation, and MOE contributes to a comprehensive understanding of the calibration process within the Vissim framework. By using the maximum queue length as an MOE, this study ensures that evaluating traffic performance is both practical and meaningful, particularly in the context of non-recurrent congestion, while also contributing to an underexplored area of traffic research.

METHODS

Research Framework

The research framework shown in Figure 1 involves inserting primary and secondary traffic data into PTV Vissim to develop a traffic model. The model is initially built using default Wiedemann 74 parameters and then validated against real-world data. If the model does not adequately represent the observed traffic conditions, calibration of the Wiedemann 74 parameters is conducted to improve its accuracy.

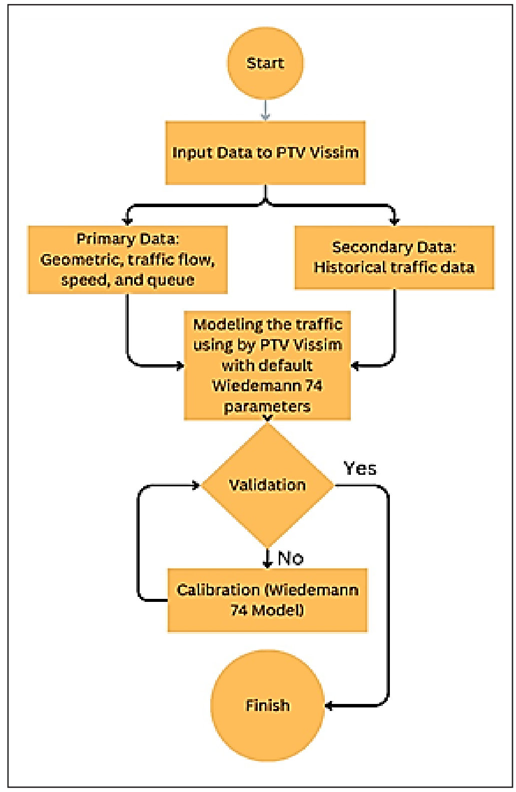

Figure 1. Research methodology framework

Data Collection

Data collection techniques in transportation studies involve primary and secondary methods. Primary data collection encompasses classified traffic counting surveys, turning movement counting surveys, spot speed surveys, and queue length surveys.

(i) Traffic Counting Survey: This survey collects data on the number of vehicles passing through a particular location over a specified period. It helps understand traffic volumes, identify peak periods, and evaluate the overall traffic flow.

(ii) Classified Turning Movement Counting Survey: Focused on analysing specific movements of vehicles at intersections. It involves identifying and classifying different turning movements, such as right turns, left turns, and through movements, to assess the traffic distribution and demand at the intersection approaches.

(iii) Spot Speed Survey: This survey aims to determine the speed of vehicles at specific locations on a roadway network.

(iv) Queue Length Survey: This survey involves measuring the length of queues or lines of vehicles at specific locations, such as signalised intersections or toll plazas. It helps in understanding congestion levels, assessing the performance of traffic control measures, and identifying areas where queue lengths exceed acceptable limits.

Secondary data collection methods include literature reviews to gather relevant information on traffic performance evaluation during festive periods and obtaining historical traffic data from relevant authorities, which supplements primary data to enrich analysis and decision-making processes in transportation planning and management.

Sampling Procedures

The sampling procedure involves purposefully selecting the signalised intersection in Lombok and the link representing Non-Recurrent Congestions (NRC). This targeted selection allows us to obtain primary data from areas most likely to experience traffic congestion challenges during Lebaran Topat while also considering secondary data sources that provide historical context.

Location Selection and Considerations

The chosen signalised intersection, as shown in Figure 2, was strategically selected to align with the research objectives, considering factors such as traffic volume, its location at a primary junction with mixed land use, including shopping centres, residential areas, and office buildings, and its role in connecting the districts of West Lombok, Central Lombok, and East Lombok to the city of Mataram. This makes it a highly strategic point for community travel, especially during the Lebaran Topat festivities, as it links several areas with popular tourist attractions in Lombok. Additionally, the study focused on this single intersection due to the limited time available for research, enabling a more detailed and focused analysis of traffic behaviour during the event.

Table 2 shows the intersection dimensions, which are the location of this research. Table 3 shows the field survey results regarding traffic volumes at the intersection. As illustrated in Figure 3, the cycle time of this intersection remains consistent on weekdays, weekends, and even during the Lebaran Topat period.

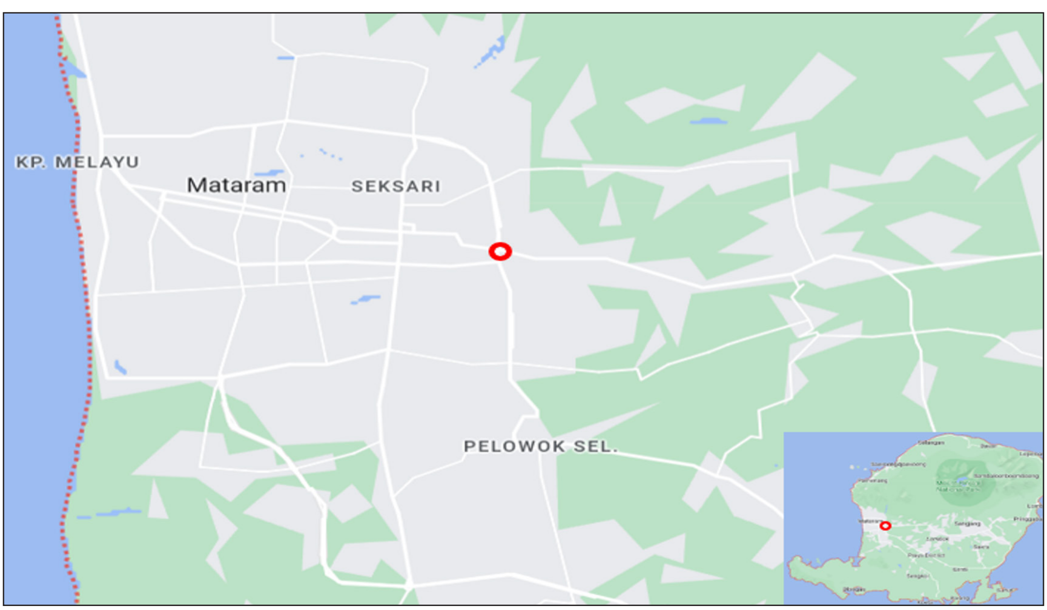

Figure 2. Study location (node)

Table 2
Detail geometry of the intersection

Approach	Type	Lane	Approach width (m)
North	Divided	4	26
East	Undivided	2	22
South	Divided	4	21.4
West	Undivided	4	19

Table 3
Traffic count for each movement

Direction	Motor cycle	Car/ Small Vans	Lorries/Large Vans	Large Lorry	Buses	Pick Up
NORTH						
Left	273	109	15	0	0	29
Straight	454	137	22	0	0	36
Right	183	64	2	0	0	26
SOUTH						
Left	368	66	2	0	0	22
Straight	356	72	23	5	0	24
Right	853	160	20	3	0	57
EAST						
Left	627	232	26	0	4	67
Straight	847	373	23	1	2	127
Right	713	232	30	0	0	74
WEST						
Left	316	100	2	0	0	39
Straight	1172	465	14	0	0	96
Right	614	87	1	0	0	21

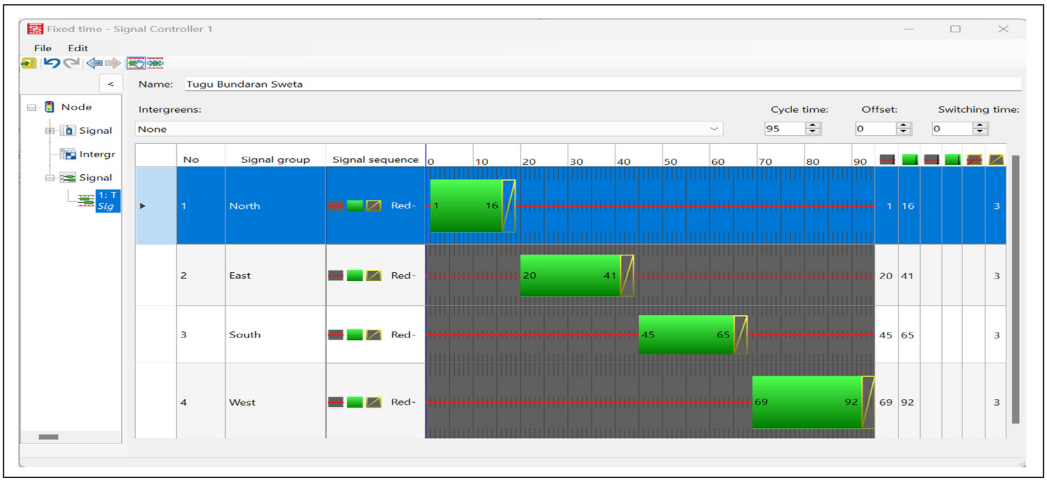

Figure 3. Cycle time of intersection

Data Analysis

Differences in maximum queue length between Vissim output and observed field data during Lebaran Topat are analysed. This ensures that the parameter selection for the modelling process is made accordingly. The datasets are appropriately prepared for analysis, which includes addressing outliers, managing missing data, and confirming data distribution assumptions. Hypothesis testing is conducted to observe any significant difference between the observed field data and the Vissim output. A chi-square test is necessary to assess the statistical significance of the difference in maximum queue length between the two datasets through the p-value obtained.

Modelling and Validation

The modelling process is done through the calibration of modelling parameters. The calibration includes selecting parameters pivotal in determining how vehicles interact and respond to traffic conditions. Then, an iterative process is conducted, with the default parameter values set based on available literature and standard settings. Subsequently, these parameters are fine-tuned to align the modelled traffic with observed field data. The calibration process is data-driven, relying on a data analysis process.

Model validation is carried out to prove whether the model used follows the field data. The validation model used is the Chi-square test. The decision is accepted (H_0 is born) based on calculations if $\chi^2_{count} < \chi^2_{table}$, where χ^2_{count} is obtained by the Equation 1 below:

$$\sum \chi^2_{count} = \sum \frac{(Q_o - Q_m)^2}{Q_o} \qquad [1]$$

Where: Q_o: max queue length (observed); Q_m: max queue length (model)

Employing the appropriate statistical method, such as the chi-square test, the difference in maximum queue length between Vissim output and observed field data during Lebaran Topat is rigorously evaluated.

RESULTS AND DISCUSSION

Calibration of NRC Traffic Model

We utilize data collected during the Lebaran Topat festival to investigate the calibration process in detail. The analysis includes adjustments to driver behaviour parameters within the PTV Vissim simulation model, which guarantees the model's accuracy in replicating real-world traffic conditions.

Bhattacharyya et al. (2020) and Severino et al. (2022) have calibrated models in urban contexts using approaches divergent from the Vissim manual yet successfully yielded statistically validated models. Similarly, Mistry et al. (2022) and Preston and Pulugurtha

(2021) found that calibrating Wiedemann 74 parameters produced Vissim outputs consistent with field conditions, enabling them to propose improved traffic management strategies.

These studies further support the planned adjustment of Wiedemann 74 parameters in this research. Despite variations in approaches and parameters utilised, these investigations collectively underscore the efficacy of calibrating driver behaviour parameters in the car-following model, particularly through applying Wiedemann 74 parameters, in producing accurate and reliable Vissim models reflective of real-world traffic conditions. Thus, the proposed parameter re-adjustment aligns to enhance the accuracy and validity of Vissim traffic simulation models.

Table 4 shows the default parameters of Wiedemann 74 in PTV Vissim before undergoing calibration. The parameters employed for calibrating PTV Vissim encompass the "max queue length," Table 5 delineates the outcomes of field measurements for this length.

After conducting the initial run using the Wiedemann 74 parameter values under default conditions specified in Table 6, the maximum queue length generated by PTV Vissim is compared with the field measurement results.

The substantial disparities between the measured field data and the PTV Vissim outputs, as evident in the maximum queue lengths at the intersection in Table 5 and Table 6, underscore the necessity for calibrating the driver behaviour parameters, specifically those related to the car following model. The divergence in these results suggests that the existing parameterisation may not accurately capture the intricacies of real-world traffic conditions. A meticulous calibration process is imperative to align the PTV Vissim outputs with the observed field measurements. This calibration will involve refining the driver behaviour parameters, ensuring that the simulated outcomes closely mirror the on-site conditions.

The Wiedemann 74 parameters were calibrated using a systematic trial-and-error approach from the first to the 28th iteration

Table 4
Default parameters for Wiedemann 74

VehClass	W74ax	W74bxAdd	W74bxMult
Car	2	2	3
HGV	2	2	3
Bus	2	2	3
MC	2	2	3
Pick Up	2	2	3
Lorries	2	2	3

Table 5
Observed maximum queue length during Lebaran Topat

Approach	Queue length max, Q (meter)
North	60.4
East	215.5
South	184.5
West	242.0

Table 6
Maximum queue length from PTV Vissim using default parameters

Approach	Queue length max, Q (meter)
North	214.7
East	219.0
South	269.4
West	246.0

to achieve an appropriate level of validity. The process involved incrementally adjusting key parameters, and at each iteration, the model's output from PTV Vissim was scrutinised for its alignment with observed field data. The calibration details, including parameter adjustments and corresponding model outputs at each iteration, are documented in Tables 7 and 8.

Table 7
28th iteration of adjusting Wiedemann 74 parameters

Vehicle type	W74ax	W74bxAdd	W74bxMult
Car	0.8	1	1.2
HGV	1.5	1.5	1.6
Bus	1.4	1.4	1.7
M	0.2	0.5	1.2
Pick Up	0.8	0.8	1
Lorries	1	0.9	1.2

Table 8
Maximum queue length comparison between existing conditions vs PTV Vissim output from 1st iteration to 28th iteration

Existing condition	Iteration 1	Iteration 2	Iteration 27	Iteration 28
60.4	156.4	203.4	63.2	59.5
215.5	218.1	218.9	218.1	218.0
184.5	242.0	268.6	199.3	183.3
242.0	246.1	246.1	246.1	246.0
$\sum \chi^2_{count}$	170.50	377.18	1.42	0.12

The parameter values at the 28th iteration (final) in Table 8 have exhibited disparities compared to the suggested range provided in both the VDOT Vissim Manual (2020) and the Vissim User Manual (2023). This finding aligns with previous research conducted by Bhattacharyya et al. (2020) and Severino et al. (2022), who calibrated models in urban contexts using approaches divergent from the Vissim manual yet successfully yielded statistically validated models. Specifically, in the case of Lebaran Topat, the utilised parameters have values smaller than the recommended ranges outlined in both manuals. This discrepancy indicates that the calibrated parameters, particularly during the festive period of Lebaran Topat, deviate from the default settings recommended by the Vissim manuals. The reduction in parameter values suggests nuanced variations in vehicle behaviour and traffic dynamics during Lebaran Topat, underscoring the importance of meticulous calibration to capture the unique characteristics of real-world scenarios within the simulation framework.

Validation of the NRC Traffic Model

Validation is made by comparing simulated outputs and observed field data using chi-square analysis. This validation process aims to establish the model's predictive accuracy and robustness through a systematic comparison between simulated outputs and observed field data. Table 9 compares the field and simulated data with a chi-square value of 0.12, whereas the critical chi-square value (χ^2) for a significance level of 98% is 0.18. This indicates that the model used aligns with a validity level of 98%, as the obtained chi-square value falls below the critical value. The model's performance is deemed consistent with the observed data, affirming its reliability and suitability for the specified level of significance.

Table 9
Comparison between observed field data and PTV Vissim output after calibration

Approach	Q_o(m)	Q_m(m)	$\frac{(Q_o - Q_m)^2}{Q_o}$
North	60.4	59.5	0.013104
East	215.5	218.0	0.028858
South	184.5	183.3	0.00828
West	242.0	246.0	0.067391
$\sum \frac{(Q_o - Q_m)^2}{Q_o}$			0.117633

Contrastingly, other researchers, such as Jehad et al. (2022), found in their study that the validity of their Vissim model, assessed through MAPE and paired t-test analysis, demonstrated no significant differences at a validity level of 98.5%. This indicates a robust alignment between their model and the observed data, albeit using different validation metrics. Similarly, Maheshwary et al. (2020) explored the use of genetic algorithms to optimise driving behaviour parameters for different vehicle classes, achieving a validity level of 95%. Their findings highlight the importance of tailored parameter optimisation for improving model accuracy. Additionally, Karakikes (2017) reported on their model's systematic calibration and validation, which encompassed a vast network of links, nodes, and origin-destination pairs. Their approach yielded highly satisfactory results, with a validation level of 96.5%, underscoring the effectiveness of comprehensive calibration techniques.

NRC Traffic Model at Field Assessment

Evaluation of traffic performance is a critical aspect of transportation management and urban planning. Therefore, we investigate assessing traffic conditions at Tugu Bundaran Sweta, a pivotal junction in the study area. The selection of these two approaches is based on considerations of the smallest volume from the approaches and the presence of a central intersection protector in the form of a monument that separates vehicle flows from the north approach to the west approach and the south approach to the east approach.

Understanding the intricacies of traffic flow and congestion at this location is paramount for devising effective strategies to alleviate congestion, enhance safety, and optimise traffic operations. Table 10 shows that the Level of Service (LOS) value during the occurrence of

Lebaran Topat is rated as F. This underscores the critical need for management intervention and subsequent actions.

Table 11 shows the node performance results after running the model using PTV Vissim. The results show a reduction in maximum queue length and delays in every approach, thereby improving the overall LOS to become D by using the average of all delays for all approaches.

Previous studies analysing the performance of signalised intersections, such as those by Sofia et al. (2018), Jiang and Wang (2019), Wu et al. (2015), and Maripini et al. (2022), which adjusted cycle times, reported improved LOS after optimising signal timings. Sofia et al. (2018) coordinated signal cycles at multiple intersections in Karbala using Synchro and Sidra. Jiang and Wang (2019) adjusted inter-green times using a Monte-Carlo simulation approach. Wu et al. (2015) optimised cycle lengths at three signalised intersections in urban areas in China, Maripini et al. (2022) implemented a traffic-responsive signal control system that adjusts signal timings according to traffic volume fluctuations.

Table 10
Node performance during Lebaran Topat

Approach	Queue length max (m)	Delay (s)	Level of Service
North	60,4	61,57	E
East	215,5	123,09	F
South	184,5	118,45	F
West	242,0	138,01	F

Table 11
Node performance during Lebaran Topat after running PTV Vissim

Approach	Queue length max, Q (m)	Delay (s)	Level of Service
North	33.97	23.02	C
East	139.23	60.6	E
South	51.6	29.75	C
West	178.7	79.27	E

CONCLUSION

The modelling of NRC traffic performance through PTV Vissim calibration is integral to ensuring the accuracy and realism of simulation models. Parameters such as average standstill distance, the additive part of safety distance, and the multiplicative part of safety distance, following the Wiedemann 74 standards, were meticulously adjusted to account for the unique characteristics of different vehicle types, with values like 0.8 for Cars, 1.5 for HGVs, and 1.4 for Buses and despite variations from suggested ranges in manuals, particularly evident during Lebaran Topat, the trial-and-error method, supported by the chi-square test, proved effective in optimising these parameters, underscoring their direct influence on vehicle behaviour within the simulated environment.

The validation assessed the NRC simulation model's accuracy in predicting traffic performance, focusing on maximum queue length at critical signalised junctions. Statistical analysis, utilising a chi-square test with a 98% significance level, showed high validity, with a chi-square value of 0.12, which is lower than the critical value of 0.18, and a p-value of 0.02, indicating no significant difference between Vissim output and observed field data. This robust validation enhances the credibility of simulation outcomes. It underscores the model's capability to inform traffic management strategies, which are crucial during non-recurrent congestions like cultural festivals such as Lebaran Topat.

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