Jurnal Teknologi Transportasi dan Logistik Volume 4 No 2, Desember 2023
p-ISSN 2716-2990; e-ISSN 2745-8954

ANALYSIS OF TOLL PAYMENT BASED ON SINGLE LANE FREE FLOW AT THE NGURAH RAI TOLL GATE IN REALIZING TRANSPORT SUSTAINABILITY

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ABSTRACT
Toll roads provide an alternative route to public roads, expediting travel through a network that requires fee payments. Recently, Asia introduced a radio toll payment system to alleviate congestion at toll gates. A more efficient toll payment system is needed. RFID stickers emerge as a cost-effective alternative. Their use is simple—affix them to the vehicle's front for scanning by RFID readers at SLFF toll gates. SLFF utilizes RFID for toll payments, aiming to embody sustainable transport implementation. The research method employed is quantitative, with field survey data collection. Findings reveal that Gate 3 stands out with a brief service time (0.6 seconds), lower fuel costs (366,171 Rupiah), and lower emission levels (CO gas 124%, HC gas 39094.7 ppm) compared to Gate 2. Gate 3's efficiency creates a superior user experience and potential significant fuel cost savings, making it a more efficient and sustainable choice for implementing the Single Lane Free Flow (SLFF) toll payment system.

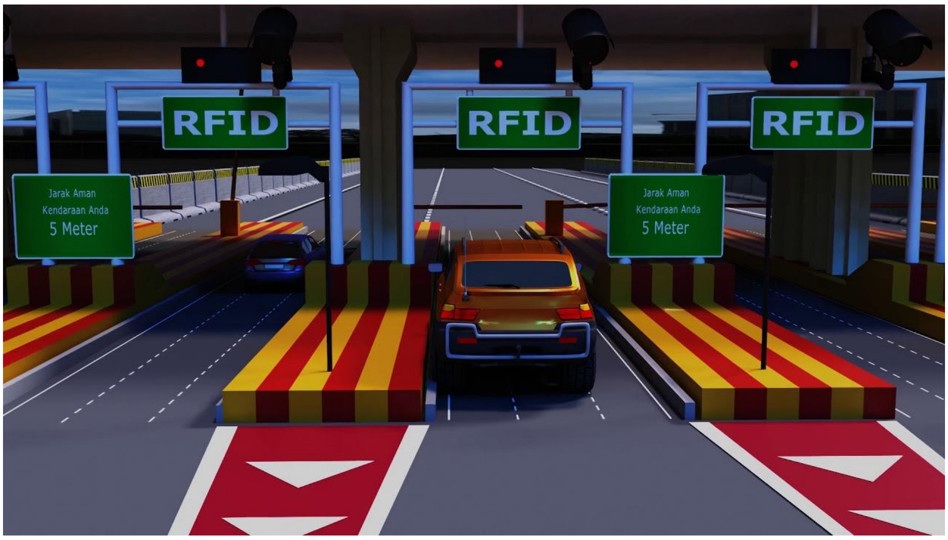
Keywords: radio frequency identification; single lane free flow; sustainable transport; tapping card

INTRODUCTION
Rapid economic growth and urbanization in the current era of globalization have significantly changed community mobility patterns (Crainic & Laporte, 2016). Along with rapid economic development, there is an increase in demand for efficient and fast mobility. This is inseparable from the push for urbanization which leads to urban growth and an increase in population in urban areas (Das et al., 2019). This phenomenon, part of the dynamics of globalization, creates new challenges in adequate transportation management to meet the increasing mobility needs of society. One aspect that reflects the impact of economic growth and urbanization is the increased use of transportation infrastructure, including toll systems (Demir et al., 2019; Donovan & Donovan, 2019). As an integral part of the transportation network, the toll system is becoming increasingly important in supporting inter-regional connectivity and facilitating the flow of goods and services. Increasing traffic density in line with economic growth can result in detrimental traffic jams, increase air pollution levels, and worsen the quality of life for urban communities (Yusianto et al., 2021).

Currently the problem is due to the queue at the toll gate, even though currently UNIK (electronic money) is used by tapping the card, it still requires an average card tapping time in conditions without human error, namely 7.6 seconds, so this makes there are delays and queues of vehicle users entering the toll road. The problem of congestion that occurs at toll gates due to queues using the tap system has a significant impact in three main aspects: social, economic and environmental. From a social perspective, congestion at toll gates can result in increased stress and discomfort for road users, especially in heavy traffic situations (Papageorgiou et al., 2021). Long queues can increase travel time and cause frustration, reducing the quality of daily life for people who have to pass through the toll gate (Muneera & Krishnamurthy, 2020). The economic impact associated with queuing involves loss of time and costs for road users and economic actors who depend on the distribution of goods and services. Congestion can also be detrimental to local and national economic sectors because it hampers logistics and trade flows

(Wang et al., 2019). From an environmental perspective, long queues at toll gates can increase levels of greenhouse gas emissions and air pollution because vehicles are stuck in inefficient traffic conditions. Therefore, solutions to overcome queuing problems at toll gates need to consider this multidimensional impact in order to achieve equitable and sustainable transportation.

The implementation of a Single Lane Free Flow (SLFF) based toll payment system at the Ngurah Rai Toll Gate is a significant innovation in efforts to realize transport sustainability. This system promises to increase efficiency and convenience in toll payments, which in turn can have a positive impact in three main dimensions: social, economic and environmental. The use of SLFF (Single Lane Free Flow) provides improvements in terms of queues, delays, fuel savings and pollutant reduction (Makridis et al., 2020). Not only that, the use of SLFF at the Ngurah Rai Toll Gate can reduce waiting time at the toll gate, increase mobility, and reduce discomfort for road users, especially for those who use private transportation. This can speed up the distribution of basic needs and reduce accessibility gaps between regions



Therefore, this research aims to conduct a comprehensive analysis of the implementation of the SLFF-based toll payment system at the Ngurah Rai Toll Gate as one of the toll gates in Indonesia that has started implementing SLFF. By delving deeper into social, economic and environmental aspects, it is hoped that this research can provide a better understanding of the impacts and potential solutions that can realize transport sustainability at the local level.

METHOD

This research will use qualitative and quantitative approaches to gain a comprehensive understanding of the implementation of the Single Lane Free Flow (SLFF) based toll payment system at the Ngurah Rai Toll Gate in the context of realizing transport sustainability. The research location will focus on the Ngurah Rai Toll Gate, as a representative case study. Data collection techniques will involve direct observation of the toll payment process and carrying out surveys calculating service times and the number of vehicles queuing, while secondary data is obtained from the relevant agency, namely PT Jasa Marga in the form of vehicle traffic volume data, vehicle speed data, and interviews using SLFF. and use tapping cards. Data analysis techniques: In the research process at the two gates/substations located at the Ngurah Rai Toll Gate to find the maximum vehicle capacity and average service time as well as looking for a comparison between arrival rates and service levels using Max Function statistical analysis, and analysis based on the PUPR Department .

RESULTS AND DISCUSSION

Currently, SLFF is only intended for four-wheeled vehicles, so in this study only 4 gates were used, namely for passenger cars, buses and trucks. In this analysis we will analyze Gate 3 which uses SLFF and Gate 2 which uses Tapping Card.

Service Time Conditions

With the service time obtained from the survey results in the field, it is also necessary to take into account the ideal conditions of service time at a toll gate in order to achieve optimization of service time performance at a toll gate. From a survey conducted at the Ramp Pondok Gede Timur 2 toll gate by looking for arrival rate data at gates/substations that use SLFF, the following results were obtained:

Table 1.
Volume of Vehicles Entering the Ngurah Rai Gate

Jam (Wita)	Gate			
	1	2	3	4
08.00 - 09.00	112	117	96	45
09.00 - 10.00	145	138	135	74
10.00 - 11.00	160	163	142	93
11.00 - 12.00	153	167	153	94

Based on the vehicle volume above, you will then get the service time at Gate 2 which uses Tapping Card and Gate 3 which uses SLFF

Table 2.
Comparison of Service Times

Gate	Information	Average Service Time (seconds)
2	Tapping Card	7.6
3	SLFF	0.6

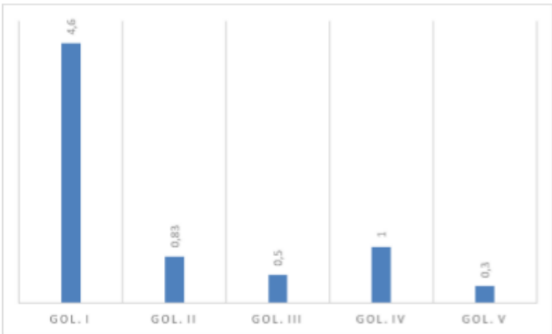
Based on the table above, it is known that the service time using SLFF at Gate 3 is faster than using Tapping Card at Gate 2. So it is assumed that the capacity that can be accommodated by the Gate in one hour is:

No	Waktu	Gate	Average Service Time (Hours)	Capacity (Kend/Hour)
(1)	(2)	(3)	(4)	(2)/(4)
1	1 Jam	2	0.0021	474
2	1 Jam	3	0.0002	6000

Based on its capacity, it is known that Gate 3 has a larger capacity compared to Gate 2 which uses Tapping Card, because Gate 3 is capable of passing 6000 vehicles in one hour compared to Gate 2 which can only serve a maximum of 474 vehicles in one hour.

Vehicle Fuel Consumption Costs

In calculating the cost of vehicle fuel consumption, we use the side taken from a distance of 40 meters from the toll booth and then count the vehicles that stop in that zone.



This data is obtained from multiplying the average number of vehicles in the sampling zone with the estimated fuel consumption of each vehicle class obtained from Energy Efficiency & Renewable Energy

Table 3.
Total Fuel Consumption Sample

Vehicle Class					Total
Gol 1	Gol 2	Gol 3	Gol 4	Gol 5	
1.8	0.2	0.5	0.4	0.2	3.1

Actual fuel consumption data is obtained from the following equation:

$$FC_{ACT} = \left(\frac{Pk}{40\ m}\ x\ FC_{zona}\ x\ Pjb\right)\ x\ Rasio\ M/L$$

Where :
FCACT : Actual Fuel
Pk: Average length of traffic jam every hour
FCzone: Total fuel consumption of the sampling zone
Pjb: Percentage of fuel type
M/L Ratio: Ratio of downtime per smooth

Based on this formula, the hourly fuel value is 0.9 liters of petrol and 0.4 diesel when experiencing traffic jams within one hour at Gate 2 and at Gate 3 the value is 0.45 liters of petrol and 0.13 liters of diesel. So on average there are 124 vehicles entering the gate with a percentage of vehicles using petrol 69% and diesel 31%. So fuel consumption at Gate 2 is 92.38 liters while at Gate 3 it is 49.63 liters. Therefore the fuel consumption costs at Gate 2 and Gate 3 are:

Table 4.
Fuel Consumption Costs

Gate	Type of Fuel (Rupiah)		
	Pertamax	Pertalite	Solar
2	196052.2	385020	104556.8
3	98026.09	192510	75635.04

Exhaust Gas Emission Level

Exhaust gas emission levels, especially HC gas (hydrocarbons) and CO gas (carbon monoxide), provide an important indication of the level of motor vehicle pollution. HC gas refers to a number of hydrocarbon compounds that have not been completely burned in a vehicle engine, and their presence in emissions can indicate combustion inefficiency. Meanwhile, CO gas is a product of incomplete combustion, which can form when combustion conditions are not optimal. High levels of HC Gas and CO Gas emissions can be a sign of problems with the vehicle's combustion system, which not only has the potential to harm the environment by increasing air pollution, but can also have a negative impact on human health. Therefore, monitoring and controlling the emission levels of these two gases is very important in efforts to maintain air quality and achieve environmental sustainability. The following is a comparison of exhaust emissions production at Gate 2 with Tapping Card and Gate 3 with SLFF:

Table 5.
Comparison of Exhaust Gas Emissions

Gate	Fuel Type	Jenis Emisi Gas Buang	
		Gas CO (%)	Gas HC (ppm)
Gate 2	Solar	76%	24195.06
	Pertamax	37%	10958.44
	Pertalite	101%	32226.17
Gate 3	Solar	55%	17502.39
	Pertamax	19%	5479.22
	Pertalita	50%	16113.09

Based on the table above, it is found that Single Lane Free Flow (SLFF) at toll gates can contribute positively to reducing exhaust emissions from vehicles. This system allows vehicles to pass without physically stopping at toll gates, optimizing traffic flow and reducing waiting times. Thus, the use of SLFF can reduce the risk of traffic jams at toll gates, which are often the main cause of inefficient fuel combustion and increased exhaust emissions. By increasing efficiency and smooth traffic at toll gates, vehicles can maintain optimal speeds, optimize combustion conditions, and ultimately reduce exhaust emissions, including HC Gas and CO Gas. Therefore, the implementation of SLFF not only increases efficiency in the toll payment system, but also has the potential to have a positive impact on environmental sustainability by reducing air pollution levels around toll gates.

Based on the results above, it is found that SLFF has advantages compared to tapping cards. This is presented in the following table:

Table 6.
Comparison between SLFF and Tapping Card

Parameter	Gate	
	Gate 2	Gate 3
Service Time (seconds)	7.6	0.6
Fuel Consumption Costs (Rupiah)	685,629	366,171
Fuel Usage Rate (Liters)	68.51	37.69
CO gas (%)	214%	124%
HC gas (ppm)	67379.7	39094.7

Based on the table above, it is found that Single Lane Free Flow (SLFF) offers a number of advantages compared to the tapping card method at toll gates in various crucial parameters. First, in terms of service time, SLFF reduces queues and waiting times at toll gates significantly because vehicles can pass without physically stopping. This has the potential to increase efficiency and smooth traffic flow. Second, the use of SLFF can reduce vehicle fuel consumption, as it reduces stopping time and allows maintaining optimal speed. Third, by reducing stopping times, fuel costs can be minimized, having a positive impact on road users and toll operators. Finally, from an exhaust emissions perspective, SLFF can reduce CO and HC gas emission levels because the vehicle can operate at more efficient combustion conditions. Thus, implementing SLFF at toll gates not only increases operational efficiency, but also has the potential to produce significant benefits in terms of time savings, fuel costs and reduced exhaust emissions.

CONCLUSION

Based on the data presented for Gate 2 and Gate 3, several conclusions can be drawn. First, in terms of service time, Gate 3 shows much better performance with a service time of only 0.6 seconds, while Gate 2 has a service time of 7.6 seconds. This shows that Gate 3 has very high efficiency in servicing vehicles, providing a better user experience. Second, in terms of fuel consumption costs, Gate 3 shows lower costs, namely 366,171 Rupiah, compared to Gate 2 which reaches 685,629 Rupiah. This indicates that implementation at Gate 3 could provide the potential for significant fuel cost savings. Third, the level of fuel use in Gate 3 is also more efficient with only 37.69 liters, while Gate 2 reaches 68.51 liters. Furthermore, in terms of exhaust emissions, Gate 3 shows a lower emission level with CO Gas at 124% and HC Gas at 39094.7 ppm, while Gate 2 has a higher emission level with CO Gas at 214% and HC Gas at 67379.7 ppm . In conclusion, Gate 3 has better performance in terms of service time, fuel costs and exhaust emission levels, so it can be considered a more efficient and sustainable option.

REFERENCES

Crainic, T. G., & Laporte, G. (2016). Transportation in supply chain management: recent advances and research prospects. International Journal of Production Research, 54(2), 403–404. https://doi.org/10.1080/00207543.2015.1120904

Das, A., Ghasemzadeh, A., & Ahmed, M. M. (2019). Analyzing the effect of fog weather conditions on driver lane-keeping performance using the SHRP2 naturalistic driving study data. Journal of Safety Research, 68, 71–80. https://doi.org/10.1016/j.jsr.2018.12.015

Demir, E., Hrušovský, M., Jammernegg, W., & ... (2019). Green intermodal freight transportation: bi-objective modelling and analysis. International Journal …. https://doi.org/10.1080/00207543.2019.1620363

Donovan, J., & Donovan, J. (2019). The four-step model. In Working with Attachment in Couples Therapy. https://doi.org/10.4324/9780429297816-7

Makridis, M., Mattas, K., & Ciuffo, B. (2020). Response Time and Time Headway of an Adaptive Cruise Control. An Empirical Characterization and Potential Impacts on Road Capacity. IEEE Transactions on Intelligent Transportation Systems, 21(4), 1677–1686. https://doi.org/10.1109/TITS.2019.2948646

Motiolabs. (2020). Single Lane Free Flow RFID. Motiolabs. https://www.youtube.com/watch?v=2HMadaXorPU

Muneera, C. P., & Krishnamurthy, K. (2020). Economic Evaluation of Traffic Congestion at Intersection: Case study from an Indian City. Transportation Research Procedia, 48(2018), 1766–1777. https://doi.org/10.1016/j.trpro.2020.08.212

Papageorgiou, M., Mountakis, K.-S., Karafyllis, I., Papamichail, I., & Wang, Y. (2021). Lane-Free Artificial-Fluid Concept for Vehicular Traffic. Proceedings of the IEEE, 109(2), 114–121. https://doi.org/10.1109/JPROC.2020.3042681

Wang, J., Chen, R., & He, Z. (2019). Traffic speed prediction for urban transportation network: A path based deep learning approach. Transportation Research Part C: Emerging Technologies, 100, 372–385. https://doi.org/10.1016/j.trc.2019.02.002

Yusianto, R., Marimin, Suprihatin, & Hardjomidjojo, H. (2021). Strategic Planning for Green Logistics Implementation in Potato Agro-Industry. Jurnal Ilmiah Teknologi Pertanian Agrotechno, 6(1), 9–16. https://doi.org/10.24843/jitpa.2021.v06.i01.p02.