Developing A Causal Loop Diagram to Reduce Road Congestion in Kuala Lumpur, Malaysia: A System Dynamics Approach

Masriah Mansur[1], Ahmad Afif Ahmarofi [2*], Zetty Ain Kamaruzzaman[3]

[1,3]Faculty of Industrial Management, Universiti Malaysia Pahang Al-Sultan Abdullah, 26300 Gambang, Pahang, Malaysia.

[2*]Integrated Simulation & Visualization (i-SiVi) Group, Faculty of Computer and Mathematical Sciences, Universiti Teknologi MARA (UiTM) Kedah, 08400 Merbok Kedah, Malaysia.

***Corresponding Author**

DOI: https://dx.doi.org/10.47772/IJRISS.2025.910000617

Received: 28 October 2025; Accepted: 04 November 2025; Published: 19 November 2025

ABSTRACT

Road congestion has long been an issue plaguing urban areas, including Kuala Lumpur, the capital city of Malaysia. Accordingly, one of the strategies to reduce road congestion, as suggested by the experts, is road pricing, which is successfully practiced in several big cities around the world. Road pricing is a direct charge levied against drivers to reduce the number of private vehicles during peak hours. However, policymakers remain doubtful of its success in effectively reducing road congestion in Kuala Lumpur. In this regard, this study aims to identify the causes and effects related to road pricing implementation to reduce road congestion. To fulfil that, a causal loop diagram (CLD) model based on the system dynamics (SD) approach is developed by considering four significant causal relationships, namely the degree of road congestion, driving attraction, public transport, and road pricing charge. In developing CLD, a curved line with an arrow is created to represent the causal relationship that links one variable to another variable. Every link in the diagram must be labelled with polarity, whether positive or negative. Subsequently, the feedback loop is indicated in two types: either the reinforcing loop or the feedback loop based on the number of negative polarities. As a result, road pricing, road congestion, and driving attraction turn into a reinforcing loop where the changes in these loops could drastically affect the whole system. From the managerial perspective, this research helps highway stakeholders in Malaysia make better decisions by having a holistic view of road pricing implementation for a better metropolitan lifestyle.

Keywords—Road pricing; Causal loop diagram (CLD); System dynamics; Traffic congestion

INTRODUCTION

Traffic congestion refers to the condition when the number of trips made by vehicles exceeds the existing roadway facilities (Ahmarofi et al., 2021). This situation overwhelmed Kuala Lumpur, the capital city of Malaysia, for a few decades. It is recorded that the number of vehicles on the road in Kuala Lumpur has reached almost seven million in 2020, which constitutes almost 90 percent of the private vehicles' trips per day (Ministry of Transport Malaysia, 2021). Furthermore, Kuala Lumpur experiences heavy traffic congestion, with vehicle ownership reaching nearly 900 per 1,000 residents and millions of vehicles entering the city daily (Asian Transport Observatory, 2023; Massachusetts Institute of Technology, n.d.; New Straits Times, 2023).

Consequently, this phenomenon increases the congestion index in the city as well. The congestion index is the ratio of the number of vehicles on the road divided by the number of vehicle capacity on the road (Moyo, Mbatha, Aderibigbe, Gumbo, & Musonda, 2022). The bigger the ratio of the congestion index, i.e., approaches 1.00, the more congested the road condition would be.

To attain a sustainable transportation system and congestion index reduction in Kuala Lumpur, the government has set a vision to achieve a mode share ratio of 75:25 for private vehicles to public transportation (Abidin, Karim, Rahman, & Alwi, 2022). To fulfil that, a road pricing strategy is proposed to be implemented, as it is one of the most effective solutions to tackle the congestion issue.

Road pricing is the term used to describe a direct charge levied against drivers who use the road network during peak hours. In urban areas, the goal of road pricing is to reduce the number of private vehicles that circulate on the roads during peak hours.

Furthermore, road pricing is one of the Travel Demand Management (TDM) strategies that have been reformulated in response to the rapid recovery of traffic from 1998 until 2000 during the national economic crisis (Lessan & Fu, 2022). However, although road pricing has been proven to reduce traffic congestion effectively in cities such as Singapore, Stockholm, and New York, to name a few, policymakers remain sceptical of its success rate if implemented in Kuala Lumpur.

In this regard, the objective of this study is to develop a dynamic road pricing model for reducing road congestion in the city. To fulfil the objective, the system dynamics (SD) method is considered in this research for its capability to view a complex system holistically in terms of cause and effect relationships, i.e., causal relationships. A causal loop diagram (CLD) based on SD principles is developed to investigate how one variable affects another variable. Moreover, CLD serves as a working theory model to investigate the causal relationship among the identified variables (Ahmarofi et al., 2021).

In the subsequent section, previous works are reviewed to highlight the implementation of road pricing and the SD method in reducing road congestion. After that, the development of CLD is presented in the following sections. The results from the developed CLD are discussed in the subsequent section, followed by the conclusion and future work.

LITERATURE REVIEW

Traffic congestion has risen dramatically as early as the 1920s. This scenario stimulated the curiosity of scholars to address this issue facing urban areas. Accordingly, economists such as Pigou in 1920 and Knight in 1924 proposed road pricing as an effective solution for reducing congested road traffic (Zefreh & Torok, 2021). They highlighted that the implementation of road pricing charges could discourage road users from using road infrastructure during peak times.

In terms of practicality, several cities are identified in implementing road pricing policies, including Singapore, London, Stockholm, and Milan (Rotaris, Danielis, Marcucci, & Massiani, 2010). Despite encountering some obstacles before the implementation of the road pricing strategy, its implementation has been demonstrated to be an effective approach to reducing traffic congestion in these urban areas.

Moreover, previous researchers have implemented various methods to evaluate the effectiveness of road pricing strategies. Among the methods, SD emerged as the prominent approach in evaluating the effectiveness of road pricing due to the method can correlate various causal relationships in a holistic view (Ahmarofi, Zainal Abidin, & Mahadzir, 2022). Based on previous works, Wang, Lu, and Peng (2008) developed an SD model to create scenarios for urban development and transportation to increase the system's sustainability.

Furthermore, Walch, Neubauer, Schildorfer, & Schirrer (2024) proposed an SD model approach using CLD to illustrate the relationship between vehicles and infrastructure in addressing traffic challenges such as efficiency, sustainability, and safety. In addition, Fontoura, Radzicki, & Ribeiro (2024) developed an SD model to verify the effects of sustainable transport policies, focusing on congestion and air pollution.

Besides, Jia & Zhu (2025) constructed an SD model for the urban road transport system that aims to reduce emissions and pollution. Subsequently, Jia, Yan, Shen, and Zheng (2017) utilized an SD model for traffic congestion pricing that considers both environmental and social benefits. Additionally, Nunes, Ferreira, Govindan, & Pereira (2021) developed a cognitive mapping and the SD approach to find which factors foster smart city success, as well as the cause-and-effect relationships for sustainable transportation.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue X October 2025

Based on the capability of SD that has been proven by the previous works, SD is considered in this research for developing a working theory related to the road pricing strategy in Kuala Lumpur. To fulfil that, CLD is implemented as a tool based on the SD principles for developing a working theory. The research methodology is further explained in the subsequent section.

RESEARCH METHODOLOGY

CLD is a qualitative tool for developing a working theory related to an articulated problem. Figure 1 exhibits the flow of developing CLD based on the principles of the SD method.

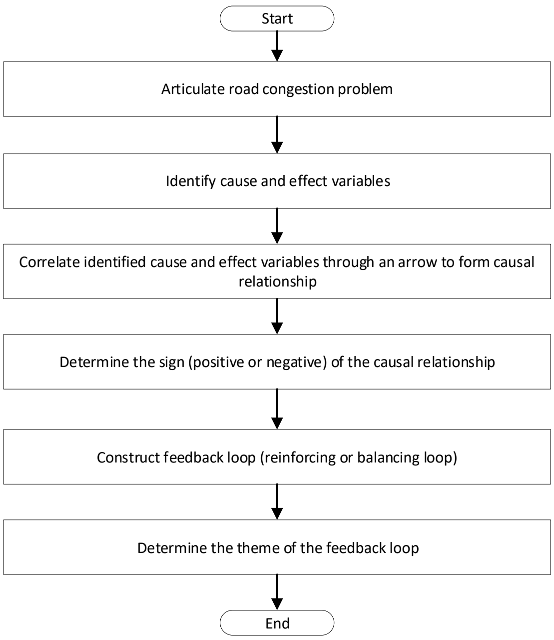


Fig. 1 The development of a causal loop diagram

Before the working theory can be developed, several factors and effects are identified to understand the behavior of the problem. Subsequently, the identified factors and effects are connected through causal relationships to correlate how a variable affects another variable.

In developing a causal relationship, a curved line with an arrow will be created to represent the causal relationship that links one variable to another variable. Every link in the diagram must be labelled with polarity, whether positive or negative. The positive sign indicates that a change in the variable's parameter will produce an identical direct change in the other variable. Figure 2 demonstrates an example of how a road pricing charge variable affects the trip cost variable**.**

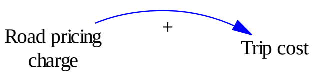


Fig. 2 The positive causal relationship

If the road pricing charge variable increases, it will contribute to an increase in the trip cost variable as well. Similarly, if the road pricing charge variable decreases, the trip cost variable will also decrease. Since both variables are changing in the same direction, the relationship polarity between these variables is indicated as a positive relationship.

In contrast, if an increase in a variable results in a decrease in another variable or vice versa, the relationship between these variables is indicated by a negative sign. Figure 3 presents the negative relationship between the

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue X October 2025

trip cost variable and the trips per day variable.

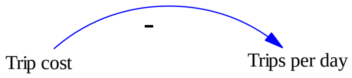
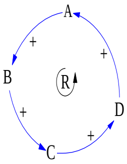
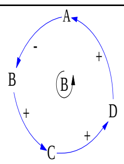


Fig. 3 The negative causal relationship

If the trip cost variable increases, the trips per day variable will decrease since the rate of utilization of roads is higher than usual. Alternatively, if the trip cost variable decreases, the trips per day variable will increase. Thus, the polarity between these variables is denoted as a negative relationship.

Subsequently, the feedback loop is constructed based on the causal relationships. The feedback loop is categorized into two types: either the reinforcing loop (labelled by 'R') or the balancing loop (labelled by 'B') by counting the number of negative polarities. If the number of negative polarities is even, then the feedback loop is considered a reinforcing loop. However, if the number of negative polarities is odd, the feedback loop is considered a balancing loop. Table 1 demonstrates the description of these two feedback loops.

Table 1: Description of the feedback process in a causal loop diagram

Example of a loop	Type of feedback loop	Label	Indication
	Reinforcing loop	R	The number of negative polarities is zero or even.
	Balancing loop	B	The number of negative polarities is odd.

Both of the feedback loops have an impact on the system. If the feedback loop is categorized as the reinforcing loop, it often leads the system into two different behaviors drastically, either exponential growth or rapid decline. In this regard, as the name implies, the reinforcing loop must be carefully observed since it will force the system into either an extreme situation. On the other hand, the feedback loop is normally characterized as a balancing loop, where the loop often serves as a stabilizer loop, i.e., controls the system to achieve an equilibrium state.

DISCUSSION

The constructed CLD conceptualizes the behavior of the road pricing system by incorporating four feedback loops, namely road congestion, driving attraction, road pricing, and public transport. The CLD model based on the SD method is presented in Figure 4.

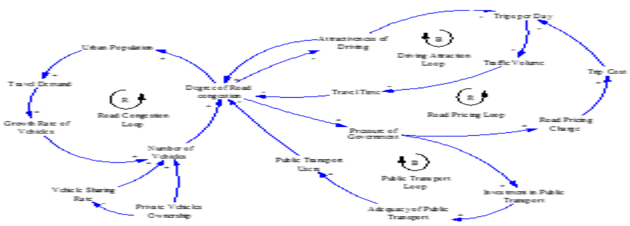


Fig. 4 Causal loop diagram regarding road congestion in Kuala Lumpur

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue X October 2025

Each of the feedback loops contains identified variables, those that should be prioritized when managing road pricing. The elaboration of each feedback loop is further explained in the following Figures 5, 6, 7, and 8, respectively.

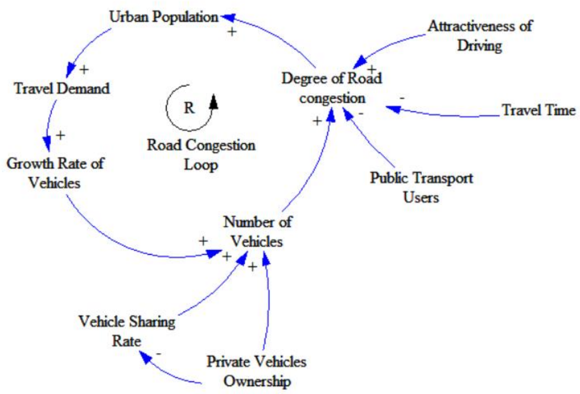


Fig. 5 Road congestion loop

As illustrated in Figure 5, the road congestion loop is considered a reinforcing loop since no negative relationship is formed. The high number of urban populations contributes to the increasing travel demand within Kuala Lumpur. Consequently, this condition affects the growth rate of vehicles as well as the number of vehicles. Besides, the vehicle sharing rate and the number of private vehicle owners have a direct impact on the number of vehicles. As a result, the degree of road congestion increases due to the increasing number of vehicles in the city.

Moreover, the degree of road congestion is contributed through the attractiveness of driving private vehicles, travel time while driving on the road, and public transport users available in Kuala Lumpur, such as light rail transit (LRT), mass rapid transit (MRT), Keretapi Tanah Melayu Electric Train Service (KTM-ETS), and Rapid KL. Hence, the variables included in this loop should be scrutinized, as they will result in unforeseen changes to the road congestion system within a short time.

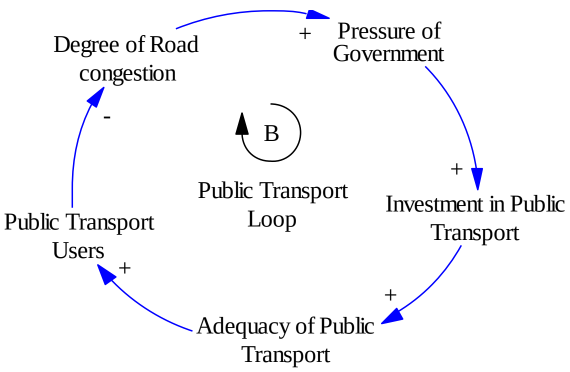


Fig. 6 Public transport loop

The public transport loop in Figure 6 is considered a balancing loop since the number of negative relationships is odd. The higher the degree of road congestion, the higher the pressure on the government could be, since the responsibility to manage this issue is on the government side, more specifically, on the Ministry of Transportation. Subsequently, the government will increase the investment in public transport to curb the issue, such as widening the road lanes, constructing new lanes for LRT, MRT, and KTM-ETS, and increasing the number of Rapid KL buses. Consequently, the public transport adequacy could be improved. As a result, the number of people using public transportation will increase, thereby decreasing the degree of road congestion. In this regard, this loop acts as a stabilizer for the system since it can control the degree of road congestion.

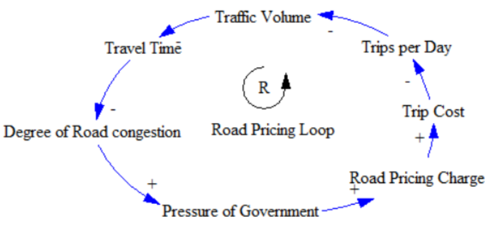


Fig. 7 Road pricing loop

Figure 7 exhibits the road pricing loop. An increase in the degree of road congestion contributes to the pressure on the government to manage the problem. Consequently, the charge for road pricing will be imposed during peak hours to resolve the road congestion. Increases in the road pricing charge will increase the trip cost, thus the number of trips per day via private vehicle will decrease in turn. The reason is that road users tend to reduce trips per day to save money. Reduced daily trips result in decreased traffic volume, and travel time could be shorter. As a result, road congestion will also decrease. Due to the even number of negative relationships, the road pricing loop is categorized as a reinforcing loop. This loop tends to create exponential growth or rapid decline in the degree of road congestion. As a result, this loop must be regularly observed by the government and stakeholders due to unexpected changes at any time.

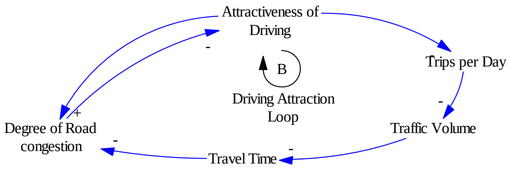


Fig. 8 Driving attraction loop

As illustrated in Figure 8, the driving attraction loop requires balancing. The balancing loop has the effect of stabilizing the variables. As a result, all variables will contribute to changes in their effect to suit the condition, respectively (increase or decrease). As the level of road congestion increases, the attraction of driving reduces. Consequently, the number of trips per day decreases as the attractiveness of driving declines. The number of trips made per day affects the volume of traffic. A decrease in daily trips parallels a decrease in traffic volume. As a result, travel times could be decreased. As travel time decreases, the degree of road congestion decreases as well.

CONCLUSION

In this paper, four feedback loops are constructed towards the road congestion in Kuala Lumpur by implementing CLD. The significant loops, namely road congestion, driving attraction, road pricing, and public transport, were constructed based on the causal relationships among related variables. CLD serves as a working theory model for conceptualizing road pricing management. Three reinforcing loops, i.e., road congestion, driving attraction, and road pricing, and one balancing loop, i.e., public transport, are identified. Based on the findings, authorities should closely monitor road congestion, road pricing, and driving attraction since these loops are categorized as reinforcing loops, i.e., influential loops. When one variable in these loops increases, other variables typically increase as well, thus creating a system of exponentially increasing or rapidly decreasing values. In this regard, road pricing could be the recommended policy for reducing road congestion effectively. In contrast, it is found that the public transport loop turns into a balancing loop. This loop will have a balancing effect on the associated variables, i.e., all of the related variables will increase or decrease to achieve an equilibrium state among the loops in the system. Furthermore, CLD proved its capability in identifying the causes and effects related to road pricing implementation to reduce road congestion in Kuala Lumpur from a holistic view from various perspectives. For further study, the constructed CLD could be extended to the development of a stock flow diagram (SFD) for quantifying the impact of each related variable on road congestion.

ACKNOWLEDGEMENT

The authors would like to express their sincere gratitude to the Kedah State Research Committee, UiTM Kedah Branch, for the generous funding provided under the Tabung Penyelidikan Am. This support was crucial in facilitating the research and ensuring the successful publication of this article.

REFERENCE

1. Abidin, N. Z., Karim, K. N., Rahman, R. A., & Alwi, A. (2022). Mitigating the Traffic Congestion in the Urban Area Using the Integration of System Dynamics and Genetic Algorithm Approaches. Civil Engineering and Architecture.
2. Ahmarofi, A. A., Kamaruzzaman, Z. A., Rahman, H. A., Masri, K. A., Rahim, N. A., Shariff, S. S. R., ... & Ahmad, A. B. (2021, December). Development of A Computer Simulation on Road Pricing Strategy to Reduce Congestion and Carbon Dioxide Emission: A System Dynamics Approach. In 2021 6th IEEE International Conference on Recent Advances and Innovations in Engineering (ICRAIE) (Vol. 6, pp. 1-5). IEEE.
3. Ahmarofi, A. A., Zainal Abidin, N., & Mahadzir, N. H. (2022). Simulating the Cycle Time Based on a Manpower Performance Through a System Dynamics Model: A Case Company in the Automotive Sector. In Human-Centered Technology for a Better Tomorrow (pp. 515-523). Springer, Singapore.
4. Asian Transport Observatory. (2023). Kuala Lumpur transport sector profile. Retrieved October 30, 2025, from https://asiantransportobservatory.org/documents/266/Kuala_Lumpur_transport_sector_profile.pdf
5. Fontoura, W. B., Radzicki, M. J., & Ribeiro, G. M. (2024). Using system dynamics to understand long-term impact of new mobility services and sustainable mobility policies: an analysis pre-and post-COVID-19 pandemic in Rio de Janeiro, Brazil. Transportation Letters, 16(7), 751-763.
6. Jia, S., & Zhu, W. (2025). Effects of carbon tax policy on vehicle pollution control and carbon reduction based on the availability heuristic and system dynamics. Sustainable Cities and Society, 118, 105990.
7. Jia, S., Yan, G., Shen, A., & Zheng, J. (2017). A System Dynamics Model for Determining the Traffic Congestion Charges and Subsidies. Arabian Journal for Science and Engineering, 42(12), 5291–5304. https://doi.org/10.1007/s13369-017-2637-5
8. Lessan, J., & Fu, L. (2022). Credit-and permit-based travel demand management state-of-the-art methodological advances. Transportmetrica A: Transport Science, 18(1), 5-28.
9. Massachusetts Institute of Technology. (n.d.). Kuala Lumpur. Malaysia Sustainable Cities Program. Retrieved October 30, 2025, from https://malaysiacities.mit.edu/kualalumpur
10. Moyo, T., Mbatha, S., Aderibigbe, O. O., Gumbo, T., & Musonda, I. (2022). Assessing spatial variations of traffic congestion using traffic index data in a developing city: lessons from Johannesburg, South Africa. Sustainability, 14(14), 8809.
11. New Straits Times. (2023, December 7). 36.3 million vehicles in Malaysia. Retrieved October 30, 2025, from https://www.nst.com.my/news/nation/2023/12/987062/363-million-vehicles-malaysia
12. Nunes, S. A., Ferreira, F. A., Govindan, K., & Pereira, L. F. (2021). "Cities go smart!": A system dynamics-based approach to smart city conceptualization. Journal of Cleaner Production, 313, 127683.
13. Rotaris, L., Danielis, R., Marcucci, E., & Massiani, J. (2010). The urban road pricing scheme to curb pollution in Milan, Italy: Description, impacts, and preliminary cost-benefit analysis assessment. Transportation Research Part A, 44(5), 359–375. https://doi.org/10.1016/j.tra.2010.03.008
14. Statistik Pengangkutan Jalan 2020, Ministry of Transportation Malaysia 2020. Retrieved from https://www.mot.gov.my/en/Statistik%20Tahunan%20Pengangkutan/Transport%20Statistics%20Malaysia%202020.pdf
15. Walch, M., Neubauer, M., Schildorfer, W., & Schirrer, A. (2024). Modelling interrelations between C-ITS impact categories: a system-dynamics approach using causal loop diagrams. European Transport Research Review, 16(1), 60.
16. Zefreh, M. M., Esztergar-Kiss, D., & Torok, A. (2021). Implications of different road pricing schemes in urban areas: A case study for Budapest. Proceedings of the Institution of Civil Engineers: Transport, 174(7), 407–418. https://doi.org/10.1680/jtran.19.00094