



Causal Structure of Toll Road Tariff Determination in Public Private Partnership Projects: A System Dynamics Approach

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Abstract

The Solo Yogyakarta Yogyakarta International Airport Toll Road is a national strategic infrastructure project in Indonesia developed under a public private cooperation scheme using a build operate transfer arrangement. In this scheme, toll tariffs function as the primary mechanism for investment recovery, making tariff determination a critical factor influencing traffic demand and project feasibility. This study aims to develop a system dynamics based model to explain the structural relationships governing toll tariff determination in toll road projects implemented through public private cooperation. The research applies a quantitative modeling approach using system dynamics, following stages of problem formulation, development of a dynamic hypothesis, and construction of a causal loop diagram. Key variables are identified through literature review, expert judgment, and secondary data analysis, including toll tariffs, average daily traffic, user affordability, operational costs, and financial performance indicators. The analysis focuses on identifying cause effect relationships and feedback structures that influence traffic demand and revenue behavior. The results show that toll tariff determination is governed by interacting reinforcing and balancing feedback loops, with traffic volume emerging as a central variable linking tariff policies to revenue and financial performance. Higher tariff levels may increase unit revenue while simultaneously reducing traffic demand due to affordability constraints, whereas economic growth and service improvements support reinforcing demand effects. This study concludes that toll tariff determination should consider dynamic interactions among demand, affordability, and financial variables rather than relying solely on static cost-based approaches.

Introduction

Toll road infrastructure development plays a critical role in enhancing regional connectivity, improving logistics efficiency, and supporting long-term economic growth. In Indonesia, the development of toll roads under the Public Private Partnership (PPP) scheme has become a key strategy for accelerating infrastructure provision while reducing fiscal burdens on the government. One of the strategic PPP projects currently under development is the Solo Yogyakarta Yogyakarta International Airport (YIA) Kulon Progo Toll Road, which aims to strengthen accessibility to major tourism destinations and YIA, as well as to facilitate interregional mobility across Central Java and the Special Region of Yogyakarta (Apriliyaningsih et al., 2025; Rahajeng et al., 2023; Wiguna et al., 2024; Tristofa & Tham, 2022; Rahajeng et al., 2024; Li et al., 2025; ; Hudalah et al., 2024).

The performance and sustainability of PPP toll road projects are not determined solely by technical design and construction execution, but are strongly influenced by the effectiveness of financing schemes and the reliability of long-term revenue projections (Castelblanco et al., 2024; Kakw'u, 2024; Akomea-Frimpong et al., 2022; Koul et al., 2021; Fauzan et al., 2023). Within this framework, toll tariffs function as the primary mechanism for investment recovery for private partners. Inappropriate tariff determination, however, poses substantial risks. Excessively high tariffs may reduce users' willingness to utilize toll roads, leading to significant decreases in Average Daily Traffic (ADT), whereas tariffs set too low may fail to recover capital and operational costs, thereby undermining financial feasibility and increasing the likelihood of government intervention (Kementerian Pekerjaan Umum dan Perumahan Rakyat (PUPR) 2025).

Empirical evidence in Indonesia demonstrates substantial variation in toll tariff levels across different corridors. The Solo Yogyakarta corridor currently applies tariffs of approximately IDR 1,800 1,900 per kilometer for Class I vehicles, while the planned Gedebage Tasikmalaya Cilacap (Getaci) Toll Road is projected to reach IDR 2,025 per kilometer, making it one of the most expensive toll roads in the country. In contrast, the Surabaya Gresik Toll Road (Dupak Tandes segment) records the lowest tariff at approximately IDR 217 per kilometer (Hakim 2024). These disparities indicate that toll tariff determination is highly context-dependent and underscore the importance of establishing tariff levels that balance user affordability with long-term investment sustainability (Kementerian Pekerjaan Umum dan Perumahan Rakyat 2024).

The Solo Yogyakarta YIA Toll Road faces several challenges that complicate tariff determination. These include disparities between tariff levels and users' ability to pay (ATP), high demand elasticity with respect to tariff changes, uncertainty in setting initial tariffs for greenfield projects, competition with well-developed free national road networks, and the absence of historical traffic data (European Investment Bank, 2024). Under such conditions, conventional tariff-setting approaches that rely primarily on cost structures and regulatory benchmarks are insufficient to capture the dynamic and non-linear behavior of traffic demand and revenue generation (El Ouadi et al., 2022; Yang et al., 2025; Darwisman, 2025). Consequently, more comprehensive analytical approaches are required to address these complexities (Kementerian Pekerjaan Umum dan Perumahan Rakyat 2017).

The project adopts a Build Operate Transfer (BOT) scheme within the PPP framework, under which the private entity is responsible for financing, constructing, and operating the toll road over a defined concession period before transferring it back to the government (Organisation for Economic Co-operation and Development 2022; Rohman, 2022; Nuwagaba et al., 2023; Thillainathan, 2021). In this scheme, toll revenue represents the sole primary source of investment recovery for the private partner. Therefore, inaccuracies in traffic and revenue projections may significantly affect financial performance, reduce investor confidence, and potentially lead to financial distress, including difficulties in loan repayment (Mashudi et al., 2021; Huang et al., 2023; Francisca, 2025; Ogunwole et al., 2024). Tariff determination in BOT-based PPP projects must therefore simultaneously account for capital recovery, expected returns, users' purchasing power, and realistic ADT projections (Komite Percepatan Penyediaan Infrastruktur Prioritas (KPPIP) 2018).

The Solo Yogyakarta region is characterized by heterogeneous socio-economic conditions, diverse travel purposes (commuting, tourism, and logistics), and the availability of alternative non-toll road networks. Applying nationally standardized toll tariffs without incorporating these local characteristics may lead to lower-than-expected toll road utilization, as users may prefer free routes (Endo et al., 2021; Jiang et al., 2023). Given the greenfield nature of the project and the absence of historical traffic data, predictive and simulation-based approaches become particularly important for evaluating tariff policies and their long-term implications.

Average Daily Traffic (ADT), as the primary indicator of toll road demand, exhibits a non-linear relationship with toll tariffs. In many cases, tariff increases do not necessarily lead to higher revenue due to disproportionate reductions in traffic volume when users perceive tariffs as unaffordable. System dynamics modeling is well suited to capturing these complex interactions, as it enables the integration of toll tariffs, ADT, project revenue, users' ATP, regional economic growth, and tourism activity within a unified analytical framework (Chiu et al. 2023; Anas et al., 2024; Arimoro & Musa, 2025).

System dynamics further allows for the explicit representation of causal relationships and feedback loops among key variables, providing insights into the long-term impacts of tariff policies on project cash flows and financial performance indicators such as Net Present Value (NPV). Accordingly, this study aims to develop a system dynamic based model for determining toll tariffs for the Solo Yogyakarta YIA PPP toll road project. The proposed model is expected to support adaptive and financially sustainable tariff policies that optimize revenue while maintaining user affordability, thereby aligning public interest objectives with private investment sustainability.

Literature Review

Toll road infrastructure development requires substantial capital investment with long payback periods, making financing mechanisms a critical determinant of project viability. In Indonesia, toll road financing is regulated under Government Regulation No. 15/2005, which recognizes government funding, private funding, and mixed funding through Public Private Partnerships (PPP). PPP schemes are primarily applied to projects that are economically viable but financially constrained, requiring fiscal support such as Viability Gap Funding (VGF) or Availability Payments (AP) to ensure financial sustainability.

PPP represents a long-term contractual arrangement between the government and private entities involving risk-sharing mechanisms regulated under Presidential Regulation No. 38/2015 and Ministry of Finance Regulation No. 223/PMK.011/2012. Common contractual forms include Build Operate Transfer (BOT), Build Transfer Operate (BTO), Build Own Operate (BOO), Design Build Finance Operate (DBFO), Rehabilitate Operate Transfer (ROT), and Rehabilitate Own Operate (ROO), with scheme selection dependent on project characteristics and risk allocation (Bappenas 2020).

Infrastructure functions as the backbone of socio-economic development, providing physical systems that support public services and economic activity (Government of Indonesia n.d.; Tu et al. 2025; Zondo 2024). Investment feasibility in toll road projects is commonly evaluated using indicators such as Net Present Value (NPV), Financial Internal Rate of Return (FIRR), Payback Period, and Minimum Attractive Rate of Return (MARR), with NPV being the most widely applied due to its ability to reflect lifecycle net benefits (Kementerian Pekerjaan Umum dan Perumahan Rakyat 2017; Liviana 2009).

Toll road revenue in PPP projects is primarily determined by toll tariffs and Average Daily Traffic (ADT), making tariff determination a key factor in financial feasibility (Fauzan et al., 2023). Tariff setting must consider users' Ability to Pay (ATP) and Willingness to Pay (WTP), which are influenced by perceived benefits such as travel time savings, comfort, and safety (Litman 30062023; Ortúzar and Willumsen 2011). Misalignment between tariffs, ATP, and WTP may reduce ADT and weaken revenue performance.

ADT serves as the primary indicator of toll road demand and underpins revenue forecasting and financial feasibility analysis. ADT projections incorporate economic growth, land-use patterns, and transportation network characteristics, and inaccuracies pose significant financial risks, particularly in greenfield PPP toll road projects (Serman 2002). Given the dynamic and non-linear relationship between tariffs and demand, System Dynamics modeling

has been increasingly applied to capture feedback mechanisms among tariffs, ADT, revenue, and macroeconomic variables, supporting more comprehensive financial analysis in PPP toll road projects (Sterman 2002; Winarsih and Muthaher 2025).

Methods

This study adopts a quantitative, simulation-based research design using a System Dynamics (SD) approach to determine toll tariffs for the Solo Yogyakarta YIA toll road project implemented under a Public Private Partnership (PPP) scheme. The SD approach is suitable for this research as toll tariff determination in PPP projects involves complex and non-linear interactions among traffic demand, revenue generation, users' ability to pay, and long-term financial feasibility.

The analysis focuses on modeling the dynamic relationship between toll tariffs and Average Daily Traffic (ADT) as the primary indicator of toll road demand. Changes in tariff levels influence users' travel behavior, affecting traffic volume, toll revenue, and project cash flows over the concession period. These interactions are represented through feedback mechanisms that capture demand revenue dynamics. Financial feasibility is evaluated using Net Present Value (NPV) as the main performance indicator, reflecting the long-term sustainability of the project under alternative tariff scenarios.

The System Dynamics modeling process follows the standard procedure proposed by Sterman (2002), including problem formulation, dynamic hypothesis development, model formulation, validation, and policy analysis. Key variables incorporated into the model include toll tariffs, ADT, capital expenditure (CAPEX), operational expenditure (OPEX), users' Ability to Pay (ATP), regional economic growth, inflation, discount rate, and concession period.

A Causal Loop Diagram (CLD) is developed to structure and visualize the causal relationships among these variables. The CLD plays a central role in identifying the reinforcing and balancing feedback loops that govern toll road performance, such as how tariff adjustments influence traffic demand, how demand affects revenue, and how revenue feeds back into financial feasibility. By mapping these feedback structures, the CLD clarifies the system's behavioral drivers and ensures that the dynamic hypothesis is logically consistent before quantitative modeling. The CLD then serves as the conceptual foundation for translating qualitative insights into a stock flow model in Vensim, enabling simulation of alternative tariff scenarios.

The study utilizes both primary and secondary data. Primary data are obtained through expert judgment and interviews with relevant stakeholders, including toll road operators, PPP concession holders, and regulators, to support model structure and parameter assumptions. Secondary data are sourced from official publications of the Ministry of Public Works and Housing, the Toll Road Regulatory Agency (BPJT), Statistics Indonesia (BPS), Bank Indonesia, and previous studies, covering tariff benchmarks, traffic projections, investment and operating costs, and regional socio-economic indicators.

The model output generates tariff scenarios that balance revenue adequacy for investors and affordability for users. By integrating traffic demand dynamics and financial performance within a unified framework, the methodology supports evidence-based toll tariff determination for PPP toll road projects, particularly for greenfield corridors with limited historical traffic data.

Results and Discussion

Toll Road Tariff Variable Identification

Toll Road Tariff Definition and Factor Influencing

The determination of an optimal toll tariff is a multidimensional process that aims to balance the financial feasibility of toll road projects and users' affordability. In Public Private Partnership (PPP) toll road schemes, toll tariffs constitute the primary revenue source for investment recovery, therefore, tariff setting must be supported by a comprehensive analysis of demand, cost structures, and financial performance indicators. Key variables influencing toll tariff determination include Average Daily Traffic (ADT), capital expenditure (CAPEX), operational and maintenance costs (OPEX), users' Ability to Pay (ATP), macroeconomic conditions, and project feasibility indicators such as Net Present Value (NPV).

The relationship between toll tariffs and project revenue is inherently non-linear. While higher tariffs increase revenue per vehicle, excessive tariff levels may significantly reduce ADT due to demand elasticity, users' affordability constraints, and the availability of alternative routes or transport modes (Martínez and Jin 2024). Conversely, moderate tariff levels that maintain stable ADT can generate sustainable long-term revenue. ADT itself is influenced by a combination of socio-economic, infrastructural, and service-quality factors, including population growth, vehicle ownership, economic activity, congestion levels on parallel roads, and toll road service performance.

From a financial perspective, project feasibility is highly sensitive to CAPEX, OPEX, and discount rates. High initial investment and operating costs tend to reduce NPV unless compensated by sufficient traffic volumes or tariff adjustments (Organisation for Economic Co-operation and Development 2022). Macroeconomic indicators such as Gross Regional Domestic Product (GRDP) per capita affect users' ATP and indirectly determine the acceptable tariff range without causing a significant decline in ADT (Politis et al. 2023). These interactions highlight the dynamic nature of toll tariff determination, where changes in one variable may trigger feedback effects throughout the system.

In PPP toll road projects, ADT is the most critical variable underpinning financial modeling and tariff policy formulation. Project revenues, cash flows, and investment returns are directly proportional to projected traffic volumes. Inaccurate ADT forecasting may result in tariff levels that are either unaffordable for users or insufficient to ensure project viability, potentially leading to revenue shortfalls and financial distress. Therefore, a clear understanding of ADT behavior and its driving factors is essential for designing optimal, equitable, and sustainable toll tariff policies. Table 1.1 summarizes the key variables influencing toll tariff determination, their characteristics, and primary data sources.

Table 1. Variable Correlation Between Tariff Toll

Aspect	Variable	Classification	Data Source
Demand	Average Daily Traffic (ADT/LHR)	Dynamic	BPJT, Ministry of Public Works and Housing
Demand	Population Growth	Dynamic	Statistics Indonesia (BPS)
Demand	Vehicle Ownership Growth	Dynamic	National Police (Korlantas), Transportation Agency
Demand	Trip Generation & Attraction (economic activity, tourism, airport)	Dynamic	JICA, Andalalin Reports

Aspect	Variable	Classification	Data Source
Demand	Alternative Routes and Transport Modes	Static	Transportation Agency, Regional Planning Documents
Service	Toll Road Service Quality	Dynamic	Operator Reports, User Satisfaction Surveys
Affordability	Ability to Pay (ATP)	Dynamic	BPS, World Bank Group
Cost	Capital Expenditure (CAPEX)	Static	Project Feasibility Study
Cost	Operational & Maintenance Cost (OPEX)	Dynamic	Toll Road Operator
Financial	Toll Tariff Level	Dynamic	BPJT Regulations
Financial	Project Revenue	Dynamic	Model Output
Financial	Net Present Value (NPV)	Dynamic	Financial Model
Macroeconomic	GRDP per Capita	Dynamic	BPS
Financial	Discount Rate	Static	Ministry of Finance, OECD

Source: Author's calculation, 2026

System Dynamics Simulation for Toll Road Tariff Analysis

Conventional feasibility studies of toll road projects commonly rely on statistical forecasting methods, such as time-series and regression analysis, to estimate traffic demand, revenue, and cash flow over the concession period (Sterman 2002). While these approaches are useful for analyzing historical trends, they are inherently static and limited in their ability to capture dynamic changes and feedback mechanisms among key variables. In toll road projects, variables such as toll tariffs, Average Daily Traffic (ADT), operating costs, users' Ability to Pay (ATP), and macroeconomic conditions interact continuously and evolve over time. Statistical methods often fail to explicitly represent cause effect relationships and non-linear interactions, potentially leading to inaccurate forecasts when policy variables, such as tariff adjustments, change.

To overcome these limitations, this study adopts a system dynamics (SD) simulation approach to analyze toll road tariff policies and their financial implications. System dynamics is well suited for complex infrastructure systems characterized by feedback loops, time delays, and uncertainty, enabling long-term simulation of system behavior under different policy scenarios (Sterman 2002). By integrating toll tariffs, ADT, revenue, cost structure, and Net Present Value (NPV) within a unified modeling framework, the SD approach allows for scenario and sensitivity analysis to evaluate the dynamic impacts of tariff changes on demand and financial feasibility. This capability provides a more robust and adaptive basis for determining optimal toll tariffs in PPP toll road projects, ensuring a balance between project financial sustainability and user affordability.

Data Collection and Analysis

Data collection was conducted to support the development and validation of the system dynamics model for assessing traffic demand and toll tariff feasibility on the Solo Yogyakarta YIA Toll Road Section I. Both primary and secondary data were utilized to construct the model structure, estimate parameters, and simulate long-term policy scenarios.

Primary data were obtained through an expert questionnaire survey conducted on 30 October 2025, involving five senior practitioners: three Deputy Project Directors of the Solo YIA Toll Road, one Technical General Manager, and one Project Manager of the Solo Yogyakarta YIA Toll Road. The survey validated key variables influencing Average Daily

Traffic (ADT) and toll tariff determination identified from the literature, and the results were used to refine the causal loop diagram prior to stock flow formulation.

Secondary data were collected from PT Jasa Marga, PT Adhi Karya, BPJT, the Directorate General of Highways (Bina Marga), Bank Indonesia, and Statistics Indonesia (BPS). These datasets include historical traffic volumes, toll tariff structures, demographic indicators, regional economic statistics, inflation, and interest rates. Baseline traffic conditions were derived from the Average Daily Traffic (ADT) along the Solo Yogyakarta corridor prior to toll road operation, as shown in Table 1.2. The data indicates that Class I vehicles dominate daily movements and that each segment exhibits distinct traffic characteristics, forming the basis for initial demand calibration.

Table 2. Average Daily Traffic (ADT) on the Solo Yogyakarta Corridor

Segment	Class (each day)					Total
	I	II	III	IV	V	
Colomadu-Delanggu	9183	1366	28	14	4	10595
Delanggu-Klaten	5910	1256	216	0	274	7656
Klaten-Prambanan	6128	1216	302	48	253	7947
Prambanan-Purwomartani	5389	1239	42	0	5	6675

The base toll tariff per kilometer established by BPJT for Section I in Table 1.3 was used as the initial tariff parameter in the model. This tariff structure served as the reference for sensitivity analyses examining the relationship between toll rates, ADT, and projected revenue.

Table 3. Base Toll Tariff per Kilometer for Section I

Vehicle Class	Tariff per Km (IDR)
I	Rp. 1,906.00
II	Rp. 2,596.00
III	Rp. 2,596.00
IV	Rp. 3,792.00
V	Rp. 3,792.00

Future traffic demand was projected using vehicle growth factors derived from historical trends in Surakarta City and the Special Region of Yogyakarta, summarized in Table 1.4. The maximum growth rate was applied to represent a conservative, worst-case scenario, ensuring that the model captures traffic dynamics under high-pressure conditions. These parameters were incorporated into vehicle growth estimation, traffic volume forecasting, and trip assignment analysis.

Table 4. Vehicle Growth Rates in Surakarta and Yogyakarta

Region	Public Transport & Bus	Freight Vehicles & Trucks	Motorcycles & Cars
Solo	0,51%	5,73%	5,37%
Yogyakarta	1,15%	5,47%	4,28%
Maksimum	1,51%	5,73%	5,37%
Average			3,87%

All collected data were synthesized to identify the main determinants of traffic growth and tariff feasibility. Traffic projections were generated using proportional relationships with population growth, regional GDP at constant prices, and GDP per capita. Macroeconomic variables such as inflation and interest rates were integrated to simulate tariff adjustments and investment performance over the concession period. The resulting analytical inputs were embedded into the system dynamics model to evaluate long-term interactions among traffic demand, toll tariffs, revenue, and financial viability under multiple policy scenarios.

System Dynamic Modelling

Problem Articulation

Problem articulation establishes analytical boundaries and identifies the core elements of the system. The central theme of this research is the dynamic behavior of Average Daily Traffic (ADT), which functions as the primary determinant of toll road utilization and revenue generation. Because ADT evolves over time and responds to tariff adjustments, a static analytical approach is insufficient. A dynamic modeling framework is therefore required to capture the nonlinear and time-dependent interactions among tariff levels, traffic demand, and financial performance.

Key variables were identified through an extensive review of prior studies and include ADT, toll revenue, operational and maintenance costs, and Net Present Value (NPV). These variables form the core structure of the model and directly influence the financial feasibility of the PPP toll road project. The simulation time horizon is set at 40 years, corresponding to the maximum concession period typically applied in BOT-based PPP arrangements. This duration allows the model to capture long-term behavioral patterns and the cumulative effects of tariff policies on project performance.

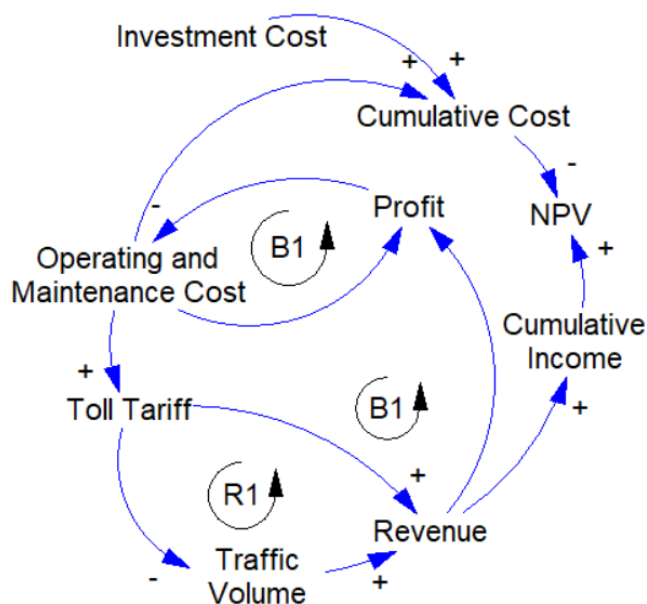


Figure 1. Model Boundary Diagram

The Model Boundary Diagram in Figure 1.1 defines the scope of the system by distinguishing endogenous, exogenous, and excluded variables. This diagram ensures that the model focuses on variables that are most relevant to the research objectives while maintaining conceptual clarity.

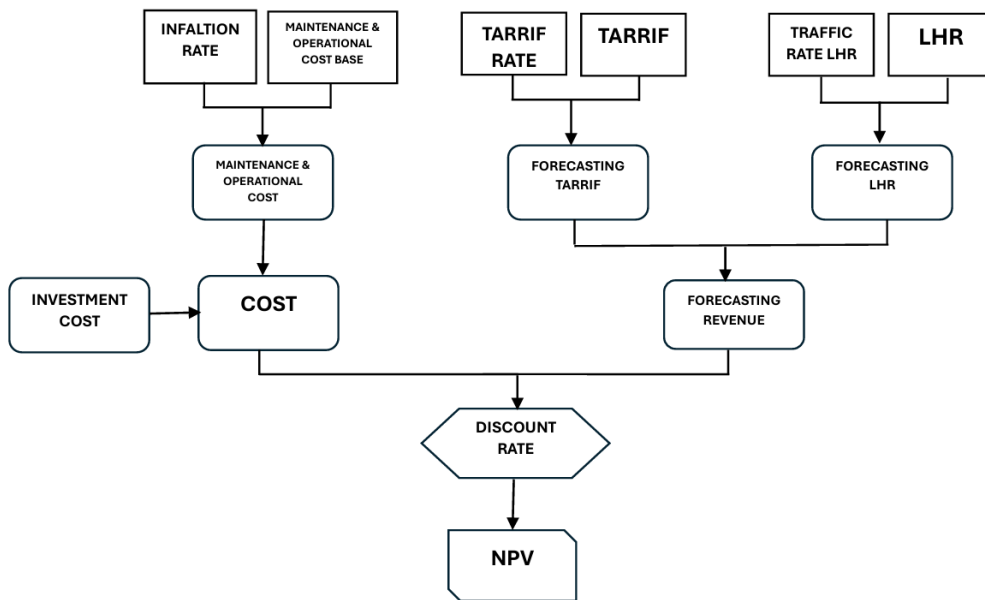


Figure 2. Subsystem Diagram

The Subsystem Diagram in Figure 2 further decomposes the system into interconnected components, illustrating how ADT, tariff levels, revenue, cost structures, and financial indicators interact within the broader system architecture.

Causal Loop Diagram

A causal loop diagram (CLD) is used to represent the feedback structure of a system by illustrating causal relationships among key variables. The diagram consists of variables connected by directed arrows, indicating cause effect relationships within the system. Positive (“+”) and negative (“-”) polarity signs are used to describe the direction of influence between variables, where a positive sign indicates that an increase in the causal variable leads to an increase in the affected variable, while a negative sign indicates an inverse relationship. In this study, the CLD is developed in Figure 1.3 to capture the dynamic interactions among traffic demand, toll tariffs, revenue, and economic factors influencing the performance of the Solo Yogyakarta YIA Toll Road.

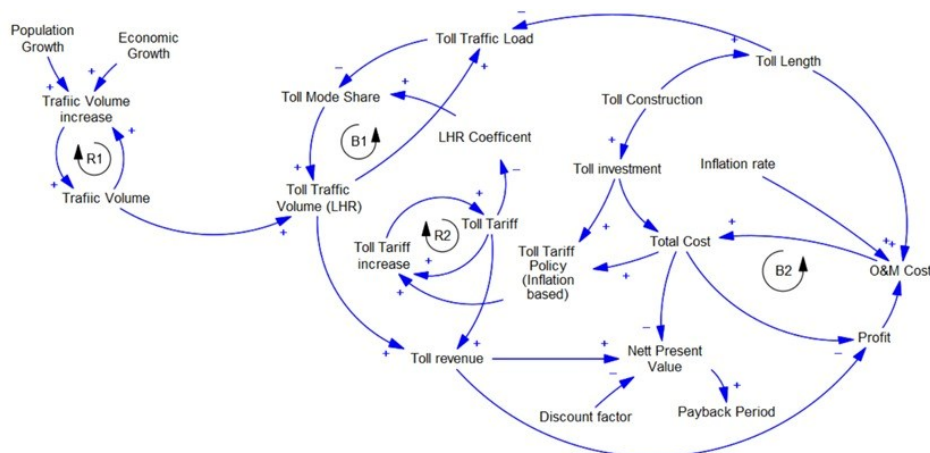


Figure 3. Causal Loop Diagram of Model

The proposed CLD in Figure 1.1 illustrates how Average Daily Traffic (ADT) is influenced by population growth, regional economic growth, and travel attractiveness, which in turn affects toll revenue. Higher toll revenue improves financial performance and investment feasibility, enabling better operation and maintenance quality, which positively feeds back

into service level and traffic demand. Conversely, increases in toll tariffs may negatively affect traffic volume due to demand sensitivity, forming a balancing feedback loop. The CLD highlights both reinforcing and balancing feedback mechanisms that govern long-term toll road performance, serving as a conceptual foundation for developing the stock flow diagram. While the CLD effectively explains the feedback behavior of the system, it does not capture quantitative detail, therefore, it is subsequently transformed into a stock flow diagram to enable dynamic simulation and policy analysis.

Conclusion

This study addresses the problem of how a system dynamics model can be developed to support toll tariff determination in Public Private Partnership (PPP) toll road projects. The results show that toll tariff determination is governed by complex and interrelated variables, including Average Daily Traffic (ADT), users' Ability to Pay (ATP), capital and operational costs, and macroeconomic conditions. These relationships form both reinforcing and balancing feedback structures that influence toll road demand and financial performance.

The developed causal loop diagram (CLD) successfully illustrates the dynamic interactions between toll tariffs and traffic demand, particularly how tariff increases may simultaneously improve unit revenue while reducing ADT through affordability constraints and demand elasticity. Conversely, improved service quality and economic growth contribute to reinforcing feedback loops that support traffic growth and revenue sustainability. By structuring these cause effect relationships, the model provides a clear conceptual foundation for understanding toll tariff behavior in PPP toll road systems.

Based on this structural analysis, the study suggests that toll tariff determination in PPP toll road projects should not rely solely on static cost-based approaches. Instead, it should consider dynamic feedback relationships among demand, affordability, and financial variables. The proposed system dynamics framework serves as a conceptual decision-support tool that can be further developed into a quantitative simulation model to evaluate tariff policies, particularly for greenfield projects with limited historical traffic data.

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