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Developing an Integrated ITS Adoption Framework: A Multidimensional Adoption Approach in the Context of Intelligent Transportation

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ABSTRACT

Urban transportation systems in developing cities like Yogyakarta face challenges such as congestion, limited infrastructure, and fragmented policies. This study aims to develop a context-specific framework for Intelligent Transportation System (ITS) adoption by integrating the Technology Acceptance Model (TAM) with external readiness factors, including infrastructure quality, technology access, socioeconomic status, and policy support. A survey of 300 transportation users was conducted, and data were analyzed using Structural Equation Modeling with Partial Least Squares (SEM-PLS). Instrument validity was confirmed through expert review and Content Validity Index (CVI). The study introduced two new constructs Smart Readiness and Social Affordability to capture individual and systemic influences on technology adoption in ITS. Results show that perceived usefulness and ease of use mediate the relationship between external readiness and behavioral intention. Government policy and infrastructure were the strongest predictors of ITS adoption. The model explained 70% of the variance in behavioral intention, indicating strong explanatory power and model fit. In conclusion, contextual factors such as infrastructure, governance, and digital access play a pivotal role in enabling ITS adoption in mid-sized developing cities. The proposed framework extends TAM by incorporating systemic urban readiness, offering both theoretical advancement and practical guidance for policy makers and urban planners.

1. INTRODUCTION

Urban transportation in many developing cities is facing increasing challenges related to congestion, emissions, and limited infrastructure. Yogyakarta, a mid-sized city in Indonesia known for its cultural tourism and educational centers, has witnessed a dramatic surge in vehicle ownership proportional upgrades to its transportation infrastructure. This imbalance has led not only to frequent traffic congestion but also to inefficiencies in public transportation systems such as TransJogja, and to socio-environmental consequences including increased travel time, noise pollution, and digital divide in ITS service accessibility [1, 2].

Although Intelligent Transportation Systems (ITS) have emerged as a promising solution to address urban mobility issues through data-driven and sensor-based innovations, their adoption in Yogyakarta remains limited. Prior research has mainly applied models such as the Technology Acceptance Model (TAM) to examine individual behavior toward ITS usage [3, 4]. However, these studies often focus narrowly on internal psychological factors, namely Perceived Usefulness (PU) and Perceived Ease of Use (PEOU), without accounting for external structural constraints such as infrastructure readiness, social equity, or the regulatory environment [5, 6].

Yogyakarta, as a medium-sized city in Indonesia, is a clear example of this complexity. The city faces increasing traffic congestion, a surge in vehicle volumes during the holiday season, and an uneven distribution of digital infrastructure, especially in suburban areas. Figure 1 shows the route of the TransJogja route map that exists at this time. Although several previous studies have used the TAM approach to explain user behavior toward ITS, the main focus of this model is limited to individual psychological constructs such as PU and PEOU [3]. However, this kind of approach does not fully reflect the reality of ITS adoption in the field, as it has not taken into account very important external factors such as infrastructure readiness, social influence, socioeconomic conditions, and government regulatory support [4, 5].

Frameworks that consider external readiness also allow for the formulation of more contextual and effective adoption strategies. Research [7] shows that cities with high integration between technological planning and public policy have a higher ITS success rate. Meanwhile, emphasized that user attitudes and behavioral intentions can only be maximized if the ITS system is designed by considering the socio-economic realities and existing infrastructure [8, 9].

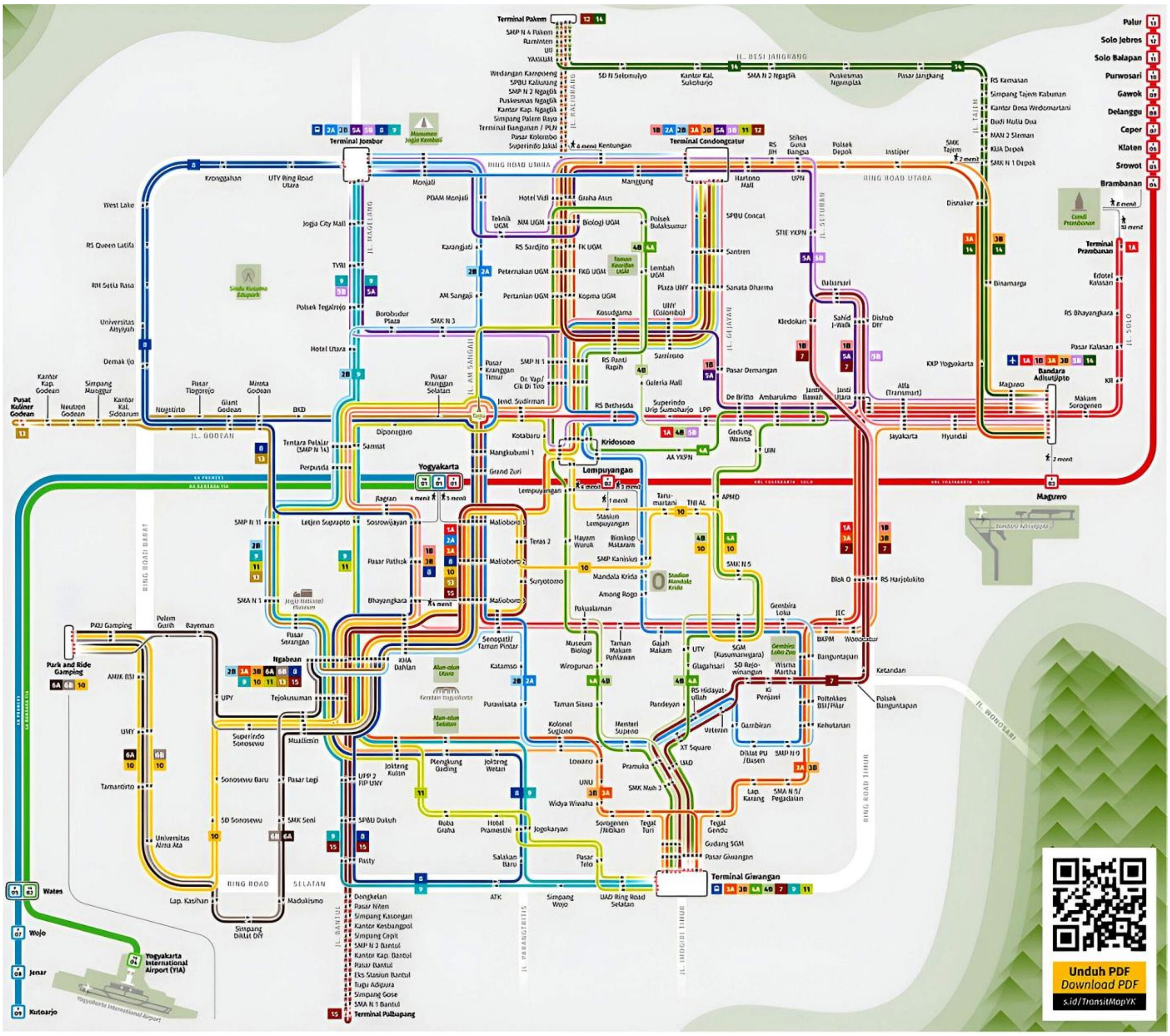

Figure 1. TransJogja map route
(https://dishub.jogjaprov.go.id/trans-jogja)

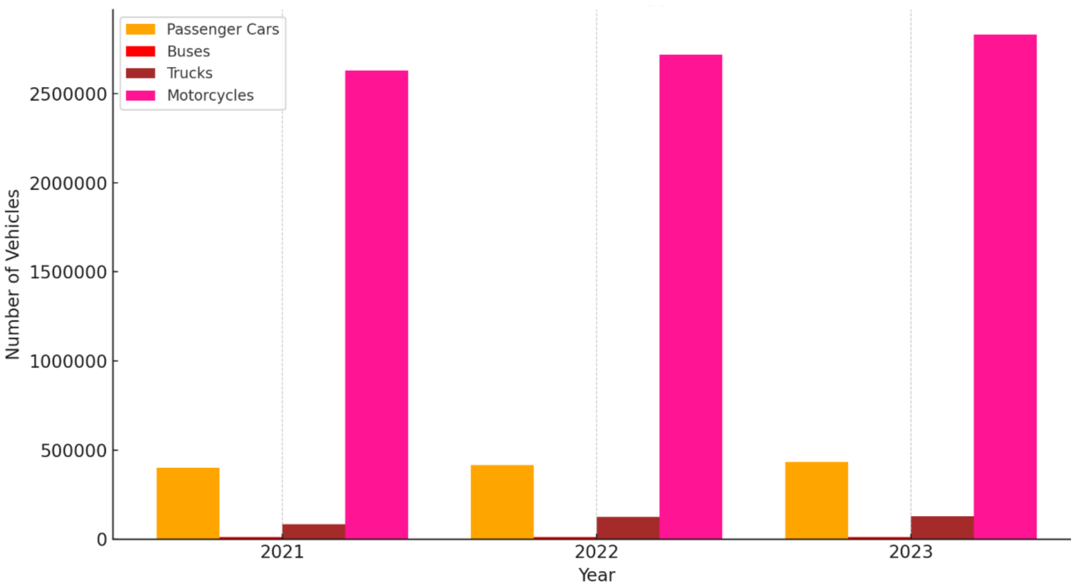

Figure 2. Increase in the number of vehicles in Yogyakarta
(https://yogyakarta.bps.go.id)

This gap is particularly important for Yogyakarta, where disparities in digital infrastructure, inconsistent government policy enforcement, and varying levels of socioeconomic accessibility hinder the successful deployment of ITS [7]. Despite several pilot ITS initiatives, such as digital signage and real-time bus tracking, there is no integrative framework that maps user acceptance with broader readiness dimensions. Furthermore, studies evaluating ITS adoption in Yogyakarta remain fragmented and have not proposed a multidimensional framework based on empirical validation [10, 11]. In addition, there have not been many ITS adoption frameworks specifically developed for medium-sized cities such as Yogyakarta, which have unique geographical, economic, and local policy characteristics [7, 10].

This research addresses this gap by proposing an extended TAM-based adoption framework that incorporates key dimensions of urban readiness: infrastructure, technology, socioeconomic factors, financing, and government policy. The study aims to answer the following research question: *How do both individual perceptions and external readiness factors influence the intention to adopt ITS in a developing city like Yogyakarta?* This framework not only tests the influence of TAM constructs but also contextualizes adoption behavior within structural conditions, thereby providing theoretical and practical contributions to ITS development in similar urban environments [7, 12, 13]. The model is designed to reflect the real conditions faced by ITS stakeholders, not only user perceptions, but also the involvement of the supporting structures of the city's transportation system.

The novelty of this research lies in its orientation in developing a contextual ITS adoption model, not just testing existing models. This study developed a new framework based on empirical data in Yogyakarta and validated it through an advanced statistical modeling approach (SEM-PLS). The final results of this study are expected not only to make a theoretical contribution to the ITS adoption literature but also to offer a policy instrument that is applicable to local governments and transport authorities to accelerate the transformation towards a smarter and more inclusive urban mobility system. This was done, seeing a very high increase in the number of vehicles, especially in the DI Yogyakarta area. Figure 2 shows the growth rate of vehicles between 2021 and 2023.

2. LITERATURE REVIEW

Digital transformation in the transportation sector has given birth to the concept of ITS, which integrates sensor technology, communication networks, and data processing platforms to improve the efficiency, safety, and sustainability of urban mobility [12, 14]. However, studies show that the development and adoption of ITS in developing countries, including Indonesia, still face major obstacles. Factors such as infrastructure inequality, lack of policy support, and low technological literacy are the main challenges in its implementation [7, 15].

In developing cities, such as Yogyakarta, these challenges are increasingly complex because they are not only in the technical aspects, but also in terms of transportation governance capacity and end-user engagement [11]. The city is experiencing significant growth in motor vehicles without adequate improvement of road infrastructure, which leads to an imbalance between the needs and capacity of the transportation system [1, 2]. Therefore, it is crucial for the research to re-evaluate its technology adoption approach by taking into account the local and structural factors typical of developing cities.

The most frequently used technology adoption model in the study of intelligent transportation is the TAM, which emphasizes two main constructs, namely PU and PEOU [16, 17]. Although TAM is potent in explaining technology adoption behavior in various sectors [18, 19], this model has limitations in the context of adopting complex systems such as ITS. In a developing urban environment, external aspects such as digital infrastructure, communication networks, and government fiscal constraints are important determinants that are not taken into account in the classic TAM model [20, 21].

Several studies have attempted to expand the TAM by adding variables such as social influence, trust in the system, and data security [13, 22]. However, there is no theoretical approach that systematically brings together user perceptions with the external readiness of the city in one comprehensive framework. This weakness leads to a gap between the prediction of adoption behavior and the reality of implementation in the field, especially in ITS policies that demand collaboration across institutions and sectors [11, 23].

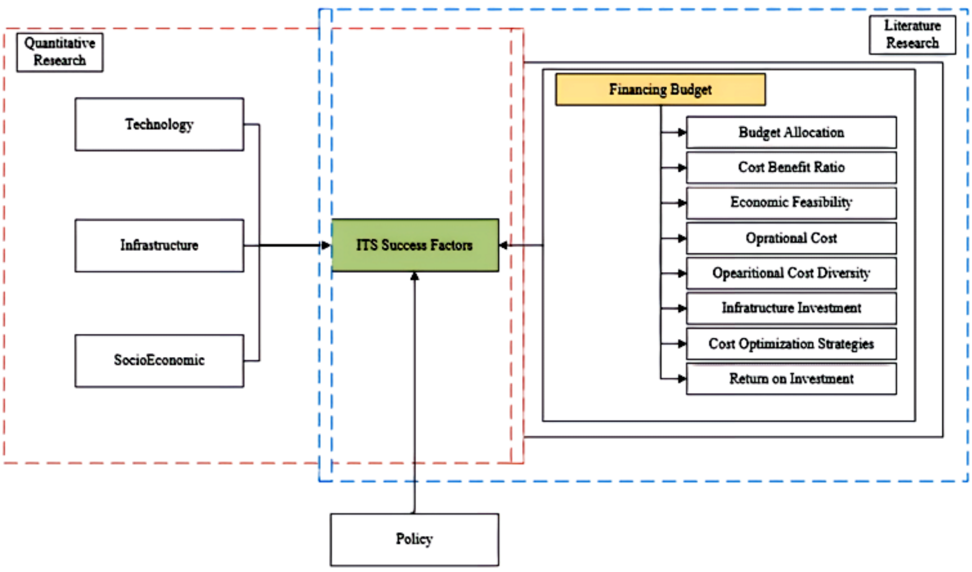

Figure 3. ITS success factor mapping

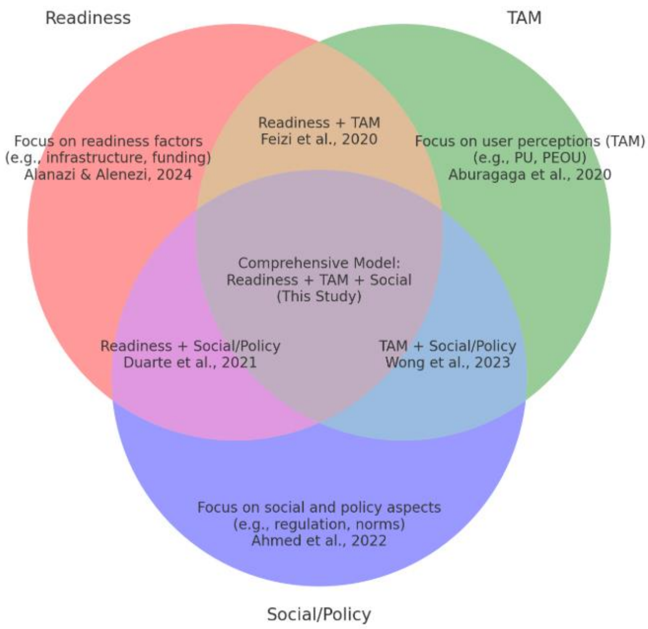

Figure 4. Research gap in ITS models

To answer this gap, recent research encourages the development of a multidimensional ITS adoption framework, which combines internal (user perception) and external (structural readiness) factors in one integrative model [11, 20]. Figure 3 shows the results of the analysis in identifying the success factor in the implementation of ITS. This approach is relevant considering that the success of ITS implementation is greatly influenced by the readiness of technological infrastructure, social awareness, and synergy between policy actors and user communities [12].

In this context, the development of an ITS adoption model based on the integration of TAM with external readiness is an important step in producing an inclusive, sustainable, and evidence-based smart transportation policy. This study tries to fill this gap by developing a framework that is responsive to the real conditions of developing cities, especially in areas such as Yogyakarta, which are at a critical point of urban mobility transformation. Figure 4 shows the gaps that occur in research related to ITS.

3. METHODOLOGY

3.1 Literature review and model development

This study adopts an explanatory quantitative approach with a methodological structure divided into four integrated phases. The main objective of this study is to develop a framework for the adoption of ITS that not only reflects user perceptions but also integrates external readiness factors such as infrastructure, government policies, and socioeconomic conditions. This research seeks to develop a comprehensive and contextual ITS adoption model to be applied in developing cities such as Yogyakarta.

This study began with a systematic literature review following the PRISMA approach, identifying 390 relevant articles from Scopus, Web of Science, and IEEE Xplore. After a three-stage screening process based on title relevance, abstract content, and full-text eligibility, 53 articles were retained. From these, two major construct groups were identified: internal constructs from the Technology Acceptance Model (TAM), namely Perceived Usefulness (PU), Perceived Ease of Use (PEOU), and Behavioral Intention (BI) and external readiness dimensions (infrastructure, technology, socioeconomic, financing, and government policy). The results of this study are the basis for the preparation of a conceptual model that integrates the readiness factor with the TAM construct. The process can be seen in Figure 5.

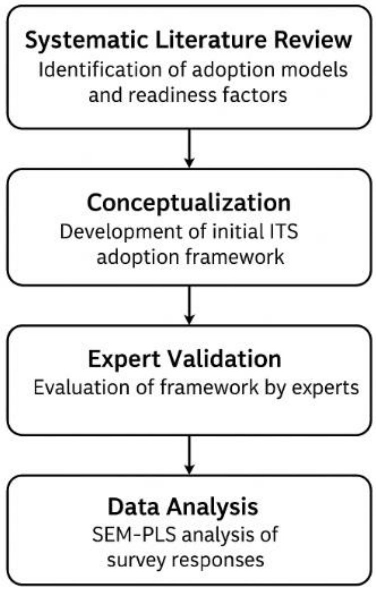

Figure 5. Data analysis process flow diagram

The second phase is the conceptualization stage of the framework. Based on the results of the literature analysis in the first phase, an initial model framework was prepared that combined the TAM construct with external readiness factors. The model formulation process is carried out carefully, ensuring that each variable has a theoretical basis and a logical linkage in the ITS adoption system. Construct readiness is assumed to have an indirect effect on the intention of use through the mediation of PU and PEOU, as well as the basic structure of the TAM model. This framework was then evaluated through an expert validation forum to assess the theoretical feasibility, clarity of the relationships between variables, and their relevance to the context of medium-sized cities in Indonesia. Validation is carried out with a qualitative approach, involving experts from the fields of transportation, public policy, and information technology.

3.2 Instrument development and validation

Furthermore, the third phase focuses on instrument development and questionnaire validation. A structured questionnaire was developed to operationalize eight constructs using 40 indicators derived from the conceptual model. The instrument underwent Content Validity Index (CVI) assessment involving three domain experts who evaluated each item for relevance, clarity, and completeness on a 4-point Likert scale. Items with CVI scores below 0.79 were revised or excluded to ensure only content-valid items were retained. After revision, a pilot test was conducted with 30 respondents representing the study population to assess comprehensibility and consistency of response.

3.3 Sampling and data collection

The fourth phase is the data collection and analysis stage. The questionnaire was distributed to respondents in the Special Region of Yogyakarta, both through online and offline surveys. Respondents were selected using purposive sampling, targeting transportation users in Yogyakarta who had familiarity with ITS features (e.g., navigation apps, smart traffic lights). The inclusion criteria included being aged 17 or above, residing in Yogyakarta, and having experience using at least one public or digital transport feature. Exclusion criteria were non-residency and no exposure to ITS-related services. Data collection was conducted via both online and offline surveys (Google Forms and face-to-face interviews), yielding a total of 300 valid responses. Ethical consent was obtained from all participants. A total of 300 valid respondent data were successfully collected and then analyzed using the Structural Equation Modeling with Partial Least Squares (SEM-PLS) method with the help of SmartPLS 4 software. SEM-PLS is used for its ability to handle complex structural models, especially when latent constructs are combined with reflective indicators and non-normal formats of data.

The analysis was carried out in two main stages, namely the evaluation of the measurement model (outer model) and the evaluation of the structural model (inner model). The evaluation of the outer model includes a construct reliability test (with Cronbach's Alpha and Composite Reliability), a convergent validity test (using an Average Variance Extracted value above 0.5), and a discriminant validity test with the Fornell-Larcker method and HTMT ratio. After that, the inner model was evaluated to test the strength of the relationship between constructs through the values of path coefficients, determination coefficients (R^2), effect size (f^2), and predictive relevance values (Q^2). Bootstrapping analysis is used to ascertain the statistical significance of all relationship paths between variables.

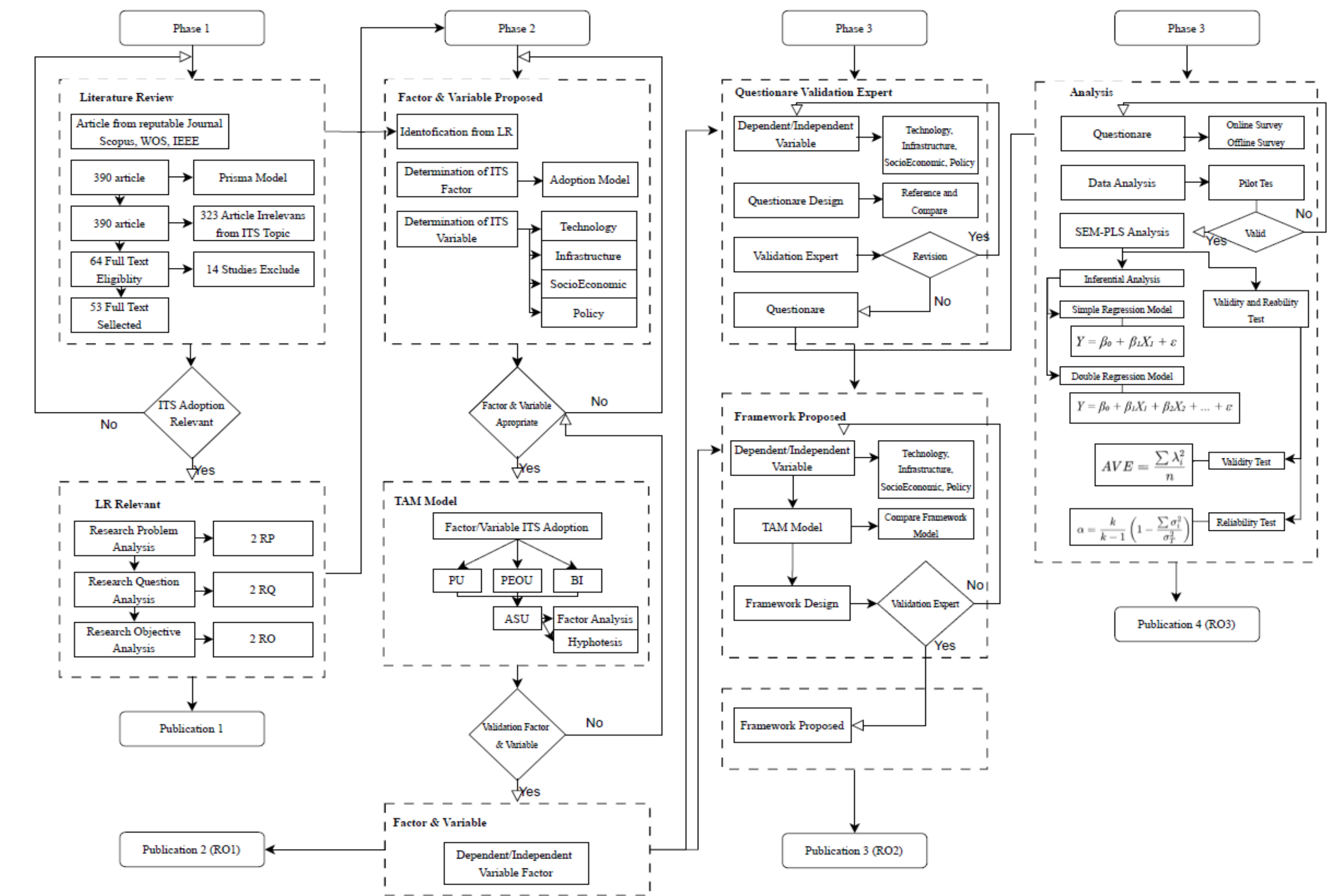

Figure 6. Methodology process

From the entire series of processes, a model ITS adoption framework was obtained that not only validates the contribution of PU and PEOU as predictors of use intention, but also emphasizes the importance of external readiness, such as infrastructure availability and government policy support. The flow methodology can be seen in Figure 6.

The framework resulting from the research contributes to the development of technology adoption theories in the transportation sector, while providing a strong empirical basis to support the implementation of inclusive, effective, and contextual smart transportation systems in developing urban areas.

In general, the process of developing the ITS adoption framework in this study began with a systematic literature review to identify the factors that affect the adoption of ITS. This literature reveals the importance of external readiness, such as technology, infrastructure, socioeconomics, and regulations, as well as internal user perceptions such as the ease and usability of the system (PU, PEOU).

3.4 Data analysis

The conceptual model was developed into a questionnaire validated by experts using the CVI. The validated instrument was then used to collect data from respondents in Yogyakarta who represented potential ITS users. Data were analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM) through SmartPLS 4. This method was chosen due to its suitability for exploratory research, tolerance for non-normal data, and capability to handle complex models with multiple constructs and indicators. The analysis involved two stages: (i) the measurement model (outer model) assessment, which tested reliability (Cronbach's Alpha, Composite Reliability), convergent validity (AVE > 0.5), and discriminant validity (Fornell-Larcker, HTMT); and (ii) the structural model (inner model) assessment, including path coefficients, R^2, effect size (f^2), and predictive relevance (Q^2). Bootstrapping with 5,000 samples was used to evaluate the statistical significance of the hypothesized paths.

The results of the analysis resulted in an empirically verified ITS adoption model. This model shows that infrastructure readiness, socioeconomic conditions, and government policies have a significant influence on user perception, which in turn has an impact on the intention of using ITS. Thus, this framework offers a holistic approach to understanding and driving contextual adoption of ITS in developing cities.

4. RESULT AND DISCUSSION

4.1 Framework result

This research aims to develop an ITS adoption framework that is relevant to the context of developing cities, with an emphasis on the integration between the internal constructs of TAM and external readiness factors that include infrastructure readiness, social influence, and policy support. This approach not only focuses on user perception of technology, but also considers the readiness of the system more thoroughly. The combination of TAM with Technology Readiness (TR) reveals that citizens' discomfort and insecurity negatively impact the ease of use and usability of smart governance services, and innovation positively influences this perception, suggesting that fostering a culture of innovation can increase technology uptake [24, 25]. Figure 7 shows the resulting framework model.

The framework model developed in this study represents a synthesis between external readiness factors and user perception constructs to explain the intention of ITS adoption in a more contextual manner. The model image shows that four main factors—Technology, Infrastructure, Social Economic, and Financing Budget—contribute to two intermediate constructs called Smart Readiness (PU) and Social Affordability (PUEO).

Smart Readiness (PU) reflects the perception of the benefits and technical readiness of the ITS system. This variable is influenced by the readiness of the available infrastructure and technology, such as the existence of sensor systems, network connectivity, and the sophistication of digital platforms. The higher this technical readiness, the higher the perception of usability of the ITS system is.

Meanwhile, PUEO is an extension of the PEOU construct, which not only contains the perception of technological convenience but also the social and economic affordability of users in accessing and utilizing ITS. This variable is influenced by socio-economic factors (digital literacy, technology inclusion) as well as budget allocation or financing schemes that allow for wider participation from the community.

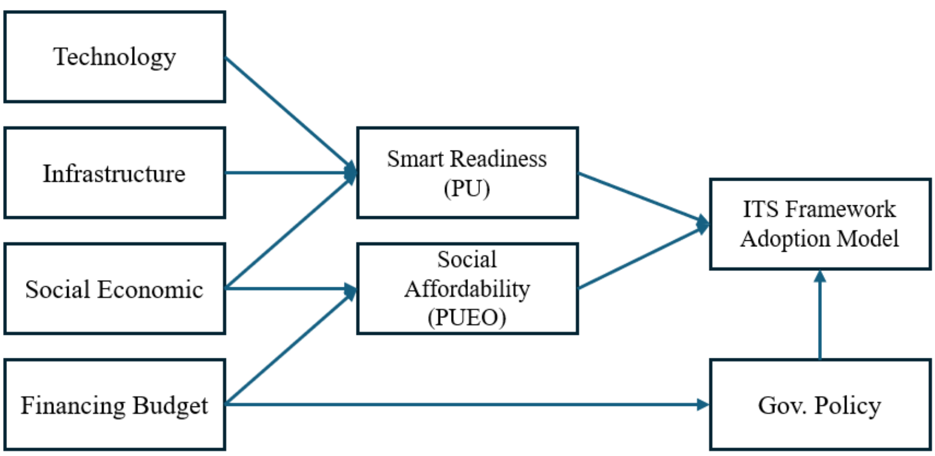

Figure 7. Framework ITS adoption model

These two constructs are the main determinants in compiling the ITS framework adoption model, which is a conceptual framework that explains how technical and social readiness are converted into the intention and behavior of adopting smart transportation technology. In addition, the model also shows that Government Policy has a dual role: first, as a direct supporter of the adoption model, and second, as a reinforcing factor in the variables of financing and infrastructure sustainability.

This model emphasizes that the success of ITS adoption in developing cities is not only determined by the perception of technology, but also supported by a supporting ecosystem in the form of policies, funding, and social readiness of the community. Therefore, a comprehensive approach as depicted in the model is a strategic key to realizing an intelligent transportation system that is inclusive, sustainable, and adaptive to local dynamics.

4.2 SEM-PLS result analysis

From the description of the framework model, the analysis was carried out based on data from respondents who used transportation in the Yogyakarta area, using the PLS-SEM approach. The measurement model showed strong validity and reliability. All outer loading values exceeded 0.70, indicating good indicator reliability. Composite reliability and Cronbach's Alpha values were also above 0.70 for all constructs, confirming internal consistency. Convergent validity was demonstrated through AVE values above 0.5, and discriminant validity was confirmed using the Fornell-Larcker criterion and HTMT ratio [26-28].

On the structural model side, it was found that the PU variable had a strong effect on ITS with a coefficient of $\beta = 0.72$ ($p < 0.05$), suggesting that the perception of real benefits such as time efficiency and ease of navigation plays an important role in shaping users' positive attitudes towards ITS [8]. Meanwhile, Infrastructure also has a significant effect on PU with a value of $\beta = 0.68$ ($p < 0.05$), which means that the easier the system is to use, the higher the perception of benefits [3, 19, 29].

In terms of external factors, infrastructure readiness makes a major contribution to PU ($\beta = 0.68$, $p < 0.05$). The existence of infrastructure such as communication networks, sensor systems, and transportation control centers is considered to increase confidence in the performance of ITS. However, there are significant constraints, especially in the suburbs of Yogyakarta, which face limitations in digital connectivity and service distribution [7, 30].

Socioeconomic factors, especially related to digital literacy and financial ability, affect PEOU with a coefficient of $\beta = 0.54$ ($p < 0.05$). People with low technological understanding and high cost perceptions tend to show hesitancy in adopting ITS [22, 31]. These findings reinforce the importance of education-based interventions and subsidies so that ITS can be accepted in a more inclusive manner.

Most notably, government policy support had a significant influence on ITS, with a coefficient of $\beta = 0.74$ ($p < 0.05$). Supportive regulations, including system interoperability, usage incentives, and data openness, strengthen public confidence in the legitimacy and benefits of ITS [4, 32].

4.3 Structural model assessment

The structural model analysis revealed statistically significant relationships between the proposed constructs. Bootstrapping with 5,000 resamples confirmed the significance of all path coefficients at $p < 0.05$. Table 1 is a summary table of the results of the SEM-PLS analysis, which shows the relationship between constructs along with the value of the path coefficient and its significance.

Overall, the developed model showed a good fit model, with SRMR values = 0.056 and $R^2 = 0.70$ for the behavioral intention variable, indicating that this model was able to explain 70% variability in the intention of adopting ITS technology. This makes the model structurally as well as contextually valid.

Table 1. Significant relationship

No.	Relationship	Path Coefficient (β)	P-Value	Significant
1	Infrastructure-PU	0.68	< 0.05	Significant
2	SocioEconomics-PEOU	0.54	< 0.05	Significant
3	Government Policy-ITS	0.74	< 0.05	Significant
4	PU-ITS	0.72	< 0.05	Significant

The resulting final model includes the following technical and non-technical dimensions:

- Perceived Usefulness & Perceived Ease of Use as the foundation of users' functional perception;
- Infrastructure as a readiness factor that strengthens PU;
- Socio-Economics as a determinant of comfort and accessibility;
- Government Regulation as a Driver of Trust and Legitimacy of Adoption;
- Social Influence as a normative reinforcer in user communities.

4.4 Comparative analysis with previous studies

The findings of this study are consistent with and extend prior research on ITS adoption. Studies such as those by Kumar et al. [3] and Nguyen et al. [22] highlighted the importance of PU and PEOU in influencing behavioral intention [5, 7]. This research builds upon that foundation by showing how external readiness factors, namely infrastructure, socioeconomic conditions, and policy support, play a crucial role in shaping those perceptions [10, 13].

For example, the strong influence of government policy ($\beta = 0.74$) aligns with findings in advanced urban contexts such as Seoul and Singapore, where integrated policies and digital infrastructure have facilitated widespread ITS adoption. Conversely, Yogyakarta faces fragmented policies and budget limitations, reinforcing the need for coordinated governance strategies [11, 14].

Socioeconomic disparities affecting digital literacy and technology access were also observed, emphasizing that smart mobility adoption depends heavily on affordability and inclusivity [10].

4.5 Contribution and recommendation

The developed ITS adoption model was empirically tested and statistically validated. It demonstrated that external readiness factors significantly shape user perceptions, which in turn drive behavioral intention to adopt ITS. The model explained 70% of the variance in intention and confirmed the vital role of policy and infrastructure in enabling smart mobility. This study contributes a context-sensitive framework for ITS policy planning in medium-sized cities, especially in developing nations like Indonesia.

Table 2 shows that the developed structural model has high statistical feasibility based on two main indicators, namely Standardized Root Mean Square Residual (SRMR) and R^2 in the Behavioral Intention (BI) construct. An SRMR value of 0.056, which is below the threshold of 0.08, indicates that the model has a good *goodness of fit* and that the residual prediction error between the observed variable and the theoretical model is relatively small. This confirms that the proposed model structure is able to accurately represent empirical data [27, 33].

Table 2. Tabel model fit and predictive

No.	Model Indicator	Value	Benchmark	Interprettion
1	SRMR	0.065	< 0.08	SRMR < 0.08 indicates a good mode.
2	R2 - ITS	0.70	> 0.50	R^2 = 0.70 means 70% of the variance in BI is explained by the model.

Meanwhile, an R^2 value of 0.70 on the BI variable shows that as much as 70% variability in user behavior intentions can be explained by a combination of constructs in the model, namely PU, PEOU, infrastructure readiness, social influence, and government policy support. This R^2 value not only exceeds the minimum threshold (0.50) commonly used in SEM-PLS-based studies but also strengthens the predictive validity of the developed model [5].

Thus, the ITS adoption model resulting from this research is not only structurally valid but also contextual and practical in answering the challenges of implementing transportation technology in developing cities such as Yogyakarta. In other words, the ITS adoption framework model has succeeded in answering the problem by providing a holistic and data-based approach to the challenges of transportation transformation in the city of Yogyakarta. So that this model becomes a strategic instrument in formulating policies for the adoption of scalable and inclusive smart transportation technology.

5. CONCLUSION

This article developed and empirically validated a comprehensive ITS adoption framework that integrates the TAM with key external readiness factors, including infrastructure, technology, socioeconomic conditions, government policy, and financing. Based on survey data from 300 respondents in Yogyakarta, the model demonstrated strong predictive accuracy ($R^2 = 0.70$) and structural validity (SRMR = 0.056). It revealed that infrastructure readiness and government regulation significantly influence perceived usefulness and ease of use, which in turn drive behavioral intention to adopt ITS.

The findings emphasize the urgency of addressing transportation challenges in rapidly urbanizing regions like Yogyakarta. Without adequate digital infrastructure and inclusive policy support, ITS cannot be effectively implemented. The study also introduces two novel constructs, Smart Readiness and Social Affordability, that contextualize technology acceptance within real-world constraints of mid-sized developing cities.

Theoretical contributions include the expansion of TAM through the integration of readiness dimensions, making it more suitable for analyzing systemic technology adoption. Practical implications highlight the need for multi-sectoral coordination, inclusive urban policies, and investment in digital literacy and infrastructure.

Policy Recommendations:

1. Local governments should prioritize ITS infrastructure funding through public-private partnerships and national support schemes.
2. A digital literacy campaign should be launched to improve awareness and usability of ITS among all socioeconomic groups.
3. An ITS governance roadmap should be developed to ensure policy coherence across city departments.

Limitations include the focus on one urban area (Yogyakarta), reliance on cross-sectional data, and exclusion of long-term behavioral change dynamics.

Future research directions may include longitudinal studies to capture evolving user behaviors, cross-city comparative frameworks, and integration of sustainability or environmental dimensions into ITS adoption modeling.

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