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Cyber-Physical System-Based Electronic Traffic Law Enforcement (ETLE) for Strengthening Public Security Governance in Indonesia

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Abstract

Electronic Traffic Law Enforcement (ETLE) represents a significant innovation in the digitalization of traffic law enforcement in Indonesia. This study aims to analyze the implementation of ETLE within the framework of *Cyber-Physical Systems* (CPS), examine its challenges and opportunities, and formulate governance-oriented policy recommendations. A descriptive qualitative approach was employed, using semi-structured interviews with 12 informants, including police officers, transportation experts, and road users. Legislative and comparative approaches were also adopted to assess the compatibility of ETLE with national regulations and to benchmark practices from Singapore, Japan, and South Korea. The findings reveal four key issues in ETLE implementation: infrastructure inequality, incomplete derivative regulations, uneven human resource capacity, and public resistance. The discussion highlights that while ETLE enhances transparency, accountability, and effectiveness, its sustainability depends on regulatory strengthening, infrastructure equity, officer capacity building, and community engagement. This study further proposes the integration of *restorative justice* principles as a participatory alternative in traffic law enforcement. Theoretically, it contributes to socio-legal studies by linking ETLE

with CPS, while practically emphasizing governance reforms to ensure fairness, legitimacy, and sustainability.

***Keywords**: ETLE,* Cyber-Physical Systems *(CPS), Governance, Restorative Justice, Traffic Law*

1. Introduction

Traffic law enforcement plays a crucial role in maintaining public safety and legal certainty. In Indonesia, conventional ticketing systems have long been criticized for weaknesses such as susceptibility to abuse of authority, limited manpower, and vulnerability to illegal collection practices (Adhitia, 2023; R. B. Denhardt & Denhardt, 2000; Dwiyanto, 2021a). To address these issues, the National Police introduced Electronic Traffic Law Enforcement (ETLE) as part of a broader effort to modernize public services and strengthen governance in the transportation sector (Borins, 2001).

Since its nationwide launch in 2021, ETLE has been regarded as a breakthrough innovation in digitizing law enforcement (Aldizar et al., 2025; Gronroos, 1990; Lincoln & Guba, 1988). By utilizing cameras, sensors, and automatic license plate recognition (ANPR), ETLE enables the detection of violations in real time without requiring the physical presence of officers (Aldizar et al., 2025; Indarsih, 2021; A. A. Putri & Yahman, 2025; Z. A. Putri, 2024). This mechanism reduces opportunities for bribery and promotes transparency, thereby supporting public trust in law enforcement.

Previous studies have highlighted ETLE's contributions to improving accountability and efficiency in traffic enforcement (Adhinugroho et al., 2024; Ariwibowo, 2024). Researchers have also examined its legal foundations within the framework of Indonesia's Road Traffic and Transportation Law (UU LLAJ) and the Electronic Information and Transactions Law (UU ITE) (Arjuna, 2020). These studies emphasize that ETLE helps ensure fairness and consistency in traffic management by minimizing discretionary practices.

At the same time, several challenges remain evident in the literature. Scholars such as Abdullah & Windiyastuti (2022) and Adhitia (2023) point to issues of infrastructure inequality, with cameras concentrated in major urban centers while rural areas remain uncovered. Others highlight the high costs of installation and maintenance, uneven human resource competence in operating advanced systems, and persistent public concerns over privacy and surveillance (Moore, 1997; Thramboulidis, 2015; Wisniewski, 2001).

Beyond the technical and legal perspectives, international studies provide useful insights into how advanced governance tools can evolve. For example, Singapore has successfully applied smart surveillance systems, Japan integrates IoT-enabled traffic sensors, and South Korea implements CPS-based enforcement models (Borins, 2001; Heeks, 2005; Mulgan & Albury, 2003). These comparative experiences demonstrate the transformative potential of integrating traffic law enforcement into the broader framework of Cyber-Physical Systems (CPS), enabling predictive analytics, automation, and participatory governance (Thramboulidis, 2015).

Despite its promise, research on ETLE in Indonesia remains limited and largely descriptive. Most existing studies focus only on technical or formal-legal aspects without examining ETLE's integration with the CPS (Ishak, 2022; Jamwal et al., 2020; Kim & Park, 2017; Simanjuntak et al., 2024; Solichan & Mashdurohatun, n.d.). There is also little discussion of restorative justice approaches, which could shift enforcement from being purely punitive toward more educative and participatory practices. This gap is problematic because without clear regulatory frameworks, adequate infrastructure, trained personnel, and citizen engagement, ETLE may fail to build long-term legitimacy and trust.

This study aims to analyze the implementation of ETLE within the CPS framework and assess its challenges and opportunities. It also aims to provide governance-oriented policy recommendations, including the integration of restorative justice principles, to ensure fair, effective, and sustainable traffic law enforcement in Indonesia.

2. Method

This study adopts an interpretivist paradigm, emphasizing subjective meanings and contextual interpretations of ETLE implementation in Indonesia. A qualitative descriptive design was chosen to capture the lived experiences of stakeholders and the socio-legal context of traffic law enforcement (Patton, 2002; Rubin & Rubin, 2011). In addition, legislative and comparative approaches were integrated to analyze ETLE's legal foundation and benchmark against international best practices. This approach is suitable because the research questions require in-depth exploration of governance, regulatory, and cultural dimensions rather than mere statistical generalization.

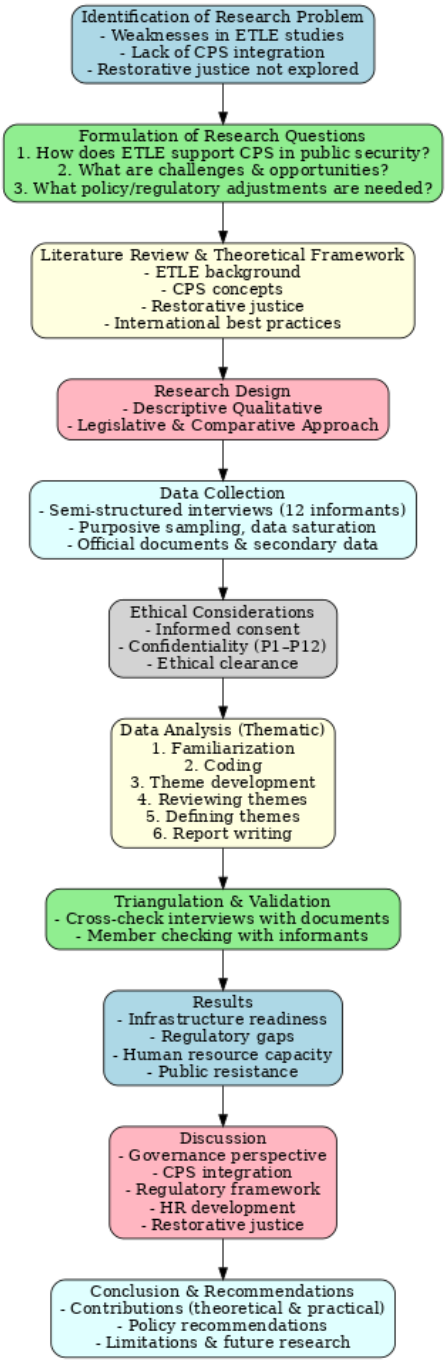

Figure 1. Research Flow Diagram

Figure 1 illustrates how the research process began by identifying the limitations in the integration of ETLE with CPS and restorative justice,

followed by formulating research questions and reviewing relevant theories. A descriptive qualitative design with a legislative and comparative approach was applied, using interviews, documents, and secondary data. Ethical principles were ensured, and thematic analysis with triangulation validated the findings (Ridder et al., 2014). The research results were categorized into four main themes, discussed from the perspectives of governance and CPS, and concluded with theoretical contributions, practical recommendations, and directions for future research (Denzin & Lincoln, 2011).

The research was conducted in Indonesia, focusing primarily on urban centers (Jakarta, Surabaya, Bandung) where ETLE cameras are most widely deployed, while also considering perspectives from smaller cities with limited technological infrastructure. The setting was chosen because it reflects both the strengths and limitations of ETLE: metropolitan areas demonstrate advanced adoption, while peripheral regions highlight infrastructural inequality (J. V Denhardt & Denhardt, 2015; Irfan, 2023; Ulrich, 1996; Zeithaml et al., 2000). The socio-cultural context of traffic behavior, law enforcement practices, and public perceptions of surveillance strongly influence the phenomenon under study.

Participants were selected using purposive sampling with the following inclusion criteria:

- Police officers directly involved in ETLE operations (technical and supervisory roles),
- Transportation experts with knowledge of digital traffic systems,
- Road users who have received ETLE tickets or are affected by its implementation.

Exclusion criteria included individuals without direct experience with ETLE or those unwilling to provide consent.

A total of 12 participants were recruited (coded P1–P12) to ensure data saturation. Demographically, the group represented diverse ages, occupations, and user perspectives. Recruitment was conducted through official correspondence with police institutions and voluntary participation of road users.

Table 1. Participant Profile

Category	Number of Participants	Description
Police Officers	5	Directly involved in ETLE operations (technical and supervisory roles).
Transportation Experts	3	Experts with academic or professional expertise in transportation systems and CPS.

Category	Number of Participants	Description
Road Users	4	Drivers or road users directly affected by ETLE tickets and enforcement.

Data were collected using three complementary techniques. First, semi-structured interviews were conducted both face-to-face and online (via Zoom), with each session lasting between 45 and 90 minutes. These interviews were guided by open-ended questions designed to explore participants' perceptions, challenges, and opportunities related to the implementation of ETLE. Second, document analysis was undertaken, focusing on statutory laws such as the Road Traffic and Transportation Law (UU LLAJ), the Electronic Information and Transactions Law (UU ITE), and the Personal Data Protection Law (UU PDP), along with ministerial regulations and policy reports issued by Kementerian Kominfo and the Indonesian National Police. Third, a comparative review was carried out using secondary data on CPS-based traffic enforcement systems implemented in Singapore, Japan, and South Korea. This triangulation of methods provided a comprehensive understanding of ETLE from both domestic and international perspectives.

The primary research instrument was an interview guide containing pre-formulated yet flexible questions, which allowed participants to elaborate on their personal experiences while maintaining consistency across sessions. For document analysis, a structured checklist was employed to classify each document based on its legal source, type of regulation, and relevance to ETLE. Validation of the instruments was conducted through peer review by academic colleagues, ensuring both content validity and clarity. Furthermore, two pilot interviews were carried out, and minor adjustments were made to refine the questions and improve the flow of interviews.

The data collection followed a systematic and sequential procedure (Creswell & Creswell, 2017). Initially, the interview guide and consent forms were prepared and reviewed for ethical compliance. This was followed by establishing initial contact with potential participants and securing institutional approval. Between March and May 2024, semi-structured interviews were conducted, during which audio recordings and detailed field notes were taken.

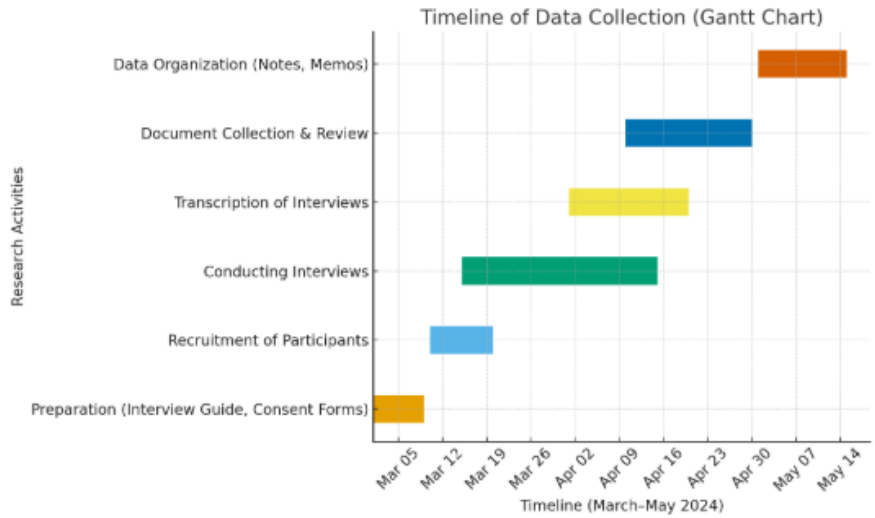

Figure 2. Data Collection Timeline (Gantt Chart)

After each session, interview transcripts were prepared to generate raw data for analysis. In parallel, relevant legal and policy documents were compiled to complement the interview data. Field notes and analytical memos were then organized to capture contextual insights and to support the subsequent coding and thematic analysis. Throughout the process, rapport was built with participants by emphasizing voluntary participation, ensuring confidentiality, and creating a safe space for open discussion (Creswell & Creswell, 2017; Denzin & Lincoln, 2011).

The data were analyzed using thematic analysis as outlined by Braun and Clarke (2006). The process consisted of six stages: (1) familiarization with interview transcripts and field notes, (2) generating initial codes through manual coding using Microsoft Word and Excel, (3) searching for broader themes by grouping codes into categories, (4) reviewing themes to ensure internal consistency and coherence with the data, (5) defining and naming themes with concise and meaningful labels, and (6) producing the final narrative that linked the findings to the research questions and theoretical framework. Themes were developed inductively from the empirical data but were also informed by theoretical constructs such as ETLE, Cyber-Physical Systems, and restorative justice.

Several strategies were employed to ensure the trustworthiness of the data. Credibility was strengthened through triangulation of data sources, combining interviews, document analysis, and secondary literature, as well as through member checking with selected participants (Rubin & Rubin, 2011). Transferability was supported by providing a thick

description of the research setting, participants, and context, enabling readers to judge the applicability of findings to other contexts. Dependability was ensured by maintaining an audit trail that documented coding processes, analytical memos, and research decisions. Confirmability was addressed through reflexivity, bracketing of researcher assumptions, and regular supervisory discussions to minimize bias and maintain objectivity.

Ethical approval for this study was obtained from the relevant institutional review board. All participants provided informed consent prior to their participation, with clear explanations of the research objectives and their rights. Confidentiality was guaranteed by anonymizing participant identities using codes (P1–P12), and sensitive information was handled with discretion. All data, including interview recordings and transcripts, were securely stored in password-protected files to ensure compliance with ethical standards for research involving human subjects and sensitive legal data.

3. Results

The analysis of interviews and supporting documents revealed four major themes regarding the implementation of Electronic Traffic Law Enforcement (ETLE) in supporting Cyber-Physical Systems (CPS) in Indonesia. These themes are: infrastructure readiness, regulatory gaps, human resource capacity, and public resistance.

Theme 1: Uneven ETLE Infrastructure

Most informants emphasized that the introduction of ETLE has reduced reliance on manual enforcement and minimized opportunities for on-the-spot negotiations. However, infrastructure distribution remains concentrated in major cities such as Jakarta, Surabaya, and Bandung, while smaller towns and rural areas remain largely uncovered.

A police officer (P3) stated:

> *"ETLE works effectively in Surabaya and Jakarta, but in small towns the technology is absent, so violations are still high."*

A transportation expert (P5) similarly noted:

> *"The government prioritized deployment in metropolitan areas, but this creates inequality in law enforcement and undermines national consistency."*

This finding is consistent with previous studies showing that ETLE deployment initially focused on metropolitan regions(Abdullah &

Windiyastuti, 2022; Adhitia, 2023; Arjuna, 2020). Official data also confirm that most ETLE cameras are concentrated in Java, with limited coverage in Eastern Indonesia (Kementerian Kominfo, 2023).

Theme 2: Regulatory Gaps

Although ETLE is legally grounded in the Road Traffic and Transportation Law (UU LLAJ) and the Electronic Information and Transactions Law (UU ITE), derivative regulations remain absent, particularly concerning evidentiary standards, appeal mechanisms, and system accountability.

A legal scholar (P8) highlighted this issue:

> *"There is still legal ambiguity. For example, if a driver disputes an ETLE fine, what is the formal appeal mechanism? Currently, the procedure is unclear, and this weakens legal certainty."*

This problem aligns with Adhinugroho, Ismiyanto, & Muhtarom (2024)), who stressed that legal certainty in ETLE is undermined by the lack of derivative regulations. Similarly, Ariwibowo (2024) argued that procedural ambiguity allows for informal settlements, thereby weakening public trust in law enforcement.

Theme 3: Human Resource Capacity

The effectiveness of ETLE depends not only on technology but also on officers' ability to operate CPS-based systems. Interviews revealed that while some officers are proficient, others struggle with data management, system maintenance, and cybersecurity protocols.

One officer (P7) admitted:

> *"We need more training; the technology is sophisticated, but not all officers are ready to use it properly."*

A senior traffic unit official (P2) echoed this concern:

> *"The system requires not just technical skills but also legal and ethical understanding. Training has been uneven, and this creates operational risks."*

Supporting studies also indicate that ETLE operator training has not been evenly distributed across regions, creating performance inconsistencies (Fauzi et al., 2023; Gibson, 1991; Indarsih, 2021; Simanjuntak et al., 2024).

Theme 4: Public Resistance

Public responses to ETLE were mixed. While some road users appreciate the transparency of electronic enforcement, others perceive ETLE as intrusive surveillance and an additional burden.

A driver (P10) commented:

> *"It feels like Big Brother is watching. Sometimes we feel over-controlled, and we are not sure if our data is safe."*

Another informant (P12), who had received multiple tickets, expressed skepticism:

> *"Sometimes the camera captures wrongly, but we don't know how to contest it. People lose trust if errors cannot be corrected."*

These findings are consistent with Ishak (2022), who emphasized the role of effective oversight in building public trust. Resistance behaviors such as tampering with license plates have also been observed, reflecting both distrust and the need for stronger public education (Adhitia, 2023; Ariwibowo, 2024; Dahlan et al., 2023; Dahlan & Jalil, 2023; A. A. Putri & Yahman, 2025).

Table 2. Results Summary Table

Theme	Definition	Frequency	Representative Quote
Infrastructure Readiness	Availability and distribution of ETLE and ANPR systems to support CPS-based traffic law enforcement.	Mentioned by the majority of informants (≥7 out of 12)	*"ETLE works effectively in Surabaya and Jakarta, but in small towns the technology is absent, so violations are still high."* (P3)
Regulatory Gaps	Absence of derivative regulations related to evidentiary standards, appeal mechanisms, and ETLE accountability.	Mentioned by >5 informants (primarily legal experts)	*"There is still legal ambiguity. For example, if a driver disputes an ETLE fine, what is the formal appeal mechanism? Currently, the procedure is unclear, and this weakens legal certainty."* (P8)
Human Resource	Officers' competencies in operating the ETLE system, including	Mentioned by >6 informants (officers and senior	*"We need more training; the technology is sophisticated, but not all officers are ready to use it properly."* (P7)

Theme	Definition	Frequency	Representative Quote
Capacity	technical skills, data management, and legal-ethical understanding.	traffic officials)	
Public Resistance	Public perceptions and reactions to ETLE, including issues of privacy, fairness, and trust in the system.	Mentioned by nearly all public informants (≥8)	*"It feels like Big Brother is watching. Sometimes we feel over-controlled, and we are not sure if our data is safe."* (P10)

4. Discussion

4.1 Governance Perspective

The findings of this study demonstrate that ETLE has contributed to advancing the principles of transparency and accountability in governance. By minimizing face-to-face interactions between officers and citizens, the system reduces opportunities for bribery and discretionary practices that have historically undermined public trust in traffic enforcement (Dwiyanto, 2021a, 2021b). However, this progress remains uneven. The concentration of ETLE infrastructure in metropolitan areas, such as Jakarta and Surabaya, has created disparities in enforcement compared to peripheral and rural regions. In practice, this means that citizens in large cities face stricter enforcement regimes, while those in smaller towns remain outside the system's reach. Such asymmetry reflects broader challenges of decentralized governance in Indonesia, where institutional capacity and resource allocation remain highly uneven (Brown & Osborne, 2012; Hartley, 2005; Osborne & Brown, 2013). Unless investments are directed toward infrastructure equity, ETLE risks reinforcing structural inequalities, thereby limiting its ability to deliver justice consistently across the nation.

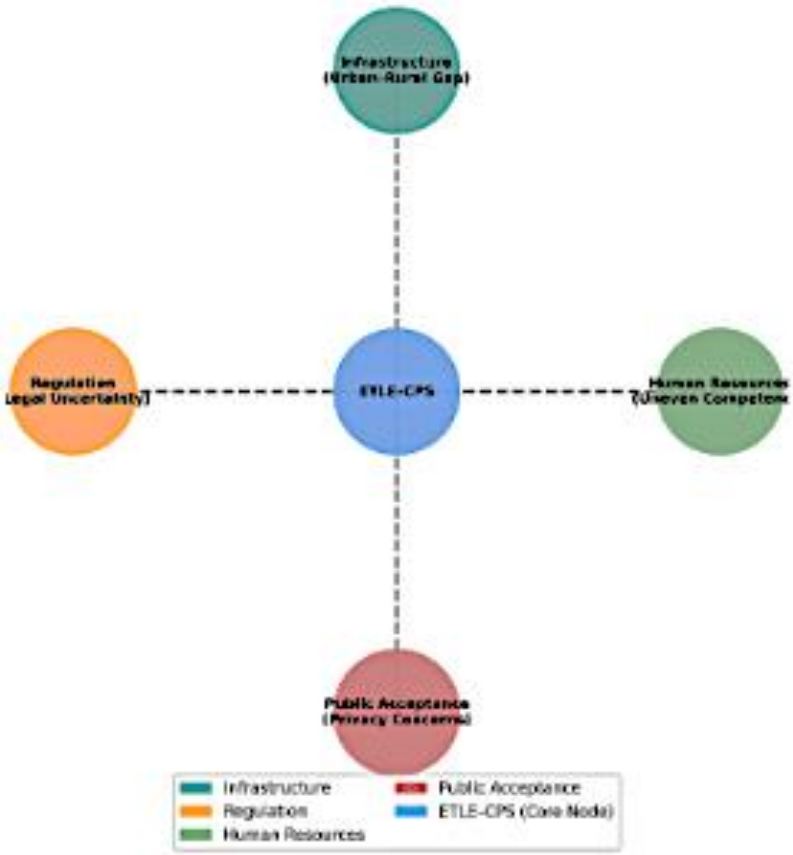

Figure 3. Thematic Network Diagram

Figure 3 illustrates the central position of ETLE–CPS as a governance innovation shaped by four interconnected dimensions: Infrastructure (Urban–Rural Gap), Regulation (Legal Uncertainty), Human Resources (Uneven Competence), and Public Acceptance (Privacy Concerns). The diagram demonstrates that ETLE–CPS operates as a multidimensional system, where weaknesses in one domain (e.g., legal uncertainty) can undermine progress in others (e.g., public trust). Conversely, strengthening domains such as infrastructure equity or human resource competence can generate positive spillover effects, reinforcing systemic legitimacy (Pambudi & Hidayat, 2022; Prabowo et al., 2025; Z. A. Putri, 2024). This model highlights that ETLE should not be seen solely as a technological innovation but as a governance ecosystem requiring balanced development across institutional, infrastructural, and societal dimensions.

4.2 CPS Integration

From a Cyber-Physical Systems (CPS) perspective, ETLE is currently limited to a reactive function: detecting violations and issuing fines. While this role has improved deterrence, it constrains ETLE's transformative potential within the intelligent governance (R. B. Denhardt & Denhardt, 2000; Lovelock & Wirtz, 2001). Ideally, CPS-based ETLE should evolve into a predictive and preventive mechanism capable of analyzing traffic flows, identifying accident-prone zones, and issuing early warnings to road users (Parasuraman et al., 1988; Pollitt & Hupe, 2011; Sedarmayanti et al., 2017). Interviews with police officers revealed demand for such predictive capacities, suggesting institutional openness to technological advancement.

Comparative experiences reinforce this trajectory: Singapore's integrated smart surveillance, Japan's IoT-enabled road sensors, and South Korea's CPS-based enforcement highlight how digital ecosystems can facilitate proactive traffic management rather than mere punishment (Heeks, 2005; Borins, 2001; Mulgan & Albury, 2003). As illustrated in Figure 3, the CPS dimension links directly to both infrastructure and human resource capacity, underscoring that predictive ETLE cannot succeed without equitable infrastructure distribution and skilled operators. For Indonesia, embracing CPS integration would not only strengthen traffic law enforcement but also embed ETLE within a broader vision of data-driven urban planning and public safety management.

4.3 Regulatory Framework

Despite technological advances, ETLE's legitimacy remains vulnerable due to the absence of comprehensive derivative regulations. Current statutory foundations—such as the Road Traffic and Transportation Law (UU LLAJ) and the Electronic Information and Transactions Law (UU ITE)—lack specific provisions governing evidentiary standards, appeal mechanisms, and accountability for system errors. This regulatory gap leaves citizens uncertain about how to contest violations and raises the risk of informal dispute handling, thereby undermining legal certainty (Dwiyanto, 2021b; Mertokusumo, 1986). Comparative evidence underscores the importance of legal clarity: Singapore's regulatory framework for electronic enforcement provides transparent procedures that enhance both compliance and public trust (Heeks, 2005; Osborne & Brown, 2013). For Indonesia, harmonizing ETLE with the Personal Data Protection Law (UU PDP) is particularly urgent to safeguard civil liberties while consolidating institutional

legitimacy. Without such reforms, ETLE may be perceived as technologically advanced but legally fragile.

4.4 Human Resource Development

The sustainability of ETLE also depends on the competence of human resources. While some officers have acquired advanced technical skills, others struggle with system operation, data management, and cybersecurity protocols. This uneven distribution of expertise reflects institutional limitations in adapting to digital governance systems. International experiences suggest that structured, continuous training programs embedded within broader public sector reforms are critical for ensuring consistent performance (Fauzi, Istania, & Giyanto, 2023; Simanjuntak, Subagyo, & Sufianto, 2024). In Indonesia, capacity-building should extend beyond technical competencies to include legal literacy—particularly in handling electronic evidence—and ethical awareness to address risks of misuse and algorithmic bias (Dwiyanto, 2021b; Sedarmayanti et al., 2017). A holistic approach to human resource development would not only improve technical proficiency but also enhance institutional accountability and strengthen citizen trust.

4.5 P*ublic Acceptance and Restorative Justice*

Perhaps the most decisive factor in ETLE's long-term viability is public acceptance. Resistance emerges from concerns about privacy, algorithmic errors, and the lack of transparent appeal mechanisms. In some cases, this resistance manifests in active countermeasures, such as tampering with license plates. Such dynamics reveal that public skepticism is not merely a technical challenge but also a governance problem, highlighting the importance of robust oversight institutions and transparent correction mechanisms (Ishak, 2022; Pambudi & Hidayat, 2022).

As shown in Figure 3, public acceptance is positioned at the base of the thematic network, symbolizing both its dependence on and influence over the other dimensions. Without trust in data security, clear regulatory frameworks, and transparent appeals, citizens are unlikely to accept ETLE as a legitimate governance tool. Addressing these concerns requires more than regulatory fixes; it also calls for a shift in enforcement philosophy. Integrating restorative justice principles provides a constructive alternative. Instead of relying exclusively on monetary fines, violators could be redirected to educational programs or community service, thereby reframing ETLE as an educative rather than repressive system. This approach aligns with the New Public Service paradigm, which prioritizes participatory governance and citizen engagement over punitive measures

(Denhardt & Denhardt, 2000; Denhardt & Denhardt, 2015). By fostering awareness-based compliance, restorative justice can transform ETLE into a catalyst for a culture of traffic discipline grounded in shared responsibility rather than fear of punishment.

4.6 *Implications for Policy and Practice*

Taken together, these findings suggest that ETLE should not be regarded merely as a technological innovation but as part of a broader agenda of systemic governance reform. Several implications follow. First, expanding ETLE infrastructure beyond metropolitan centers is essential to ensure equity and consistency in law enforcement. Second, the development of derivative regulations, particularly those aligned with the Personal Data Protection Law, is critical for clarifying appeal procedures, accountability mechanisms, and data governance standards. Third, continuous investment in human resource capacity must be prioritized, with training programs that address not only technical competencies but also legal and ethical dimensions. Fourth, public engagement strategies, including digital literacy campaigns and transparent communication, are necessary to build trust and counter misinformation. Finally, piloting restorative justice alternatives, such as traffic education and community service, would complement monetary fines and foster participatory compliance.

5. Conclusion

The implementation of Electronic Traffic Law Enforcement (ETLE) within the Cyber-Physical Systems (CPS) framework in Indonesia demonstrates both notable progress and persistent challenges. The Results section highlighted four major themes: infrastructure readiness, regulatory gaps, human resource capacity, and public resistance, which together shape the system's effectiveness and legitimacy. These findings provide a nuanced picture of how ETLE operates in practice, capturing both its promise as a governance innovation and the barriers that continue to limit its full potential.

The Discussion further emphasized that ETLE represents more than a technological advancement; it is a test case for digital governance reform. Its contribution lies in promoting transparency, accountability, and consistency in law enforcement, yet uneven infrastructure, weak derivative regulations, skill disparities among officers, and skepticism from the public hinder its institutionalization. Addressing these issues requires not only technical fixes but also governance-oriented solutions, including equitable

infrastructure investment, regulatory clarity, continuous capacity building, and restorative justice integration.

By situating ETLE within the broader theoretical framework of CPS and New Public Service, this research extends scholarly debates on how digital enforcement can balance efficiency with fairness, and control with participation. At the same time, it offers practical recommendations to policymakers for strengthening legitimacy and sustainability in Indonesia's traffic law enforcement.

Ultimately, effective governance through ETLE requires both systemic reform and societal engagement. It demands technical sophistication combined with ethical sensitivity, regulatory robustness aligned with citizen rights, and innovation that fosters not only compliance but also trust. In this sense, the long-term success of ETLE-CPS will depend on Indonesia's ability to weave together technological capability, institutional integrity, and public participation into a coherent, adaptive, and inclusive model of digital governance.

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