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Digital Transformation of Road Safety Systems: A Mediating Model for Transportation Safety Pillars in Indonesia

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ABSTRACT

Road transportation safety remains a major public policy challenge in Indonesia, characterized by high accident rates and substantial socio-economic impacts. The government has introduced the National General Plan for Traffic and Road Transportation Safety 2021–2040, structured around five key safety pillars. However, policy implementation continues to face challenges, including institutional fragmentation, weak cross-sectoral coordination, limited data integration, and the suboptimal use of digital technologies. Prior studies have predominantly examined road safety from fragmented perspectives, often positioning technology as a supporting factor rather than a systemic component. Consequently, empirical evidence on the mediating role of technology in strengthening road safety policy outcomes remains limited, particularly within developing country contexts. This study addresses this gap by conceptualizing technology as a mediating variable within the national road safety policy framework. A quantitative approach was adopted using the Structural Equation Modeling–Partial Least Squares (SEM-PLS) method, based on survey data from 1,000 respondents comprising policymakers, law enforcement officers, transportation stakeholders, and road users. The findings demonstrate that the five road safety pillars, safe systems, safe roads, safe vehicles, safe road users, and post-crash management have a positive and statistically significant effect on road transportation safety performance. In addition, technology was empirically validated as a significant mediating variable that enhances the effectiveness of each safety pillar. These results emphasize the strategic importance of digital transformation for achieving integrated, evidence-based road safety governance. Policy implications include strengthening integrated data systems, reinforcing lead agency functions, enhancing institutional capacity, and adopting a Digital Safe System approach.

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1. INTRODUCTION

Road transportation safety is a strategic national issue with direct implications for people's quality of life, sustainable development, and economic stability. Traffic accidents cause approximately 1.19 million deaths annually globally, with over 90% occurring in low- and middle-income countries [1]. In Indonesia, the Indonesian National Police Traffic Corps (Korlan Lalu Lintas Polri) reported a persistent increase in accident fatalities, particularly involving two-wheeled vehicles [2]. This situation prompted the government to establish the National General Plan for Traffic and Road Transportation Safety (RUNK LLAJ) 2021–2040 through Presidential Regulation Number 1 of 2022, which adopted five road safety pillars as the main policy framework. However, various studies have shown that the existence of policies alone is insufficient to guarantee a reduction in fatalities if not accompanied by coordinated, data-driven implementation that adapts to technological developments [3], [4].

Theoretically, the modern road safety approach is based on the Safe System Approach, rooted in Systems Theory, which views accidents as systemic failures rather than simply individual errors [5], [6]. In the context of public policy, successful implementation is influenced by communication factors, resources, implementer disposition, and bureaucratic structure [7], [8], [9]. The adoption of safety technology is explained through the Diffusion of Innovation Theory [10], the Technology Acceptance Model [11], and the Theory of Planned Behavior [12], which emphasize the importance of user acceptance. Meanwhile, Human Factors Theory [13], [14] explains human limitations in transportation systems. Empirical research shows that technologies such as ITS, ADAS, ETLE, and e-Call have been proven to reduce accidents and fatalities [15], [16], [17]. However, most of these studies are still partial and have not examined the role of technology as a strengthening mechanism for cross-pillar policy implementation.

Based on these gaps, this study aims to: (1) analyze the influence of Safe Transportation Systems, Safe Roads, Safe Vehicles, Safe Road Users, and Accident Victim Handling on improving road transportation safety; (2) examine the role of technology as a mediating variable in strengthening the relationship between safety pillars; and (3) identifying policy gaps and technology integration needs in the implementation of RUNK LLAJ in Indonesia. This research is expected to contribute to the development of an empirical model of road safety based on technology integration, relevant to the context of developing countries and supporting the achievement of the 2030 SDG targets.

2. METHOD

2.1. Data Collection Method

This study uses a quantitative, explanatory research design to analyze causal relationships among variables in the implementation of road transportation safety policies. Data collection was conducted through a structured questionnaire survey distributed to 1,000 respondents, including transportation sector stakeholders, law enforcement officers, drivers, and the general public, across various regions of Indonesia. The questionnaire instrument was designed based on indicators of the five pillars of road safety and technology variables, with responses measured on a five-point Likert scale. In addition to primary data, this study used secondary data, including policy documents, traffic accident statistics, and official reports from relevant ministries and institutions, to strengthen the contextual analysis.

2.2. Data Processing and Analysis Method

This study used Structural Equation Modeling–Partial Least Squares (SEM-PLS) through SmartPLS software. SEM-PLS was chosen because it can test complex structural relationships, accommodate mediation models, and does not require normal data distributions or large sample sizes [18]. The analysis was conducted through two main stages: evaluation of the measurement model (construct validity and reliability) and evaluation of the structural model (testing the significance of path coefficients and mediation effects). This approach allows empirical testing of the role of technology as a mediating variable in strengthening the influence of the five safety pillars on improving road transportation safety, yielding robust, evidence-based findings [19].

2.3. Mathematical Formula

1. Confirmatory Factor Testing

   Confirmatory factor analysis is conducted to analyze whether the observed model variables contribute to the latent variables.

   a. Goodness-of-fit is a test used to assess the degree of fit between a model and the data. The model fit criteria include [20].

      1) Chi-square Statistics

         This measurement uses the likelihood ratio chi-square statistic. A model is considered good if the chi-square value is low. The basis for acceptance is the probability with a cut-off value of $p = 0.05$ or $p = 0.10$.

      2) Goodness of Fit Index (GFI)

         GFI is a measure of the range of values between 0 and 1.0, while marginal fit ranges from 0.80 to <0.90 (better fit).

      3) Adjusted Goodness of Fit Index (AGFI)

         If the AGFI is 0.90 or greater, the model is accepted. A value of 0.95 can be interpreted as a generally good level of model fit, while a value between 0.9 and 0.95 indicates a fair level of fit.

      4) Comparative Fit Index (CFI)

         This index ranges from 0 to 1, with values closer to 1 indicating the best level of fit.

   b. Factor Weight Significance Test

      The factor weight significance test is conducted to determine whether a variable, individually or in combination with other variables, contributes to the explanation of the latent variable. This test is conducted in two ways: based on the lambda value (the required lambda is ≥ 0.5) and factor weights (assessment criteria: $CR > 1.96$ and $p < 0.05$) [20].

c. Reliability Test

Model reliability is a measure of the consistency of a model's indicators, defined as the average variance extracted from each indicator. Reliability testing is performed by examining the construct reliability (CR> 0.7, indicating that the indicators used have sufficient reliability to explain the construct) and the Variance Extraction (AVE > 0.5) [20].

3. RESULTS AND DISCUSSION

3.1. Results

Data Validity Test

Construct validity was assessed using Confirmatory Factor Analysis (CFA) with Convergent Validity criteria [18]. The results of the construct validity test, as shown in Figure 1, indicate that all latent constructs in the research model met the required validity criteria. Convergent validity, evaluated through outer loadings, showed that most indicators had loadings above 0.70, indicating a strong relationship between the indicators and the constructs being measured. Several indicators with outer loading values in the range of 0.60–0.69 were retained because they still met the acceptance limit and were supported by theoretical relevance. Furthermore, the Average Variance Extracted (AVE) values for all constructs were recorded as greater than 0.50, indicating that each construct was able to explain more than half of the variance in its indicator. Discriminant validity was evaluated using the Fornell–Larcker criterion, which showed that the square root of the AVE for each construct was higher than the correlation between the other constructs.

These findings confirm that each construct has adequate differentiation and measures conceptually distinct concepts. Overall, these results confirm that the measurement instrument has good construct validity and is suitable for use in structural model analysis and hypothesis testing in this study.

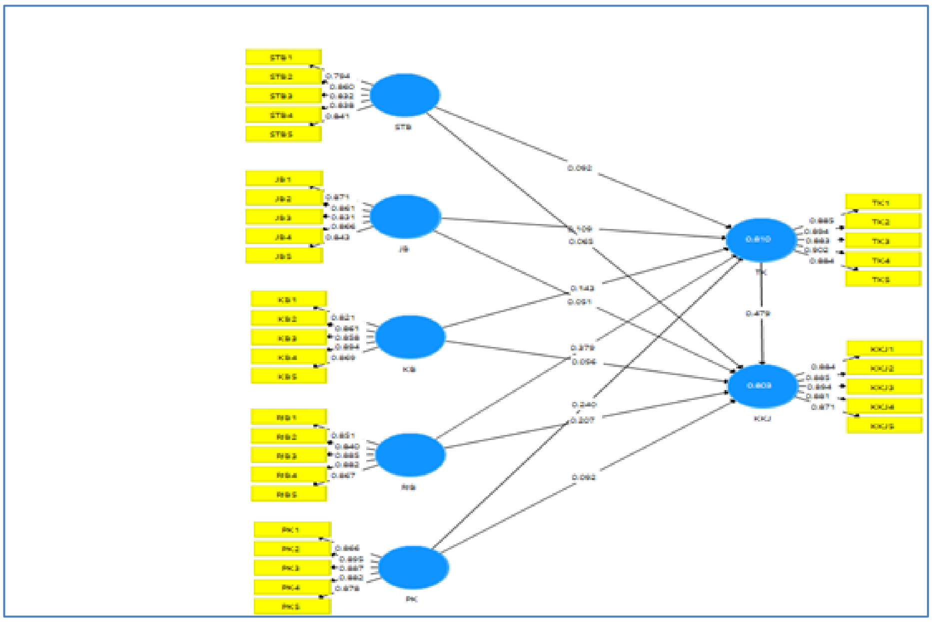

Figure 1: Path diagram of output results

Discriminant Validity

The results of the discriminant validity test indicate that all constructs in the research model exhibit adequate differentiation. The evaluation was conducted using the Fornell–Larcker criterion, which indicates that the square root of the Average Variance Extracted (AVE) value for each construct is greater than the correlation values between the other constructs. This finding indicates that each construct explains its indicators' variance better than the variance shared with other constructs. Furthermore, testing using the Heterotrait–Monotrait Ratio (HTMT) showed that all HTMT values were below the threshold of 0.85, thereby strengthening the evidence that there is no overlap between the constructs. By meeting the Fornell–Larcker and HTMT criteria, it can be concluded that the constructs in this study are discriminant and measure conceptually distinct concepts. Therefore, the measurement model is deemed suitable for proceeding to the structural model analysis stage and testing the causal relationships between variables.

Table 1. Average Variance Extracted Value

Variables	Average Variance Extracted (AVE)
Safe Road	0.731
Safe Vehicles	0.741
Road Safety Policy	0.780
Safe Road Users	0.748
Post-Accident Handling	0.777
Safe Transportation System	0.695
Safety Technology	0.792

Source: Processed Results, 2025 (PLS 3.0)

Reliability Testing

Reliability testing in this study was conducted within the PLS-SEM framework to ensure the instrument's internal consistency and accuracy in measuring latent constructs. The research instrument was structured as a Likert-scale questionnaire, with each construct represented by a set of reflective indicators. In PLS-SEM, reliability testing is part of the evaluation of the measurement model (outer model) and must be met before conducting structural model analysis [21]. Construct reliability evaluation was conducted using two main measures: Cronbach's Alpha and Composite Reliability (CR). Cronbach's Alpha is used to assess the internal consistency of indicators within a construct, with a threshold value of ≥ 0.60 as the acceptance criterion. The analysis results showed that all constructs had Cronbach's Alpha values above 0.88, indicating high reliability. However, in the context of PLS-SEM, Composite Reliability is preferred because it provides a more accurate estimate of reliability than Cronbach's Alpha, which tends to underestimate [18].

Table 2. Reliability Test Results

Variables	Cronbach Alpha	Conclusion
Safe Transportation System	0,889	Reliable
Safe Road	0,907	Reliable
Safety Vehicle	0,913	Reliable
Post-Accident Handling	0,928	Reliable
Safe Road Users	0,916	Reliable
Safety Technology	0,934	Reliable
Road Safety Policy	0,929	Reliable

Source: Processed Results, 2025

Table 3. Reliability Level Results

Variables	Cronbach's Alpha	Composite Reliability
Safe Road	0.908	0.931
Safe Vehicles	0.913	0.935
Road Safety Policy	0.930	0.947
Safe Road Users	0.916	0.937
Post-Accident Handling	0.928	0.946
Safe Transportation System	0.890	0.919
Safety Technology	0.934	0.950

Source: Processed Results, 2025 (PLS 3.0)

The results of the Composite Reliability test indicate that all constructs have CR values above 0.90, which fall within the very good category. This finding confirms that the indicators within each construct exhibit strong internal consistency and reliably represent the latent variables. By fulfilling these reliability criteria, it can be concluded that the measurement model in this study has met the reliability requirements and is suitable for proceeding to the structural model evaluation stage and testing the research hypotheses.

Inner Model Analysis (Structural Model)

The structural model (inner model) is used to test and predict causal relationships among latent variables, grounded in theory. The structural model testing in this study was conducted using the Partial Least Squares–Structural Equation Modeling (PLS-SEM) approach, with bootstrapping and blindfolding procedures in SmartPLS. The structural model evaluation included testing the coefficient of determination (R-square), model fit, and path significance tests to test the research hypotheses [22]. The results of the coefficient of determination test indicate that the Road Safety Policy variable has an R^2 value of 0.803, while the Safety Technology variable has an R^2 value of 0.810. These values exceed the 0.67 threshold, indicating that the model has strong predictive ability. These findings indicate that the exogenous variables in the model explain more than 80% of the variation in each endogenous variable; thus, the quality of the structural model can be assessed as very good.

Table 4. Coefficient of Determination

	R Square	Adj R Square
Road Safety Policy	0.803	0.802
Safety Technology	0.810	0.810

Source: Processed Results, 2025

Furthermore, the model fit test results indicate that the model meets the goodness-of-fit criteria. The Standardized Root Mean Square Residual (SRMR) value of 0.032 is below the threshold of 0.08, while the Normed Fit Index (NFI) value is 0.915, exceeding the minimum limit of 0.90. The resulting RMS_theta value is close to zero, indicating a low level of residual error of the indicator. Overall, these results confirm that the developed structural model is in good agreement with the empirical data.

Table 5. Standardized Root Mean Square Residuals

Criteria	Saturated Model	Estimated Model
SRMR	0.032	0.032
d_ULS	0.646	0.646
d_G	0.515	0.515
Chi-Square	3529.234	3529.234
NFI	0.915	0.915
rms Theta	0.105	

Results of Direct and Indirect Hypothesis Testing

The results of the direct-effect hypothesis testing using SEM-PLS indicate that not all relationships among variables have a significant effect on Road Safety Policy. Safe Roads → Road Safety Policy and Safe Vehicles → Road Safety Policy were declared insignificant because the p-value was greater than 0.05, thus rejecting the hypothesis. This finding indicates that improvements in road physical conditions and vehicle roadworthiness do not directly drive the development of road safety policies. Conversely, both variables had a significant influence on Safety Technology, indicating that improvements in infrastructure and vehicle quality first drive the adoption and utilization of safety technology. The variable Safe Road Users showed a very strong and significant influence on both Road Safety Policy and Technology at the 1% significance level. This confirms that road user behavior, compliance, and awareness are key factors in developing and implementing safety technology policies. Post-accident Handling and Safe Transportation Systems also exerted a significant influence on policy and technology, albeit to a lesser degree. The most important finding from the direct effect test is the Technology → Road Safety Policy path, which has the largest beta coefficient, confirming that technology is a key determinant in driving more modern and responsive road safety policies.

Table 6. Direct Effect Hypothesis Test

	TEORY	BETA	STDEV	T Stat	P-Values (1 Tail)	DECISION
JB -> KKJ	+	0.051	0.047	1.091	0.138	Ditolak
JB -> TK	+	0.109	0.050	2.190	0.014	Diterima**
KB -> KKJ	+	0.056	0.046	1.231	0.110	Ditolak
KB -> TK	+	0.143	0.045	3.151	0.001	Diterima***
PJB -> KKJ	+	0.207	0.053	3.865	0.000	Diterima***
PJB -> TK	+	0.379	0.046	8.227	0.000	Diterima***
PK -> KKJ	+	0.092	0.051	1.797	0.036	Diterima**
PK -> TK	+	0.240	0.043	5.623	0.000	Diterima***
STB -> KKJ	+	0.065	0.038	1.719	0.043	Diterima**
STB -> TK	+	0.092	0.035	2.607	0.005	Diterima***
TK -> KKJ	+	0.479	0.059	8.088	0.000	Diterima***

Note: Significance Level ***1%; **5% and *1%

Source: Processed Results, 2025

The results of the indirect effect test indicate that all mediation pathways through technology are statistically significant. Safe Roads, Safe Vehicles, Safe Road Users, Post-Crash Handling, and Safe Transportation Systems all have a positive influence on Road Safety Policy through Technology. The largest indirect effect comes from Safe Road Users, indicating that technology-facilitated behavioral change is the most decisive factor in shaping safety policy. This finding reflects the real-world situation in Indonesia, where road safety policies generally develop after being supported by technologies such as ETLE, ATCS, digitized accident data, and traffic management systems. Overall, these results confirm that technology plays a key role as a mediator, bridging physical conditions, behaviors, and transportation systems to support effective, evidence-based road safety policies.

Table 7: Indirect Effect Hypothesis Test

	BETA	STDEV	T Stat	P-Values (1 Tail)	Decision
JB -> TK -> KKJ	0.052	0.024	2.126	0.017	Diterima**
KB -> TK -> KKJ	0.069	0.024	2.896	0.002	Diterima***
PJB-> TK -> KKJ	0.182	0.033	5.506	0.000	Diterima***
PK -> TK -> KKJ	0.115	0.024	4.700	0.000	Diterima***
STB -> TK -> KKJ	0.044	0.018	2.500	0.006	Diterima***

3.2. Discussion

The measurement model evaluation (outer model) was conducted to ensure construct validity and reliability prior to structural analysis. The test results showed that all indicators had factor loadings above 0.70 and Average Variance Extracted (AVE) values above 0.50, confirming convergent validity. The discriminant validity test also showed that each indicator had the highest cross-loading on its respective construct, thereby preventing overlap among constructs. In terms of reliability, the Cronbach's Alpha and Composite

Reliability values for all constructs were above 0.90, indicating excellent internal consistency and instrument stability. The structural model evaluation (inner model) showed that the model had very strong predictive ability. The R-Square values of 0.803 for Road Safety Policy and 0.810 for Safety Technology indicated that the exogenous variables could explain more than 80% of the variation in the endogenous variables. Model fit indicators, such as SRMR (0.032), NFI (0.915), and RMS_theta, which approached zero, met the feasibility criteria; thus, the model was deemed representative in describing the relationships among road safety variables.

The results of the direct effect analysis indicate that Safe Roads and Safe Vehicles have no direct effect on Road Safety Policy, but significantly influence Safety Technology. Conversely, Safe Road Users, Post-Crash Handling, and Safe Transportation Systems have significant effects on both policy and technology. The Technology → Policy pathway demonstrated the largest effect, confirming the role of technology as a key driver of modern safety policy. All indirect effects through technology proved significant, confirming the role of Safety Technology as a key mediator. These findings indicate that technology integration is a strategic factor in bridging the physical, behavioral, and transportation system aspects toward effective, evidence-based road safety policies.

The results of the SEM-PLS analysis, which place technology as the primary mediator, align with various theoretical foundations for safety and technology adoption. From a Systems Theory perspective, road safety is the result of a dynamic interaction among users, vehicles, roads, and governance that cannot be separated [5]. The finding that Safe Roads and Safe Vehicles do not directly influence Road Safety Policy, but significantly through technology, suggests that modern safety systems require new connecting mechanisms. In this context, technology functions as a feedback loop that strengthens the interconnections between subsystems and improves the overall safety system performance. Furthermore, the Diffusion of Innovation Theory [10] and the Technology Acceptance Model [11] explain why technology is a significant mediator. The strong influence of Safe Road Users on Technology indicates that the adoption of safety innovations is driven by perceived usefulness, ease of use, and compatibility with existing practices. This finding is also in line with the Theory of Planned Behavior [12], which emphasizes that changes in road user safety behavior are largely determined by intentions formed through attitudes, social norms, and perceived control reinforced by technology. From a Human Factors Theory [13] perspective, technology plays a role in closing the gap between human error and systemic failure. The Technology pathway's greatest influence on Road Safety Policy is that technology enables more responsive, data-driven policy formulation. In the Indonesian context, these findings reflect the reality that road safety policies generally evolve after digital evidence is available through ETLE, ATCS, vehicle telematics, and integrated emergency response systems. The digitization of user behavior, post-crash handling, and transportation system integration demonstrates that technology has become a key enabler of road safety policies. Therefore, technology integration is not merely a technical matter but a national strategy to reduce accident fatalities and support the achievement of the 2040 RUNK LLAJ targets.

4. CONCLUSION

This study empirically proves that digital transformation plays a strategic role in improving the effectiveness of road safety policy implementation in Indonesia. The results of the SEM-PLS analysis indicate that the five pillars of road transportation safety—Safe Transportation Systems, Safe Roads, Safe Vehicles, Safe Road Users, and Accident Victim Management have a positive and significant impact on improving road transportation safety. Furthermore, technology plays a significant mediating role, strengthening the relationship between the safety pillars and road safety policies. These findings emphasize that the main problem of road safety in Indonesia lies not in the absence of policies, but in the fragmentation of implementation and the low integration of technology across pillars and institutions. Therefore, digital transformation must be positioned as a core enabler in the national road safety system. Based on these findings, this study recommends that the government position technology as a core element in implementing the RUNK LLAJ by developing an integrated, real-time national road safety data system. Strengthening the role of lead agencies and coordination across ministries/institutions and local governments is key to ensuring evidence-based decision-making. Furthermore, continued investment in priority safety technologies must be accompanied by increased human resource capacity and technology-based safety literacy among road users. These measures are expected to make road safety policies more adaptive, integrated, and effective in reducing accident fatalities and supporting the achievement of the RUNK LLAJ targets and the 2030 SDGs.

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REFERENCES

[1] World Health Organization. (2023). Global status report on road safety 2023. WHO Press.
[2] Badan Pusat Statistik. (2024). Statistik kecelakaan lalu lintas di Indonesia 2023. BPS RI. https://www.bps.go.id
[3] Bliss, T., & Breen, J. (2013). Implementing the safe system approach to road safety. World Bank. https://openknowledge.worldbank.org
[4] World Health Organization. (2017). Save LIVES: A road safety technical package. WHO Press
[5] Larsson, P., Dekker, S., & Tingvall, C. (2010). The need for a systems theory approach to road safety. Safety Science, 48(9), 1167–1174. https://doi.org/10.1016/j.ssci.2010.03.006
[6] Stanton, N. A., Salmon, P. M., Rafferty, L. A., Walker, G. H., Baber, C., & Jenkins, D. P. (2020). Human factors methods: A practical guide for engineering and design (2nd ed.). Ashgate.
[7] Edward III, G. C. (1980). Implementing public policy. Congressional Quarterly Press
[8] Winarno, B. (2016). Kebijakan publik: Teori, proses, dan studi kasus (Edisi revisi). CAPS.
[9] Agustino, L. (2016). Dasar-dasar kebijakan publik (Edisi revisi). Alfabeta.
[10] Rogers, E. M. (2003). Diffusion of innovations (5th ed.). Free Press
[11] Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. MIS Quarterly, 13(3), 319–340. https://doi.org/10.2307/249008
[12] Ajzen, I. (1991). The theory of planned behavior. Organizational Behavior and Human Decision Processes, 50(2), 179–211. https://doi.org/10.1016/0749-5978(91)90020-T
[13] Reason, J. (1990). Human error. Cambridge University Press.
[14] Wickens, C. D., Hollands, J. G., Banbury, S., & Parasuraman, R. (2013). Engineering psychology and human performance (4th ed.). Pearson.
[15] Cicchino, J. B. (2018). Effectiveness of forward collision warning and autonomous emergency braking

systems in reducing front-to-rear crash rates. Accident Analysis & Prevention, 99, 142–152. https://doi.org/10.1016/j.aap.2016.11.009

[16] Papadoulis, A., Quddus, M., & Imprialou, M. (2019). Evaluating the safety impact of connected and autonomous vehicles on motorways. Accident Analysis & Prevention, 124, 12–22. https://doi.org/10.1016/j.aap.2018.12.019

[17] European Commission. (2013). eCall impact assessment. Directorate-General for Communications Networks, Content and Technology. https://ec.europa.eu

[18] Hair, J. F., Hult, G. T. M., Ringle, C. M., & Sarstedt, M. (2019). A primer on partial least squares structural equation modeling (PLS-SEM). Sage.

[19] Sarstedt, M., Ringle, C. M., & Hair, J. F. (2017). Partial least squares structural equation modeling. Handbook of Market Research. Springer.

[20] Ferdinand, A. (2014). Metode Penelitian Manajemen: Pedoman Penelitian untuk Penulisan Skripsi, Tesis, dan Disertasi Ilmu Manajemen (Edisi 5). Semarang: Badan Penerbit Universitas Diponegoro

[21] Ghozali, I., & Latan, H. (2015). Partial least squares: Konsep, teknik, dan aplikasi menggunakan program SmartPLS 3.0 (Edisi ke-2). Badan Penerbit Universitas Diponegoro

[22] Sekaran, U., & Bougie, R. (2016). Research methods for business: A skill-building approach (7th ed.). Wiley