

Digital and Institutional Capacity to Encourage Adaptive Election Governance to Vulnerability Risk

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Abstract

Regional elections are a vital arena for realizing democratic governance with integrity, yet disparities in the Election Vulnerability Index (IKP) indicate uneven institutional and stakeholder capacity across regions. This study examines the relationships between Information and Communication Technology (ICT), institutional quality, skills, and electoral vulnerability across 38 districts/cities in East Java. Using 2024 secondary data from the Regional Competitiveness Index (BRIN) and IKP (Bawaslu), Principal Component Analysis (PCA) was first employed to reduce correlated indicators and construct parsimonious component measures prior to Structural Equation Modeling (SEM). This two-stage strategy was adopted because the analysis involved only 38 regional observations and therefore required a deliberately parsimonious structural specification. PCA identified one dominant component (RC1, eigenvalue = 2.857; 57.1% variance). The resulting component was used as a parsimonious representation of the correlated indicators in the structural model. SEM results show that skills directly reduce IKP ($\beta = -0.453$, $p = 0.040$), while ICT adoption shows an indirect negative association with IKP through skill enhancement ($\beta = -0.316$, $p = 0.054$). Institutional quality also significantly reduces IKP ($\beta = -0.328$, $p = 0.044$). Given the small regional sample, the findings should be interpreted as statistical associations within the observed districts/cities rather than definitive causal effects. Thus, electoral resilience is associated with competent human resources, digital readiness, and strong institutional governance.

Keywords

Stakeholder Capacity; ICT adoption; Skills; Institutions; Election Vulnerability Index; Machine Learning, Regional Governance

Introduction

General elections are the main pillar of democracy that determines the legitimacy and stability of local governments. However, in practice, the implementation of elections at the local level still faces various challenges such as administrative vulnerabilities, low public participation, and threats to the integrity and transparency of the electoral process. The development of ICT has opened up great opportunities to improve election governance, both in terms of efficiency, accuracy, and public information disclosure. However, the effectiveness of digital transformation is highly dependent on the capacity of human resources and regional institutions in managing it. Therefore, understanding the relationship between ICT adoption, institutions, and stakeholder capacity to the level of vulnerability to regional elections is an important academic and policy urgency. ICT strengthens citizen participation and democratic governance, but still faces the challenges of

privacy, digital divide, and data security (Asimakopoulos et al., 2025). E-democracy and smart government have the potential to increase citizen engagement if supported by sustainable digital governance, data-driven systems, and a balance between inclusivity, transparency, and security (Liu & Khalid, 2025; Terán et al., 2024). Technologies such as

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blockchain can strengthen trust in e-voting, but its success depends on public trust and institutional readiness (Baudier et al., 2021). At the local level, the effectiveness of e-government still needs to be evaluated in depth, in line with the importance of strengthening human resource and institutional capacity to overcome socio-cultural and technological barriers (Tawakkal, 2022).

The vulnerability of regional elections in Indonesia is still a crucial issue, characterized by variations in IKP scores between regions. This condition raises questions about the factors that affect the level of vulnerability. While studies have highlighted the role of institutions and technology in improving electoral integrity, not many have examined how the simultaneous adoption of ICT and human resource capacity affects the risk of electoral insecurity. The main challenge lies in how to build an empirical model capable of explaining the causal relationship between digital capacity, institutional quality, and electoral stability at the regional level. In Estonia, trust in institutions determines the adoption of i-voting more than trust in the technology itself (Romanov et al., 2025), while in South America, e-voting has been shown to reduce invalid votes although not necessarily increasing participation (Aragón et al., 2025). In low-income countries, mobile internet access increases electoral transparency and accountability (Yeandle, 2025), while in Slovenia, trust in technology and government shapes the intention to use i-voting post-pandemic (Decman & Kozel, 2023). The expansion of the Technology Acceptance Model confirms that the perception of the benefits and readiness of digital human resources is more dominant in the adoption of e-voting than trust in institutions alone (Zahra et al., 2025). A comparative Kenya-Estonian study confirms that technology strengthens democracy only in countries with strong institutions, while in weak countries it exacerbates vulnerabilities (Siteki, 2025). The effectiveness of ICT in elections depends on the interaction between ICT capacity, institutional quality, and human resource readiness, which demands quantitative methodological approaches such as data panels, SEM, or natural experiments to measure causal relationships empirically (Garnett & James, 2023).

Most previous research has focused on normative aspects of election governance or the evaluation of e-voting technology, but has not systematically integrated regional socio-economic dimensions, such as digital skills, labor markets, and local human resource capacity, into quantitative analyses of electoral vulnerability. Although it is known that trust in electoral institutions determines the adoption of technology more than trust in the technology itself (Romanov et al., 2025), and that internet access and government ICT indexes have an impact on participation

and accountability (LeRoux et al., 2020), the relationship between technological capacity, institutional quality, and human resource readiness at the regional level has not been empirically modeled. The innovation adoption literature and global studies show that the effectiveness of ICT in elections depends on the interaction between digital infrastructure, human capabilities, and institutional power (Higashijima et al., 2024; Labudova & Fodranova, 2024), but the integration of all three in a single analytical framework is still absent.

Because the regional competitiveness indicators represent multiple and potentially correlated dimensions of digital, institutional, and human resource capacity, a two-stage analytical strategy combining dimensionality reduction and structural modeling is appropriate for the present study. Principal Component Analysis (PCA) is used to summarize correlated indicators into a smaller number of empirical dimensions while retaining the dominant variation in the data. The resulting component score is subsequently incorporated into Structural Equation Modeling (SEM) to examine the theoretically specified structural relationships among ICT adoption, skills, institutional quality, and electoral vulnerability. This approach also provides a more parsimonious model specification, which is particularly relevant because the analysis covers only 38 districts/cities. Thus, PCA serves as a data-reduction and parsimonization step, whereas SEM is used to assess the structural relationships proposed in the conceptual framework. This study fills this gap by developing an empirical model based on Principal Component Analysis (PCA) and Structural Equation Modeling (SEM) using official secondary data to simultaneously evaluate the influence of ICT adoption, workforce skills, and institutional quality on election vulnerability at the regional level. This research provides conceptual and empirical contributions to the development of governance capacity theory and digital institutionalism in the context of regional elections in Indonesia. Academically, this research expands the understanding of the role of digital and institutional capacity in reducing electoral vulnerability through strengthening human resources. Practically, the results of this research can be the basis for election organizing institutions such as the KPU and Bawaslu, as well as local governments, to design a strategy to increase the capacity of stakeholders that are more integrated between aspects of technology, human resources, and institutional governance. Thus, this research contributes to efforts to build a more inclusive, transparent, and integrity electoral system at the local level.

Methods

This study uses a quantitative approach (Gosiewska & Biecek, 2020) with an explanatory design to examine the structural relationships between ICT Adoption, Institutions, Skills, Labor Market, and IKP. Because the study uses cross-sectional secondary data, the term structural relationship is used rather than causal relationship; the estimated paths are interpreted as statistical associations rather than definitive causal effects. The design was selected because SEM enables the examination of direct and indirect relationships among variables within a theoretically specified model.

The research was conducted in 38 districts/cities in East Java Province, Indonesia, using secondary data in 2024. Two main data sources were used, namely the National Research and Innovation Agency (BRIN, 2025) through the Regional Competitiveness Index which includes the pillars of ICT Adoption, Institutions, Skills, and the Labor Market, and the General Election Supervisory Agency (Bawaslu, 2024) through the 2024 IKP, which measures potential disruptions to the integrity and security of election administration. The research context focuses on how digital readiness and regional governance can affect the level of electoral vulnerability, taking into account labor and labor market conditions as mediators (Table 1). The data collection instrument in this study consists entirely of quantitative secondary data obtained from BRIN and Bawaslu Indonesia. The Regional Competitiveness Index data (BRIN, 2025), measured on a standardized 0–5 scale, were used to operationalize ICT Adoption, Institutions, Skills, and Labor Market. The IKP data (Bawaslu, 2024), measured on a 0–1 scale, were used as the dependent variable.

Table 1. Operational Variables and Definitions

Variable Type	Code	Variable Name	Operational Definition	Indicators/ Measures
Independent	X ₁	ICT Adoption	The level of use of information and communication technology by the government and the community in supporting governance and public services	ICT Adoption pillar score (0–5)

Independent	X ₂	Institutions	The quality of regional institutions in supporting governance, transparency, and policy effectiveness	Institution pillar score (0–5)
Mediation	M ₁	Skills	The capacity of regional human resources in mastering technical and digital skills	Skill pillar score (0–5)
Mediation	M ₂	Labor Market	Efficiency, absorption and balance between labor demand and supply	Labor Market pillar score (0–5)
They depend	Y	IKP	Measures of potential vulnerabilities to the integrity, security, and implementation of elections in the regions	IKP Score (0–1)

Given the limited number of observations (38 districts/cities), the analytical strategy was designed to maintain a parsimonious relationship between the number of empirical dimensions and the available observations. The analysis was conducted in two sequential stages. First, PCA was used as a data-reduction procedure to summarize correlated regional competitiveness indicators into a smaller number of empirical dimensions. Second, the resulting component measure was incorporated into a parsimonious SEM framework to examine the theoretically specified direct and indirect relationships among the study variables. Thus, PCA and SEM serve different but complementary purposes: PCA reduces dimensionality, whereas SEM evaluates the structural relationships among the resulting empirical constructs.

Principal Component Analysis

PCA was employed to identify the dominant empirical dimension underlying the correlated regional competitiveness indicators. This procedure was particularly relevant for the present study because the analysis covered only 38 districts/cities and therefore required a parsimonious representation of the information contained in multiple indicators before structural modeling.

The PCA mathematical model is expressed as:

$$Z_i = a_{i1}X_1 + a_{i2}X_2 + \dots + a_{ip}X_p \quad (1)$$

With Z_i is the main component of i ; X_p is the standardized variable; and a_{ip} is the loading or weight of the variable X_p . The requirements for orthogonality between components are met by

$$\text{Cov}(Z_i, Z_j) = 0 \text{ for all } i \neq j \quad (2)$$

The eigenvalue (λ_i) indicates the variance described by the i th component. The component is selected if $\lambda_i > 1$, and is confirmed via the scree plot. The eigenvalue (λ_i) indicates the amount of variance explained by the i th component. Components with an eigenvalue greater than 1 were considered for retention and were additionally evaluated using the scree plot. The PCA produced one dominant component (RC1) with an eigenvalue of 2.857, explaining 57.1% of the total variance. The resulting component score was subsequently used as a parsimonious empirical representation of the relevant correlated indicators in the structural analysis.

Because only one dominant component was retained, no interpretation of relationships among multiple rotated components was required. Accordingly, the PCA results are reported based on the component loadings and explained variance rather than relying on an oblique rotation procedure.

2.2. Structural Equation Modeling

SEM was subsequently used to examine the direct and indirect structural relationships between ICT Adoption, Institutions, Skills, Labor Market, and IKP. The SEM specification was deliberately kept parsimonious because the study contains only 38 district/city observations. The model therefore focuses on theoretically motivated structural paths and avoids unnecessary free parameters. The structural model is specified as the following system of equations:

$$M_1 = a_1 + b_{11}X_1 + b_{12}X_2 + e_1 \quad (3)$$

$$M_2 = a_2 + b_{21}X_1 + b_{22}X_2 + e_2 \quad (4)$$

$$Y = \alpha_3 + \gamma_1X_1 + \gamma_2X_2 + \delta_1M_1 + \delta_2M_2 + \varepsilon_3 \quad (5)$$

The effect of mediation is calculated by:

$$IE_{X_1 \rightarrow Y} = (b_{11} \times d_1) + (b_{21} \times d_2) \quad (6)$$

$$IE_{X_2 \rightarrow Y} = (\beta_{12} \times \delta_1) + (\beta_{22} \times \delta_2) \quad (7)$$

The model parameters were estimated using Maximum Likelihood (ML). Given the small sample size, ML estimation was applied within the deliberately restricted and parsimonious structural specification. The results are therefore interpreted cautiously, with particular attention to the uncertainty associated with parameter estimates and significance tests in a small-sample setting. The analysis does not treat statistical significance as evidence of definitive causal effects or broad population-level generalization.

Model evaluation included the chi-square statistic, degrees of freedom, p-value, and standardized path coefficients. Where available, additional model-fit measures should also be reported to provide a more complete assessment of the adequacy of the specified structural model. All analyses were performed using JASP software with a nominal significance level of $p < 0.05$.

Conceptual Model

Figure 1 presents the conceptual model describing the hypothesized structural relationships among ICT Adoption, Institutions, Skills, Labor Market, and IKP. Independent variables (ICT Adoption and Institutions) are specified as having direct relationships with IKP and indirect relationships through Skills and Labor Market.

The conceptual framework integrates digital capacity, institutional quality, and regional human resource conditions into a single parsimonious structural model. PCA provides the empirical data-reduction stage, while SEM provides the framework for examining the hypothesized direct and indirect structural relationships. This combination enables the study to retain information from multiple correlated regional indicators while limiting model complexity in a small district/city-level sample.

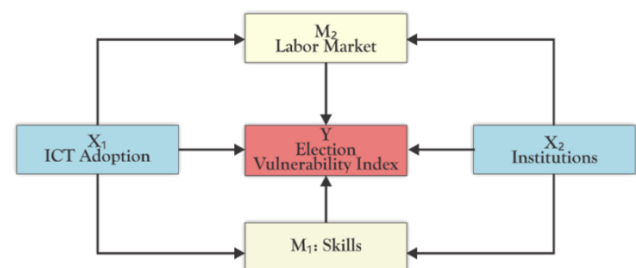


Figure 1. Conceptual Model of The Influence of ICT Adoption and Institutional Capacity on Election Vulnerability through Skills and Labor Market. (Arrow direction caption: Straight arrow ($\rightarrow$): direct effect, Chain path ($X \rightarrow M \rightarrow Y$): indirect effect (mediation)).

Because the analysis is based on a single cross-sectional year and only 38 regional observations, the findings are interpreted as empirical associations within the observed East Java districts/cities. The methodological design is intended to identify patterns of direct and indirect relationships rather than establish definitive temporal or causal effects.

Results

Principal Component Analysis

The analysis involved five main variables: ICT Adoption, Institutions, Skills, Labor Market, and the IKP. Considering the relatively limited number of observations (38 districts/cities), PCA was first conducted to identify the dominant empirical dimension and reduce the dimensionality of the observed variables before estimating the structural relationships. In this study, PCA functions as a data-reduction procedure rather than as a confirmatory test of latent constructs.

The PCA results are presented in Table 2. One dominant component (RC1) was identified with an eigenvalue of 2.857, explaining 57.1% of the total variance. Skills had the highest loading on RC1 (0.896), followed by ICT Adoption (0.845), Labor Market (0.742), and Institutions (0.716). IKP had a negative loading of -0.526 . The relatively high loadings of Skills, ICT Adoption, Labor Market, and Institutions indicate that these variables are strongly associated with the dominant empirical dimension, whereas the negative loading of IKP indicates an inverse association with that dimension. The magnitude of a PCA loading represents the strength and direction of association with the component and should not be interpreted as a statistical significance test (Sadat, 2025).

The dominant contribution of Skills to RC1 indicates that human-resource capability constitutes an important component of the observed regional-capacity structure. This finding is consistent with the growing emphasis on digital and human-resource capabilities in explaining differences in public-sector and regional performance (Fink et al., 2025; Romanov et al., 2025). ICT Adoption also showed a strong loading, indicating that digital readiness forms an important part of the same empirical dimension. The result is consistent with previous evidence emphasizing the role of digital technologies and digital transformation in strengthening public-sector capacity and governance (Fink et al., 2025; Jin, 2024; Mack et al., 2021; Walther et al., 2023).

Labor Market and Institutions also demonstrated substantial positive loadings on RC1. The contribution of labor-market conditions to regional capacity is consistent with studies emphasizing the role of employment, workforce characteristics, and labor-market institutions in shaping regional socioeconomic outcomes (Hansen et al., 2022; Lybeck et al., 2024). Similarly, the loading for Institutions indicates that institutional conditions are closely associated with the dominant regional-capacity dimension. This pattern is in line with research highlighting institutional quality and administrative capacity as important components of regional and governance performance (Lee-Geiller, 2024; Männasoo et al., 2023).

The negative loading of IKP (-0.526) indicates that IKP varies inversely with the dominant component. Thus, districts/cities with higher scores on the combined empirical dimension of ICT Adoption, Institutions, Skills, and Labor Market tend to exhibit lower electoral vulnerability. This inverse pattern is compatible with literature emphasizing the relationship between digital government capacity, institutional quality, and governance resilience (Gasco-Hernandez et al., 2022; Mack et al., 2021; Yuan et al., 2023). However, the PCA result is descriptive and does not by itself establish that improvements in these dimensions cause reductions in electoral vulnerability.

Table 2. Principal Component Analysis Results

Variabel	Component Loading (RC1)	Uniqueness
Skills	0.896	0.198
ICT Adoption	0.845	0.285
Labor Market	0.742	0.45
Institutions	0.716	0.487
IKP	-0.526	0.723

Note: RC1 represents the dominant principal component. Loadings indicate the strength and direction of association between each observed variable and RC1.

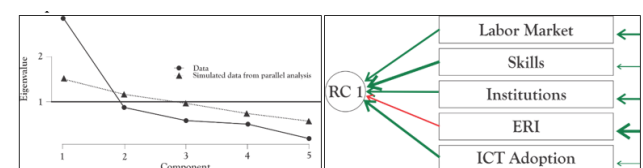


Figure 2. Scree Plot and Component Loading Diagram of the PCA Results

Figure 2 presents the scree plot and PCA component-loading diagram. The scree plot illustrates the dominance of the first component, while the loading diagram shows the relative contribution and direction of the five observed variables. Because only one component was retained, the

interpretation focuses on the dominant empirical dimension rather than on rotated multiple-component structures.

3.2 Structural Equation Modeling

Following the PCA, SEM was conducted to examine the theoretically specified structural relationships among ICT Adoption, Institutions, Skills, Labor Market, and IKP. The SEM specification was deliberately kept parsimonious given the 38 district/city observations. The results therefore represent statistical associations within the observed regional sample and should not be interpreted as definitive causal effects.

The direct, specific indirect, and total associations are presented in Table 3. The direct-path results show that Skills had a statistically significant negative association with IKP ($\beta = -0.453$, $SE = 0.221$, $z = -2.051$, $p = 0.040$). In contrast, ICT Adoption did not show a statistically significant direct association with IKP ($\beta = 0.272$, $SE = 0.229$, $z = 1.192$, $p = 0.233$). Institutions also did not show a statistically significant direct association with IKP ($\beta = -0.221$, $SE = 0.164$, $z = -1.352$, $p = 0.176$), while Labor Market had a small and statistically non-significant association with IKP ($\beta = -0.063$, $SE = 0.133$, $z = -0.469$, $p = 0.639$).

The significant negative association between Skills and IKP suggests that higher regional skill capacity is statistically associated with lower electoral vulnerability. This result is consistent with previous research emphasizing the importance of human-resource and digital competencies for public-sector performance and governance capacity (Fink et al., 2025; Romanov et al., 2025). The result also complements the PCA finding, in which Skills exhibited the strongest loading on the dominant empirical component.

The specific indirect pathways provide further information about the role of Skills and Labor Market as mediating variables. The indirect association between ICT Adoption and IKP through Skills was negative ($\beta = -0.316$, $SE = 0.164$, $z = -1.923$), but its p -value was 0.054. Because $p = 0.054$ is greater than the conventional 0.05 threshold, the specific ICT Adoption $\rightarrow$ Skills $\rightarrow$ IKP pathway is not statistically significant at the 5% level. Nevertheless, its negative coefficient indicates that the estimated direction of the association is consistent with the hypothesized relationship.

The observed direction is compatible with previous studies showing that digital transformation can be linked to improvements in skills, administrative capabilities, and governance outcomes (Fink et al., 2025; Gasco-Hernandez et al., 2022; Jin, 2024; Mack et al., 2021; Walther et al., 2023). However, the present result does not provide

sufficient statistical evidence to conclude that Skills significantly mediates the relationship between ICT Adoption and IKP at the 5% level.

The indirect association from ICT Adoption through Labor Market was not statistically significant ($\beta = -0.031$, $SE = 0.066$, $z = -0.467$, $p = 0.640$). Similarly, the indirect association from Institutions through Skills to IKP was not statistically significant ($\beta = -0.096$, $SE = 0.060$, $z = -1.596$, $p = 0.111$), nor was the indirect association through Labor Market ($\beta = -0.010$, $SE = 0.024$, $z = -0.417$, $p = 0.677$).

The absence of statistically significant specific indirect pathways through Labor Market is consistent with the relatively weak direct association between Labor Market and IKP observed in the structural model. Previous studies have nevertheless demonstrated that labor-market conditions can interact with institutional and human-resource capacity in shaping regional development and public-sector outcomes (Hansen et al., 2022; Lybeck et al., 2024). Thus, the non-significant estimates in the present study should be understood within the specific regional and cross-sectional context of the 38 East Java districts/cities.

The total-effect estimates provide an additional perspective. The total association between ICT Adoption and IKP was not statistically significant ($\beta = -0.074$, $SE = 0.164$, $z = -0.452$, $p = 0.651$). In contrast, Institutions showed a statistically significant negative total association with IKP ($\beta = -0.328$, $SE = 0.162$, $z = -2.016$, $p = 0.044$).

The significant total association of Institutions with IKP, despite the non-significant direct path, indicates that the overall relationship differs from the direct relationship once the specified structural pathways are taken into account. This finding is consistent with the broader literature emphasizing the role of institutional quality and administrative capacity in shaping governance outcomes (Lee-Geiller, 2024; Männasoo et al., 2023). The result should nevertheless be interpreted as an empirical association rather than evidence of a causal institutional effect.

Table 3. Direct, Indirect, and Total Structural Associations

Direct Effect Test Results					
Jalur	Standard Coefficients	Std. Error	z-value	p-value	Significance
Adoption of ICT $\rightarrow$ IKP	0.272	0.229	1.192	0.233	Insignificant
Institutions $\rightarrow$ IKP	-0.221	0.164	-1.352	0.176	Insignificant
Skills $\rightarrow$ IKP	-0.453	0.221	-2.051	0.040	Significant

Labor Market → IKP	-0.063	0.133	-0.469	0.639	Insignificant
Indirect Effects Test Results					
Mediation Pathway	Standard Coefficients	Std. Error	z-value	p-value	Significance
ICT Adoption → IKP → Skills	-0.316	0.164	-1.923	0.054	Close to significant
ICT Adoption → Labor Market → IKP	-0.031	0.066	-0.467	0.64	Insignificant
Institutions → Skills → IKP	-0.096	0.06	-1.596	0.111	Insignificant
Institutions → Labor Market → IKP	-0.01	0.024	-0.417	0.677	Insignificant
Total Effects and Overall Indirect Effects					
Jalur	Total Effect	Std. Error	z-value	p-value	Significance
Adoption of ICT → IKP	-0.074	0.164	-0.452	0.651	Insignificant
Institutions → IKP	-0.328	0.162	-2.016	0.044	Significant
Total Indirect (Adoption of ICT → IKP)	-0.347	0.167	-2.082	0.037	Significant
Total Indirect (Institusi → IKP)	-0.106	0.069	-1.534	0.125	Insignificant

Note: Statistical significance is evaluated at $\alpha = 0.05$. Negative coefficients indicate an inverse statistical association with IKP. Because the data are cross-sectional, the estimated paths represent statistical associations within the observed districts/cities rather than definitive causal effects.

The total indirect association of ICT Adoption with IKP was statistically significant ($\beta = -0.347$, $SE = 0.167$, $z = -2.082$, $p = 0.037$), whereas the total indirect association of Institutions with IKP was not statistically significant ($\beta = -0.106$, $SE = 0.069$, $z = -1.534$, $p = 0.125$).

The distinction between the specific and total indirect associations is important. Although the individual ICT Adoption → Skills → IKP pathway did not reach statistical significance at the 5% level ($p = 0.054$), the combined total

indirect association of ICT Adoption across the specified mediating pathways was statistically significant ($p = 0.037$). Accordingly, the findings support a significant total indirect association of ICT Adoption with IKP, but they should not be reported as evidence of a statistically significant specific mediation pathway through Skills.

Figure 3 illustrates the estimated structural model. The model shows that Skills has the only statistically significant direct association with IKP, while Institutions has a statistically significant total association. ICT Adoption demonstrates a statistically significant total indirect association, although none of its individual specific indirect pathways reaches the 5% significance threshold.

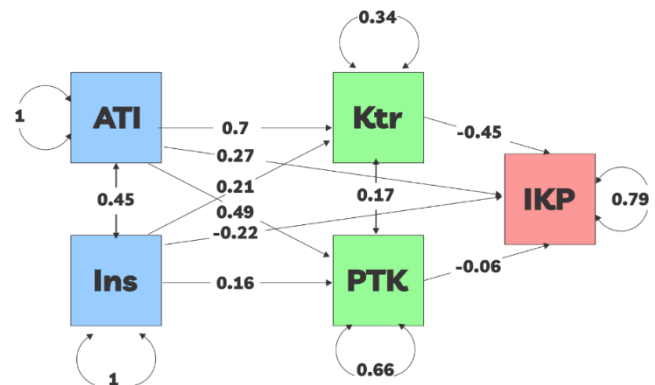


Figure 3. Structural Equation Model of the Relationships among ICT Adoption, Institutions, Skills, Labor Market, and Election Vulnerability

The results indicate that human-resource skills, institutional conditions, and digital capacity are empirically interconnected with electoral vulnerability, although the strength and statistical significance of the relationships differ across direct, specific indirect, and total pathways. The PCA results identify a dominant empirical dimension in which Skills, ICT Adoption, Labor Market, and Institutions are positively aligned, while IKP is inversely associated with this dimension. The SEM results further show that Skills has a significant direct negative association with IKP, Institutions has a significant negative total association, and ICT Adoption has a significant total indirect association.

These findings are broadly consistent with previous research emphasizing the interconnected roles of digital transformation, institutional quality, human resources, and regional governance capacity (Gasco-Hernandez et al., 2022; Lee-Geiller, 2024; Mack et al., 2021; Männasoo et al., 2023; Yuan et al., 2023). At the same time, the non-significant direct and specific indirect paths indicate that these relationships should not be assumed to operate

uniformly across all dimensions. Given the cross-sectional design and the limited number of observations, the findings should be interpreted within the observed 38 East Java districts/cities and should not be generalized as definitive causal mechanisms.

Discussion

The results of the study show that Skills have a significant direct negative association with the Election Vulnerability Index (IKP), while ICT Adoption and Institutions show different patterns of direct, indirect, and total associations through the specified mediation variables. Specifically, Skills have a significant direct association with IKP ($\beta = -0.453$, $p = 0.040$), whereas the specific indirect pathway ICT Adoption $\rightarrow$ Skills $\rightarrow$ IKP is negative but does not reach the conventional 5% significance threshold ($\beta = -0.316$, $p = 0.054$). Nevertheless, the total indirect association of ICT Adoption with IKP is statistically significant ($\beta = -0.347$, $p = 0.037$), indicating that the overall indirect relationship of ICT Adoption becomes more apparent when the specified mediating pathways are considered jointly. These findings indicate that strengthening human capacity, especially in digital and adaptive skills is a crucial element associated with lower levels of election vulnerability at the regional level. Thus, the results suggest that the availability of digital technology alone does not fully characterize regional electoral resilience; the capacity of human resources to use, manage, and adapt to digital systems is also empirically relevant.

The effectiveness of election digitalization and public governance is highly dependent on human capacity, not just the availability of technology. In South Africa, the success of digital electoral systems is determined by the ability of field operators to accurately manage devices (Maseko, 2024), while in Zimbabwe, low digital literacy hinders the implementation of e-voting and fuels public distrust (Tom, 2023). Trust in e-voting is shaped by technological reliability and human competence (Osmanaj et al., 2025), and the application of artificial intelligence in elections is only effective if supported by increased analytical capacity and digital ethics in regional bureaucracies (Springer Nature, 2025). The combination of technical competence and institutional integrity has been shown to reduce the potential for fraud in developing countries (Long, 2023), while without human readiness, technology instead creates a digital dependency that weakens institutional resilience (Sætra, 2023). Even in Europe, the success of regional crisis response depends on the ability of the apparatus to integrate technology with transparent governance procedures (Springer Nature, 2024), emphasizing that human capacity

is the main foundation of the success of digital transformation in democracy. Taken together, these studies provide a contextual explanation for the significant Skills–IKP association observed in the present study, although differences in institutional settings and electoral systems mean that the findings cannot be assumed to operate identically across countries.

The specific indirect association of ICT Adoption through Skills ($\beta = -0.316$, $p = 0.054$) should be interpreted cautiously. Because the p-value is slightly above the conventional 0.05 threshold, the result does not provide sufficient statistical evidence to conclude that Skills significantly mediate the ICT Adoption–IKP relationship at the 5% level. However, the negative coefficient is consistent with the broader argument that digital technology requires corresponding human capabilities to generate effective governance outcomes. This finding supports the view that technology is not the sole determining factor; rather, digital systems are more likely to be operationally meaningful when accompanied by the ability of human resources to manage, supervise, and interpret the election digitization process. This is in line with the theory of institutional capacity which emphasizes that the effectiveness of public governance is largely determined by the synergy between human capabilities and the technological systems used.

The significant total indirect association of ICT Adoption with IKP ($\beta = -0.347$, $p = 0.037$) provides additional evidence that ICT Adoption has an overall indirect statistical relationship with IKP across the specified mediating pathways. This result should be distinguished from the non-significant specific ICT Adoption $\rightarrow$ Skills $\rightarrow$ IKP pathway. Therefore, the present study does not establish a statistically significant mediation effect through Skills alone; instead, it identifies a significant aggregate indirect association of ICT Adoption within the structural model. This distinction is important because the relationship between technology and electoral vulnerability may involve more than one organizational or socioeconomic mechanism rather than a single linear mediation pathway.

In addition, the negative total association of Institutions with IKP confirms the important role of strong regional governance in the observed structural model. Although the direct Institutions $\rightarrow$ IKP path was not statistically significant ($\beta = -0.221$, $p = 0.176$), its total association was statistically significant ($\beta = -0.328$, $p = 0.044$). This difference suggests that the institutional relationship with electoral vulnerability becomes more evident when the other specified pathways are taken into account. In other words, good institutional governance not only functions as

a regulator, but also as an enabler for stakeholders in maintaining the integrity of elections.

The effectiveness of digitalization in the democratic process depends heavily on human capacity and institutional strength, not just on technological infrastructure. In Estonia, public trust in internet voting is determined by a balance between technological reliability and trust in institutions, with the role of humans as a key mediator (Romanov et al., 2025), while in Spain, citizens' digital participation depends on the ability of local governments to provide inclusive channels managed by competent apparatus (Alcaide Muñoz et al., 2025). The adoption of technology by political parties only increases participation if their managers have communication skills and digital adaptation (Kaczorowska, 2023), and the failure of electoral digitalization often stems from the low digital literacy of the apparatus, not the technology (Maseko, 2024). In Africa, strong regional institutions are needed to maintain political stability in the midst of digital transformation (Tolulope, 2025), in line with the finding that local institutions are the main bulwark against electoral manipulation (Long, 2023). Even advanced technologies such as blockchain are only effective if they are accompanied by technical training and ethical understanding for organizers (Baudier et al., 2021), and technology without humans actually widens the governance gap and increases the risk of abuse (Sætra, 2023). These results support the research concept that digital capacity, institutions, and regional socio-economic skills are interrelated dimensions in the dynamics of integrity and adaptive election governance. The present findings extend this perspective by showing that the statistical strength of these relationships differs according to whether direct, specific indirect, or total pathways are considered.

The findings of this study enrich governance capacity theory and digital institutionalism by showing that the governance capacity of regional elections in Indonesia is the result of an interaction between technological readiness, human capital, and institutional performance, not just the function of formal institutions (Hansen et al., 2022). The empirical path of ICT Adoption $\rightarrow$ Skills $\rightarrow$ IKP shows a negative estimated indirect association, although it does not reach statistical significance at the 5% level, reflecting the digital governance chain, where strengthening digital skills may represent one mechanism through which digital capacity is connected with election integrity, in line with the concept of digital empowerment (Monahan, 2020) and evidence that public sector digital competence drives institutional innovation (Cordella et al., 2024).

The distinction between the estimated direction and statistical significance is particularly important in

interpreting this result. The coefficient for ICT Adoption $\rightarrow$ Skills $\rightarrow$ IKP is negative ($\beta = -0.316$), but $p = 0.054$. Therefore, the result provides an indication of the direction of the estimated relationship but does not meet the conventional 5% criterion for statistical significance. At the same time, the significant total indirect association of ICT Adoption ($\beta = -0.347$, $p = 0.037$) suggests that the broader indirect relationship remains statistically detectable when the specified mediating pathways are considered jointly.

Meanwhile, the negative relationship between Institutions and IKP supports the theories of institutional robustness (Casas, 2020) and resilient governance (Hafiz, 2025), which emphasize the role of credible institutions in suppressing electoral risks. The significant total association observed in this study is consistent with this theoretical perspective, although the cross-sectional design does not permit the direction of causality to be established. These findings also reinforce the view that a healthy digital democracy requires the capacity of local actors, not just ICT infrastructure, to drive ethical participation, transparency, and public trust (Bi, 2024; Chaeruddin et al., 2024; Firmstone & Coleman, 2015; Novelli & Sandri, 2024). This study provides empirical evidence of an interconnected governance ecosystem in which technology, human resources, and institutions are statistically related to the dynamics of local election vulnerability (Simonofski et al., 2021; Zaki et al., 2022).

Practical Implications

Practically, this study shows that resilient and integrity regional election governance requires three strategic pillars: strengthening the digital skills of stakeholders, integrating ICT policies with human resource capacity building, and institutional reform. These implications are derived from the observed pattern of associations rather than from claims of direct causal effects. In particular, the significant Skills $\rightarrow$ IKP association and the significant total indirect association of ICT Adoption indicate that human capacity and digital readiness should be considered together in designing regional election-governance interventions.

Strengthening digital literacy, for both organizers and voters is a prerequisite for participation and legitimacy of elections in the digital era (Drápalová & Wegrich, 2021; Mudau, 2022). ICT adoption is only effective if it is carried out in conjunction with increasing the capacity of the apparatus, because the main obstacle to e-government often comes from the low digital literacy of human resources, not technological limitations (Dupe Ayesha et al., 2025; Matteucci et al., 2023). Accordingly, digitalization programs should be accompanied by systematic

competency development, including technical operation, data interpretation, cybersecurity awareness, digital ethics, and adaptive problem-solving. This recommendation is consistent with the observed importance of Skills in the structural model.

On the institutional side, the success of e-voting in developed countries depends on public trust and institutional commitment (WU & Gmeinwieser, 2025), as well as strengthened transparency through AI and blockchain-based audits (Adisa et al., 2025). In addition, ICT adoption must be framed in policies that ensure digital ethics and data protection (Asimakopoulos et al., 2025), as well as supported by transparent digital public participation (Alcaide Muñoz et al., 2025). The significant negative total association between Institutions and IKP ($\beta = -0.328$, $p = 0.044$) further indicates that institutional dimensions should not be treated separately from technological and human-resource development. Institutional reform can therefore be directed toward clearer digital governance procedures, accountability mechanisms, transparent monitoring, competency standards, and coordination among electoral stakeholders.

The synergy between digital capacity, human resources, and institutions is the operational foundation to support lower electoral vulnerability and strengthen trust in local democracy. However, because the present analysis is based on 38 cross-sectional district/city observations, these practical implications should be understood as evidence-informed priorities rather than as experimentally established causal prescriptions. Future studies using larger samples, longitudinal data, or repeated regional observations could further test whether improvements in digital skills, institutional capacity, and ICT adoption are followed by measurable changes in electoral vulnerability.

Conclusion

This study found that human and institutional capacity is the main determinant in reducing the level of vulnerability in regional elections. The results of the analysis showed that Skills had a significant direct influence on the Election Vulnerability Index (IKP), while ICT Adoption had an indirect effect through the Skills mediation variable. In addition, the Institution showed a significant negative total influence on the IKP, indicating that strong and credible institutional governance is a key factor in maintaining the integrity of elections at the local level. Conceptually, this study emphasizes that strengthening the capacity of stakeholders—through digital skills improvement, technological adaptation, and institutional strengthening—

is an important foundation in building participatory, transparent, and resilient election governance. These findings strengthen the theory of governance capacity and digital institutionalism in the context of regional electoral democracy in Indonesia.

This research still has limitations in the use of secondary data and limited area coverage in East Java Province. Therefore, further research is recommended to: mExpand geographical and temporal coverage by involving other provinces or use longitudinal data to analyze stakeholder capacity dynamics over time; adding contextual variables such as community participation, transparency of election information, or public trust indices to enrich regional election governance models; using a mixed methods approach to explore qualitative perspectives from election stakeholders on practices and challenges in the application of ICT and institutional management. With the direction of the research, it is hoped that a comprehensive model can be built on how digital, institutional, and social capacities interact in strengthening election governance with integrity and sustainability in Indonesia.

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