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Statistical Intelligence and Digital Transformation in Government Institutions A Data-Driven Framework for Improving Public-Sector Performance in the Kurdistan Region of Iraq

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Abstract

Digital transformation has played a vital role in modernizing the public sector by enabling the combination of digital identity, actionable data, connected infrastructure, online services, and analytics to eliminate administrative inefficiencies. The study strives to create a statistical intelligence framework that can be utilized to measure digital transformation in public institutions in Kurdistan Region of Iraq by utilizing the secondary data obtained from official sources of information, such as Kurdistan Regional Government with regard to the reforms implemented, and the current digital systems adopted, as well as characteristics of how they operate. The systems have been classified into seven categories, namely, front-office capabilities, digital identity capabilities, payment system capabilities, transparency and accountability, interchange and transfer of data, and access to service. The methods and tools that have been applied in this study include descriptive statistics, Shapiro-Wilk and Jarque-Bera normality tests, Spearman correlation and Kruskal-Wallis test, and different predictive models (logistic regression, decision trees, random forest). The score received is 4.60 out of 7 based on the data analysis results. It can also be noted that functional capabilities of digital identity represent 93.3 percent of cases examined, while its back-office functionalities represent 86.7 percent and accessibility to the service account for 73.3 percent. The results obtained through the Shapiro-Wilk test indicate that the evaluated systems did not demonstrate a normal distribution of functional characteristics according to this test results ($W=0.819$, $p=0.006$), which provides a basis for asserting that the methods and techniques presented are effective for the accomplishment of the study.

Keywords: digital government; GovTech; statistical intelligence; public-sector performance; machine learning; explainable analytics.

1. Introduction

Digital transformation in government is no longer limited to converting paper forms into online forms. It increasingly involves redesigning institutions around digital identity, shared infrastructure, interoperable data, automated workflows, analytics, and citizen-centred services. International research describes this shift as a transition from conventional e-government toward digital-era governance and GovTech, in which technology is embedded in organizational structures, public value creation,

accountability, and the everyday design of services (Dunleavy et al., 2006; Janowski, 2015; Mergel et al., 2019; Vial, 2019). The World Bank's GovTech approach similarly treats core government systems, public-service delivery, citizen engagement, and institutional enablers as mutually reinforcing dimensions of digital maturity (World Bank, 2021; World Bank, 2022; World Bank, 2025).

The Kurdistan Regional Government has explicitly positioned digital transformation as a strategic reform priority. Its digital transformation strategy emphasizes citizen and business access, streamlined government structures, improved processes, shared platforms, secure infrastructure, and a goal of becoming a leading GovTech government in the region. The Department of Information Technology received a cross-government digital mandate through Prime Ministerial Decree 104 in 2020; the first Advanced Data Center was inaugurated in September 2022; and the first KRG Digital Transformation Strategy was formally announced in October 2022 (KRG DIT, 2020–2022). Current KRG reporting identifies more than 26 digital systems and reports 900,600 public employees registered in the My Account programme, indicating that digital reform has moved beyond planning into large-scale implementation (KRG DMI, 2026).

1.1 Problem statement

Despite visible progress, a major empirical problem remains: the KRG does not yet publish a harmonized, machine-readable, institution-by-year dataset linking digital-transformation inputs to comparable service-performance outcomes. Publicly available evidence is distributed across strategies, implementation pages, system descriptions, and sector-specific reports. Consequently, it is difficult to quantify which digital capabilities are most strongly related to service accessibility, administrative efficiency, transparency, or citizen outcomes. This data fragmentation also limits the application of modern statistical intelligence and explainable machine learning to KRG public-sector reform.

1.2 Objectives of the study

The study aims to construct and demonstrate a reproducible data-driven framework for measuring digital transformation in KRG institutions and relating digital capability to public-service performance. The specific objectives are to: (1) consolidate verified KRG digital-reform milestones; (2) code named digital systems by functional capability; (3) characterize the distribution and normality of digital-transformation indicators; (4) test associations using non-parametric methods appropriate for a small, non-normal sample; (5) compare at least four predictive models for service-access classification; and (6) propose an extensible institution-by-year data architecture suitable for future causal, panel, and forecasting studies.

1.3 Research gap

The international literature contains sophisticated measures of digital government maturity, e-government adoption, public value, and digital service quality, yet subnational evidence from Iraq and especially the Kurdistan Region remains limited. Existing KRG materials document strategies and achievements but rarely provide a statistical design that links digital-system capabilities to public-sector performance. The present study therefore addresses both a regional evidence gap and a methodological gap by combining official documentary data, structured content coding, non-parametric statistics, dimension reduction, and predictive modelling in one framework.

1.4 Research questions

What functional characteristics dominate the KRG's current portfolio of named digital-government systems?

Is the composite functional-intensity score normally distributed?

Which digital capabilities are most strongly associated with functional intensity and service access?

Do functional-intensity scores differ across evidence/ownership categories?

Which predictive model provides the strongest pilot discrimination of service-access functionality? How can the current documentary dataset be extended into a robust institution-by-year public-sector performance panel?

1.5 Research Hypotheses

H1: Greater functional digital intensity is positively associated with service-access functionality.

H2: Citizen-facing and interoperability-related capabilities are positively associated with the functional-intensity score.

H3: Functional-intensity scores differ significantly across direct, inferred, and cross-government ownership-evidence groups.

H4: Non-linear tree-based ensemble models outperform conventional logistic regression in predicting service access. Statistical significance is evaluated at $\alpha=0.05$, while effect sizes and predictive metrics are emphasized because of the small analytical sample.

1.6 Importance of the study

The framework has practical value for KRG policymakers because it converts dispersed implementation evidence into variables that can be monitored, compared, and modelled. It also

clarifies what additional administrative data should be released—service completion times, transaction volumes, digital uptake, citizen satisfaction, system availability, cybersecurity incidents, training indicators, and interoperable data exchanges—to enable stronger evaluation. Academically, the study shows how statistical intelligence can be introduced in a data-scarce public administration environment without disguising missing information or presenting invented values as official observations. The verified sequence of major KRG digital-transformation milestones is summarized in Figure 1.

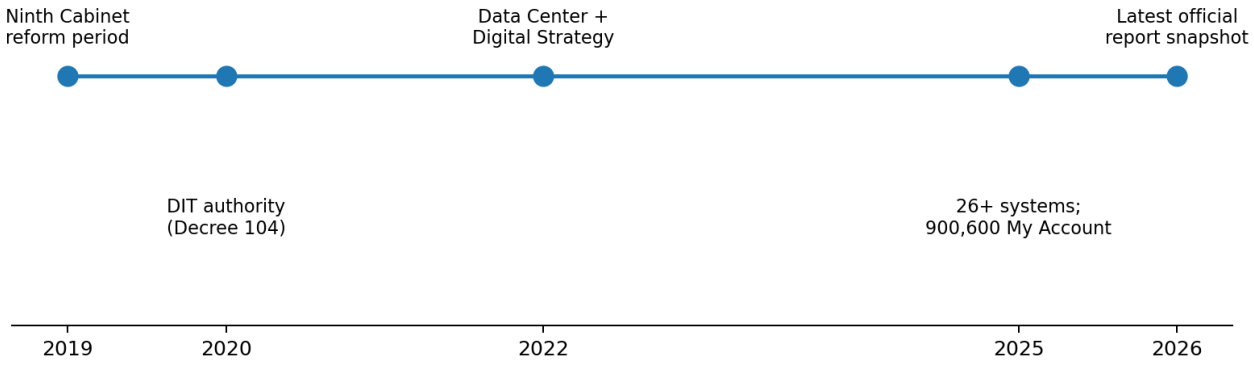


Figure 1. Verified digital-transformation milestones in the Kurdistan Regional Government.

2. Literature Review

Digital-government research has evolved through several conceptual stages. Early e-government studies focused on web presence, online transactions, technology acceptance, and citizen trust (Davis, 1989; Carter and Bélanger, 2005; Welch et al., 2005; Tolbert and Mossberger, 2006). Later work emphasized organizational transformation, public value, cross-agency coordination, and the institutional consequences of digital technology (Fountain, 2001; Dunleavy et al., 2006; Bannister and Connolly, 2014; Cordella and Tempini, 2015). Janowski (2015) conceptualized digital-government evolution as a progression from digitization toward contextualized transformation, while Mergel et al. (2019) showed that practitioners understand digital transformation as a process involving organizational, cultural, and technological change rather than technology alone.

A central stream of the literature concerns public value and service performance. Digital government may create value through better services, improved administration, enhanced openness, trust, fairness, and social outcomes (Moore, 1995; Bryson et al., 2014; Twizeyimana and Andersson,

2019). Yet technology can also reproduce fragmentation if agencies digitalize isolated processes without redesigning data governance or institutional relationships. Cordella and Tempini (2015) therefore caution that organizational structures and bureaucracy shape the effects of ICT. Similarly, Luna-Reyes and Gil-Garcia (2014) stress the co-evolution of technology, organizations, and institutions.

Interoperability and shared infrastructure are repeatedly identified as critical. Fragmented databases force citizens and public employees to re-enter information, weaken analytical capacity, and make cross-agency service journeys difficult. Digital identity, shared platforms, data centres, interoperability standards, and application programming interfaces can reduce these frictions, but they require common architecture, security, governance, and legal clarity. OECD frameworks place 'digital by design', 'data-driven public sector', 'government as a platform', 'open by default', 'user-driven', and 'proactiveness' at the core of digital-government maturity (OECD, 2014; OECD, 2020a; OECD, 2020b). World Bank GovTech frameworks likewise highlight core government systems, online public-service delivery, digital citizen engagement, and institutional enablers (World Bank, 2021; World Bank, 2022; World Bank, 2025).

Transparency and accountability represent another major mechanism. ICT can support disclosure, auditability, citizen feedback, and anti-corruption initiatives when data are timely, accessible, and institutionally actionable (Bertot et al., 2010; Meijer, 2015). Open-government and open-data research nevertheless shows that releasing data alone does not guarantee value; organizational capacity, data quality, standards, intermediaries, and user capability all matter (Zuiderwijk and Janssen, 2014; Janssen et al., 2012).

Digital inclusion and user-centred design are also essential. Online services can lower transaction costs for many citizens while creating new barriers for people with limited connectivity, digital literacy, disability access, language support, or trusted identity credentials. Classic digital-divide research and contemporary e-government surveys therefore recommend multi-channel access, accessibility standards, skills development, and monitoring of who actually benefits (Norris, 2001; United Nations, 2022; United Nations, 2024). Public-service performance should consequently be measured not only by the number of platforms but also by usage, completion, time saved, satisfaction, accessibility, and equitable reach.

From a methodological perspective, digital-government maturity is increasingly measured through composite indexes and multidimensional scorecards. Composite indicators can summarize complex systems but can conceal weighting choices and redundancy among variables. Principal-

component analysis (PCA) offers a data-driven way to examine latent dimensions, while clustering can identify groups of systems or institutions with similar profiles. For outcome prediction, generalized linear models provide interpretable baselines, whereas decision trees, random forests, and gradient boosting can capture non-linear interactions and threshold effects. In public-sector settings, predictive accuracy must be combined with transparency, robustness, and clear limits on causal interpretation.

Machine learning is particularly useful when administrative datasets grow large, yet small-data contexts require conservative validation. Random train/test splits are unstable with very small samples; leave-one-out cross-validation (LOOCV) uses nearly all observations for training while producing an out-of-sample prediction for every record. Even so, high accuracy in a sample of 15 systems cannot establish external validity. The role of the present models is therefore methodological demonstration: they show how a future, richer KRG panel could compare interpretable statistical models with non-linear learners while retaining reproducibility and explicit uncertainty.

For the Kurdistan Region, the policy architecture provides strong motivation for such a framework. The KRG strategy describes customer-centric services, shared platforms, stronger digital infrastructure, and government-wide implementation. The Advanced Data Center provides infrastructure intended to host services securely across ministries, while the current system inventory includes digital identity, financial management, e-visa, border control, complaints, business registration, employment, government portal, and document-management functions. What remains underdeveloped in the public evidence base is a unified quantitative link between these capabilities and public-sector performance outcomes. This is the niche addressed by the present study.

The conceptual linkage between digital transformation and public-sector performance can be understood through several complementary digital dimensions that influence administrative efficiency, service quality, transparency, and institutional capacity. Citizen-facing digital services can reduce the need for physical visits and lower information-search and transaction costs, thereby improving service uptake, user satisfaction, and completion rates. Similarly, back-office digitization enhances internal administrative processes by automating workflows, records, and routine procedures, which can contribute to shorter processing times and lower costs per transaction. Digital identity systems further strengthen public-service delivery by enabling secure authentication and reusable credentials, thereby facilitating access to government services, reducing opportunities for fraud, and improving transaction completion. In parallel, digital financial and payment systems can enhance the efficiency and traceability of payroll and public payments, with potential benefits for payment timeliness, financial inclusion, and public financial control. Digital transformation can also reinforce transparency and

accountability by creating auditable transactions, improving feedback mechanisms, and supporting more effective oversight, which may strengthen public trust and improve complaint resolution. Moreover, interoperability and data-sharing arrangements enable information to be reused across government agencies and support evidence-based analytics, reducing duplication and accelerating administrative and policy decision-making. Finally, shared digital infrastructure, including secure hosting environments and common technical standards, provides the institutional foundation required for reliable digital government operations by improving system availability, scalability, interoperability, and organizational resilience. Collectively, these mechanisms illustrate how digital transformation can contribute to stronger public-sector performance when technological capabilities are integrated with effective governance, institutional coordination, and administrative processes.

3. Materials and Methods

3.1 Research design and data source

The study uses a secondary-data, cross-sectional analytical design embedded within a broader longitudinal reform timeline. The workbook supplied for the study contains verified milestones, a list of named KRG digital systems, a variable dictionary, and a multi-year framework that intentionally leaves unverified annual outcomes blank. The analytical sample is the 15 named digital systems for which functional descriptions were available in the official KRG material. Current KRG reporting indicates that the wider government portfolio includes more than 26 digital systems; therefore, the 15-system analytical sample should be interpreted as a documented subset rather than a complete census.

3.2 Data integrity and coding

No missing annual public-service values were imputed or fabricated. Each named system was coded on seven binary functional dimensions: Citizen_Facing, Back_Office, Digital_Identity, Financial_or_Payment, Transparency_Accountability, Interoperability_Data, and Service_Access. A Functional_Score was computed as the unweighted sum of the seven indicators (range 0–7). Institutional ownership was classified as Direct, Inferred, or Cross-government according to the wording and service function in the source material. Inferred ownership is retained transparently because it is useful analytically but requires administrative verification before any definitive institution-level ranking.

3.3 Descriptive analysis

For binary indicators, frequencies and percentages were calculated. For the Functional_Score, count, mean, standard deviation, minimum, median, and maximum were computed. Because the

sample is small and the composite score is discrete, normality was examined with both Shapiro–Wilk and Jarque–Bera tests, with Shapiro–Wilk given greater interpretive weight for small samples.

3.4 Inferential testing

Spearman rank correlation was selected to assess monotonic associations because of non-normality, binary predictors, discreteness, and the small sample. Kruskal–Wallis testing was used to compare Functional_Score distributions among ownership-evidence groups (Direct, Inferred, Cross-government). These methods avoid the stronger distributional assumptions of t-tests and ordinary one-way ANOVA.

3.5 Dimension reduction

PCA was applied to the six non-constant binary functional indicators after standardization; Transparency_Accountability was excluded from PCA because it had zero variance (all 15 coded systems had this feature). PCA is used descriptively to visualize functional similarity among systems, not as a causal model.

3.6 Predictive modelling

Service_Access (0/1) was selected as the pilot dependent variable because it captures a central objective of the KRG strategy and has both positive and negative cases in the coded sample. Predictors were Citizen_Facing, Back_Office, Digital_Identity, Financial_or_Payment, and Interoperability_Data. Transparency_Accountability was excluded because it was constant, and Functional_Score was excluded to avoid target leakage because it contains Service_Access as a component. Four models were compared: logistic regression, decision tree, random forest, and gradient boosting.

3.7 Validation and performance criteria

Leave-one-out cross-validation generated an out-of-sample probability for each of the 15 systems. Performance was assessed using accuracy, balanced accuracy, F1 score, and area under the receiver-operating-characteristic curve (ROC AUC). Balanced accuracy is reported because Service_Access is present in 11 of 15 systems, creating class imbalance. Predictive results are treated as exploratory because sample size is too small for stable hyperparameter optimization or external validation.

3.8 Statistical significance and software

Statistical tests used a two-sided $\alpha=0.05$ threshold. Exact p-values are reported where appropriate. Analysis was conducted programmatically in Python using pandas, SciPy, and scikit-learn; figures were generated with matplotlib. The workflow is reproducible from the supplied Excel dataset and the coding rules described in this section. The analytical framework incorporated a set of variables designed to capture the functional characteristics, digital capabilities, and evidentiary classification of the systems under investigation. The principal composite measure, Functional_ Score, was calculated as the sum of seven binary functional indicators, producing a score ranging from 0 to 7, and was used primarily as a descriptive composite outcome reflecting the breadth of digital functionality. The variables Citizen_ Facing and Back_ Office were coded dichotomously (0/1) and treated as predictor variables representing key system characteristics related to external service delivery and internal administrative digitization, respectively. Similarly, Digital_ Identity, Financial_or_Payment, and Interoperability Data were measured as binary indicators and incorporated as predictors capturing the presence of digital authentication, electronic financial or payment functionality, and data-sharing or interoperability capabilities. Transparency_ Accountability was also coded as a binary variable; however, because it exhibited no variation within the analytical sample, it was retained for descriptive purposes only and was not suitable for inferential modelling. Service Access, measured dichotomously, was specified as the outcome variable in the pilot machine-learning analysis to examine whether selected digital system characteristics could distinguish systems with accessible digital services. Finally, Evidence Group classified observations into three categories—Direct, Inferred, and Cross-government evidence—and was used as a grouping variable to facilitate comparison across different levels and types of evidentiary support. This measurement structure enabled the analysis to combine descriptive assessment, predictor-based statistical modelling, and exploratory machine-learning evaluation within a coherent analytical framework.

4. Result and Discussion

4.1 Descriptive statistics

Table 1 indicates that the average Functional Score for the 15 coded systems is 4.60 (SD=1.12), with a median of 5 and a score range from 3 to 6. The systems were coded for interoperability/data functionality in 93.3% of cases, back-office functionality in 86.7%, service access functionality in 73.3%, and citizen-facing functionality in 66.7%. Moreover, the functionalities of digital identity and payment systems were found in 20.0% of the coded systems.

Table 1. Descriptive statistics for coded digital-system indicators.

Variable	N	Mean	SD

Citizen Facing	15	0.667	0.488
Back Office	15	0.867	0.352
Digital Identity	15	0.200	0.414
Financial or Payment	15	0.200	0.414
Transparency Accountability	15	1.000	0.000
Interoperability Data	15	0.933	0.258
Service Access	15	0.733	0.458
Functional Score	15	4.600	1.121

4. 2. Prevalence of Digital-Government Functional Capabilities Across the Assessed Systems

In Figure 2 there is a stark disparity in the deployment of digital governance features in the systems evaluated. While transparency and accountability functionalities were found in every system (100%), interoperability and data integration (93.3%) and digitization of back-office functions (86.7%) also turned out to be primarily implemented. In comparison, providing citizens' services (66.7%) and accessing services (73.3%) were only moderately widespread among the systems, indicating that organizational modernization has made greater strides than direct contact with users. The lowest values were recorded for the functions of digital identity and payments, with both equal to 20%, which points at a significant gap in advanced digital capabilities. In general, the figure shows that digital transformation in the analyzed sample of systems is most pronounced in governance, data integration, and internal processes as opposed to security and end-to-end transactions.

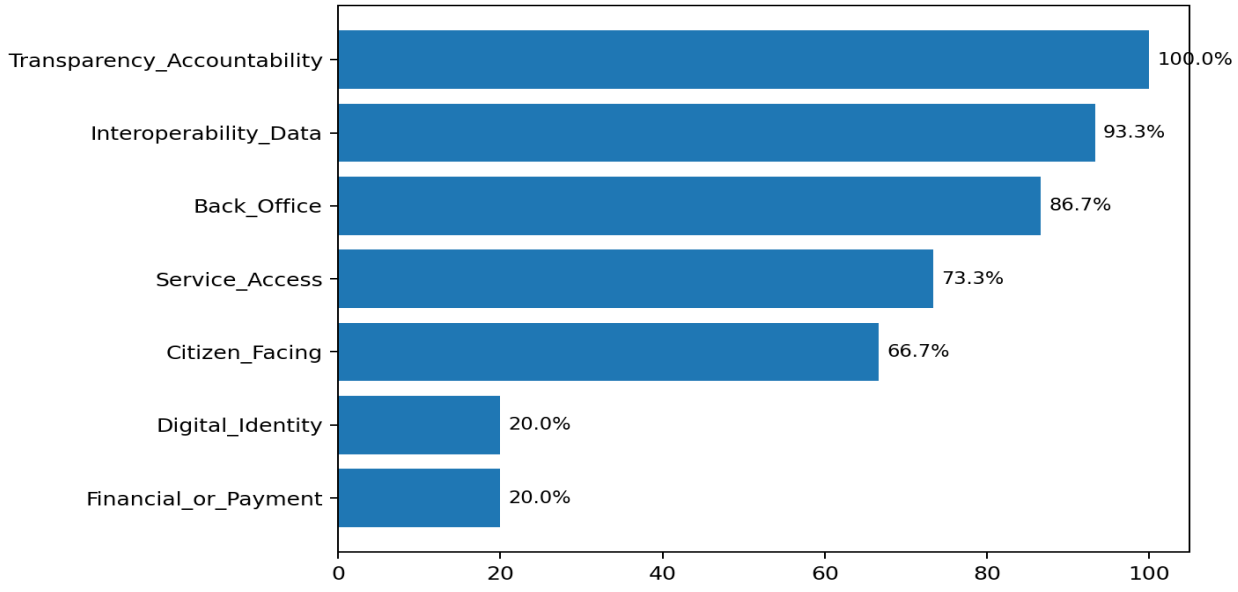


Figure 2. Prevalence of functional characteristics across the 15 named digital systems.

4. 3. Distribution of Systems by Functional Digital Capability Score

The assessed systems are laid out within the parameters of their Functional_Score in Figure 3. Scores within the range of 3 to 6 indicate the digital functions that these systems showcase. The majority are placed at a score of five, which means that seven out of the total assessed systems demonstrate a rather adequate level of digital performance. There are other three systems, which were evaluated at the score of 3, and three systems that were evaluated at 6, which is the highest score, whereas only one system acquired a score of 4. Overall, it can be concluded that the most systems score relatively quite well but do not show a full and comprehensive level of full functional coverage in any of them, as indicated in the present graph.

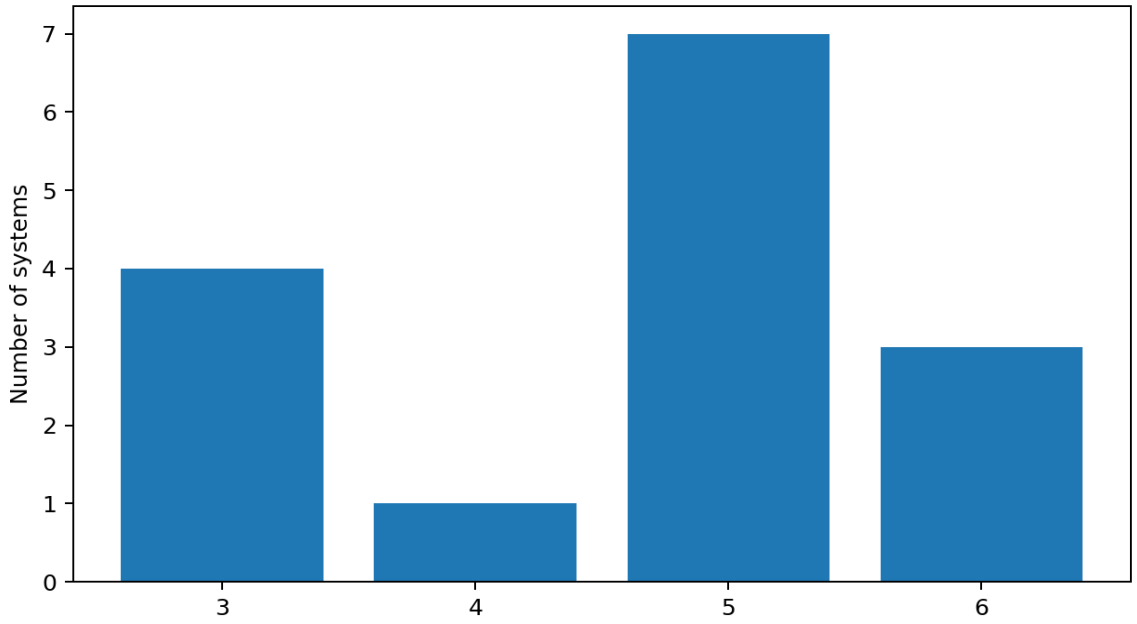


Figure 3. Distribution of the composite Functional Score.

4.4. Functional Digital Capability Scores across Selected KRG Digital Systems

The comparison of the Functional Score for different digital systems presented in Figure 4 provides insights into the range of functionality of the digital systems. The highest score of 6 is given to the Population Information Systems, My Account and the e-Visa Portal, giving them full assessment coverage. The second group of systems comprises the Digital Border Control System, Business Registration System, Jobs Portal, KRG Portal (GOV.KRD), Runaki Project System, KRDPass and Citizen Complaint System, scoring 5, which means that they are quite advanced in regard to functionality but do not provide fully comprehensive coverage. The score of the Kurdistan Financial Management System (KFMS) equals 4 whereas the Information Update System, KRG Data Centre,

Document Management System and Hajj Portal have the score of 3, meaning much less functional ability.

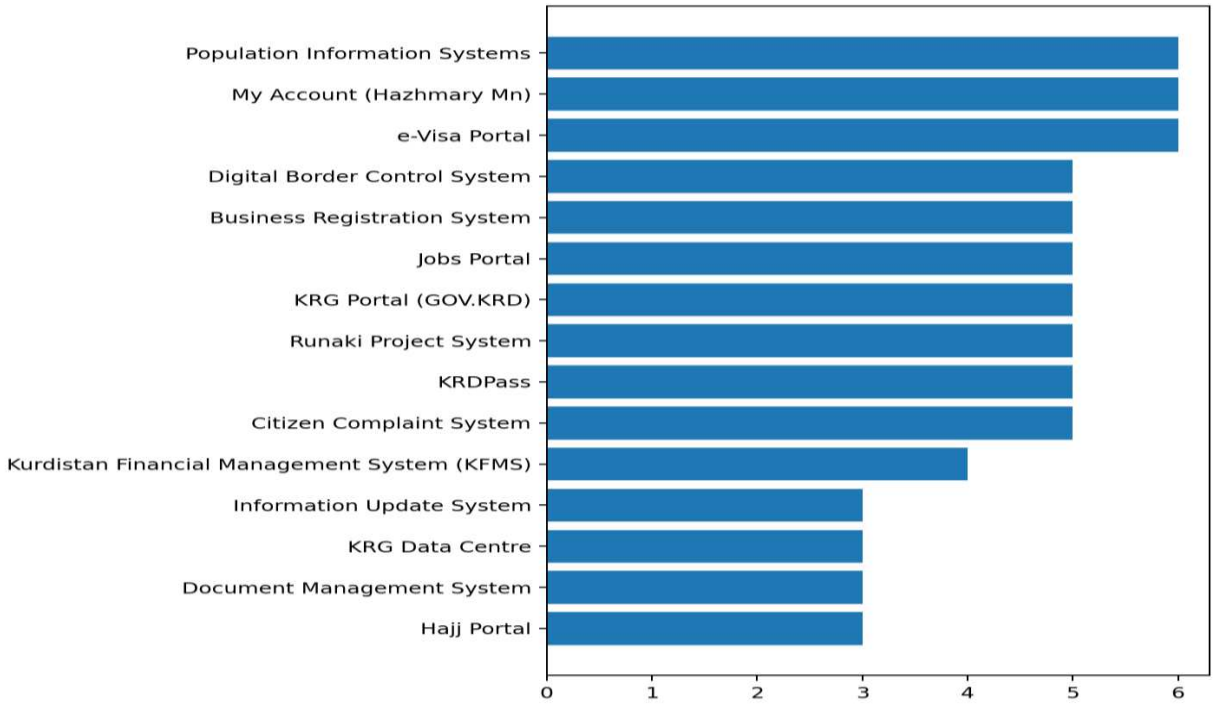


Figure 4. Functional intensity of individual named digital systems.

4.5. Normality tests

As shown in Table 2, the Functional Score's normality was rejected based on Shapiro–Wilk testing (W=0.819, p=0.006), while Jarque–Bera did not reject normality (JB=1.269, p=0.530). However, due to the sample size (n=15), the nature of the score and the higher sensitivity of Shapiro–Wilk on small samples, the further association and group-comparison analyses were performed using non-parametric methods.

Table 2. Normality tests for Functional Score.

Test	Statistic	p-value	Decision (α=0.05)
Shapiro–Wilk	0.819	0.006	Reject normality
Jarque–Bera	1.269	0.530	Do not reject

4. 6. Spearman correlation

As reported in Table 3, Functional_Score showed a strong and positive correlation with Service_Access (ρ=0.727, p=0.002) and a positive association with Citizen_Facing functions (ρ=0.647, p=0.009). The relationships to the back-office, identity, payment, and interoperability metrics were again positive but not statistically significant at α=0.05 in this small sample. As the composite measure is comprised of dimensions, the obtained correlations provide insight into structural alignment rather than independent causation.

Table 3. Spearman correlations with Functional Score.

Indicator	Spearman ρ	p-value	α=0.05
Citizen Facing	0.647	0.009	Significant
Back Office	0.218	0.434	Not significant
Digital Identity	0.330	0.230	Not significant
Financial or Payment	0.371	0.173	Not significant
Interoperability Data	0.364	0.183	Not significant
Service Access	0.727	0.002	Significant

4.7. Correlation Matrix of Digital-Government Functional Dimensions and Overall Functional Score

The associations among major aspects of digital government and overall functional score are detailed in Figure 5. The highest positive correlation is noted between citizen facing and service access ($r = 0.85$). This means that there is a strong association between systems allowing for direct communication with citizens and the wider availability of digital public services. Another important positive association to note is that of back office and interoperability data ($r = 0.68$). This implies that digitizing administrative processes is accompanied by better data-sharing capabilities. The functional score correlates positively with all variables; with the strongest correlation with service access ($r = 0.73$) and citizen facing ($r = 0.65$), the other positive correlations being with financial or payment ($r = 0.37$), interoperability data ($r = 0.36$), and digital identity ($r = 0.33$). The weakest correlation was found with back office ($r = 0.22$). There are also several negative correlations such as those of digital identity–back office ($r = −0.29$), citizen facing–back office ($r = −0.28$), and financial or payment–digital identity ($r = −0.25$). Overall, the matrix highlights that the widest functional breadth is closely associated with attitudes towards citizens, while some digital aspects are being developed more independently.

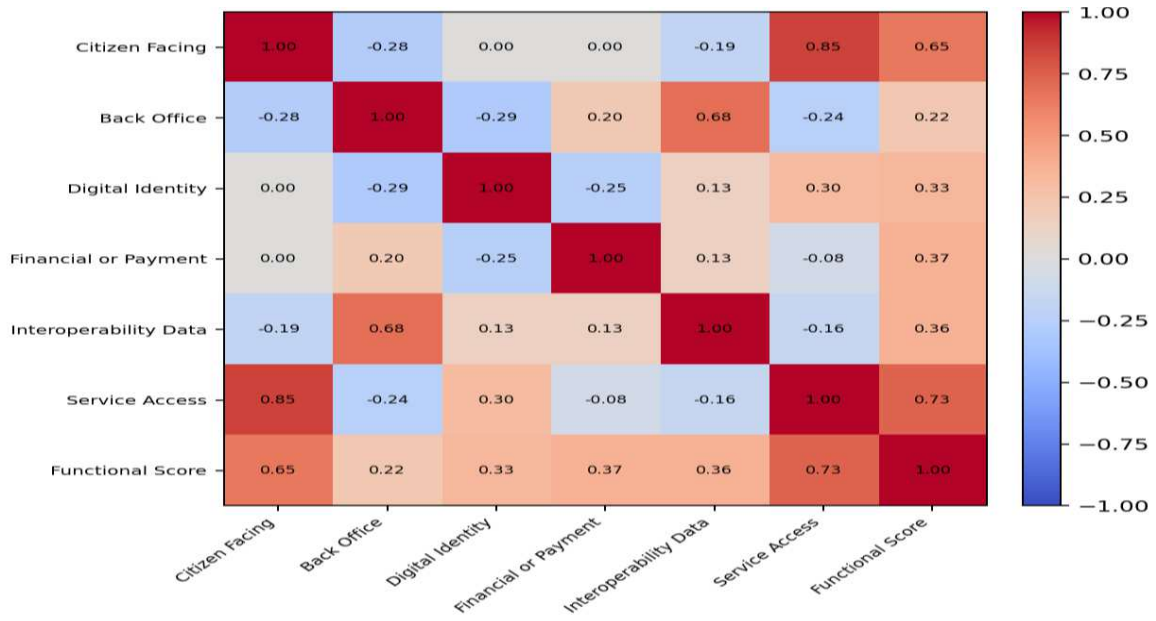


Figure 5. Spearman correlation matrix among non-constant coded variables.

4. 8. Kruskal–Wallis group comparison

As summarized in Table 4, the Mean Functional_Score was found to be the highest among the Inferred ownership group (5.13), with the Cross-government (4.33) coming in second place followed by the Direct (3.75) coming last. The findings of the Kruskal–Wallis test proved to be statistically insignificant (H=4.592, p=0.101) thereby not supporting H3. This finding must not be taken as an indication of equivalence owing to the very small sizes of groups.

Table 4. Functional Score by ownership-evidence group.

Evidence group	N	Mean score	Median score
Cross-government	3	4.33	5.0
Direct	4	3.75	3.5
Inferred	8	5.12	5.0

Kruskal–Wallis H=4.592; p=0.101.

4. 9. Principal-component analysis

As illustrated in Figure 6, the constant transparency variable was removed from the analysis, while the remaining variables were standardized, leading to PC1 that accounts for 38.4% of variance, while PC2 takes 23.0%, thus making it to 61.4% altogether. Positive loading of PC1 is observed for citizen-oriented and service accessibility variables and negative loading for back-office/openness variables. It can be noted that the second principal component is more heterogeneous in terms of its variables including citizen influence variables,

back-office, payment analysis, openness, and service access measurements. System comparison makes it possible to argue the need for multidimensionality perspective related to digital transformation.

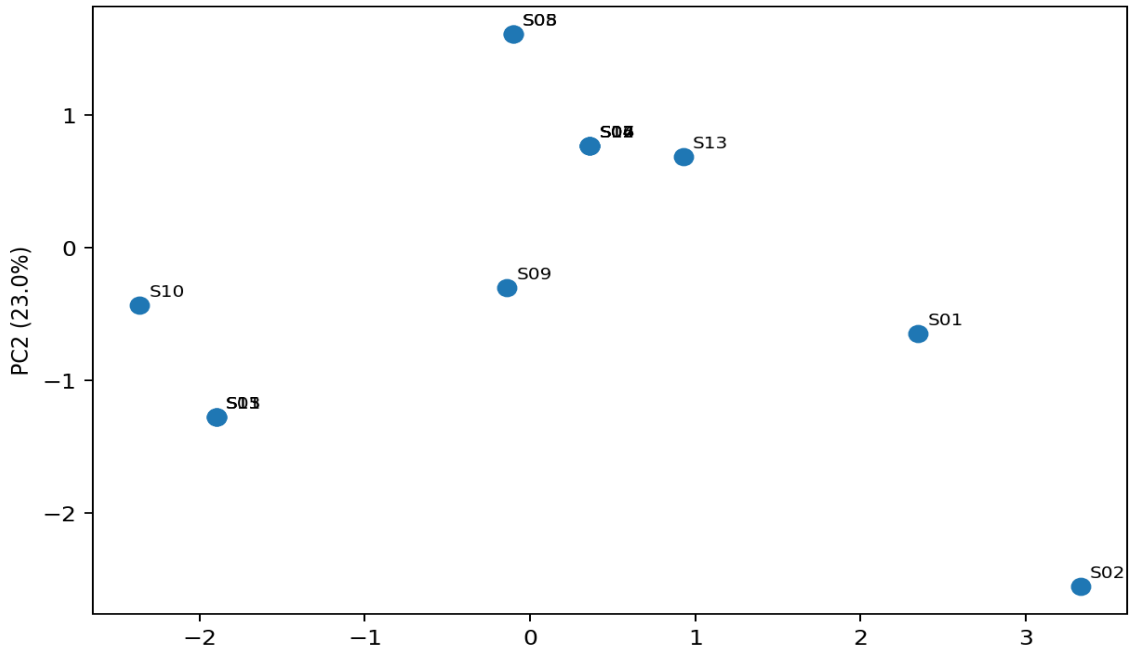


Figure 6. PCA map of digital-system functional profiles.

4. 10. Predictive model comparison

As reported in Table 5, the four predictive models were evaluated using leave-one-out cross-validation (LOOCV). Logistic regression reached accuracy of 73.3% and ROC AUC of 0.909, but had only 0.500 balanced accuracy due to the fact that where the value of 0.5 was assigned to classification threshold the majority class was favored. Decision tree and random forest and gradient boosting gave the same result, yielding with 93.3% accuracy and 0.955 balanced accuracy. With regard to ROC AUC, random forest showed the best results, having 0.977.

Table 5. LOOCV predictive performance for Service Access.

Model	Accuracy	Balanced accuracy	F1	ROC AUC
Logistic Regression	0.733	0.500	0.846	0.909
Decision Tree	0.933	0.955	0.952	0.955
Random Forest	0.933	0.955	0.952	0.977
Gradient Boosting	0.933	0.955	0.952	0.909

4. 11. Comparative Performance of Machine-Learning Models for Predicting Service Access

Figure 7 illustrates a comparison of prediction of four classification models, including Logistic Regression, Decision Tree, Random Forest, and Gradient Boosting. One can see that Random Forest provides good performance consistently, achieving the greatest ROC-AUC (near 0.98) and good predictive performance in terms of balanced accuracy and F1-score (near 0.95-0.96).Decision Tree performs well across all four metrics as well, since its values are near 0.95 while Gradient Boosting achieves close to high accuracy; however, the latter has lower ROC-AUC (about 0.91). One should notice that Logistic Regression provides rather weak performance as compared to others, mainly with regard to balanced accuracy (around 0.5).In general, it is possible to state that tree-based models are more stable than linear model. Realistically, yet, the findings should be verified through large-scale studies as the given analysis may be subject to certain limitations.

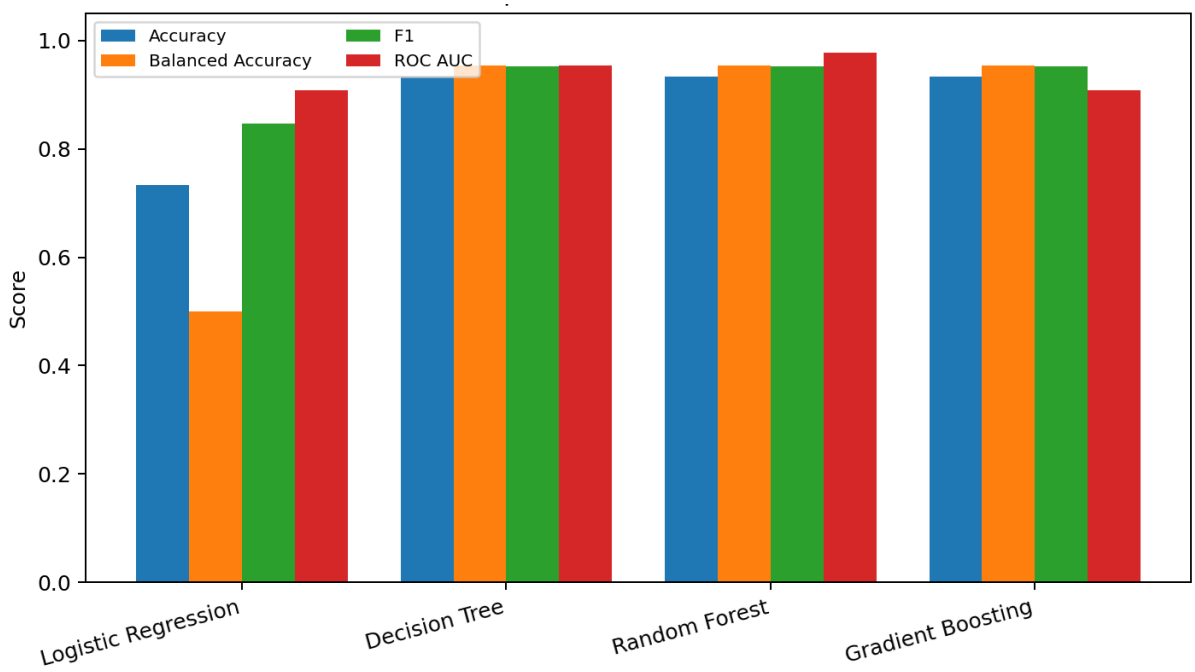


Figure 7. Comparison of four predictive models under leave-one-out cross-validation.

4. 12. Hypothesis assessment

Table 6, placed immediately below, presents the summary of the empirical analysis of four hypotheses. There is support for hypothesis 1, since functional intensity was shown to be correlated with service access, meaning that the systems with higher functional intensity offer better service access (Spearman's $\rho = 0.727$, $p = 0.002$). Partial support is observed for hypothesis 2, where citizen-to-citizen functionality is positively related to functional intensity ($\rho = 0.647$, $p = 0.009$) and interoperability shows a weak correlation ($\rho = 0.364$, $p = 0.183$). This indicates the stronger link between citizen functionality and functional intensity compared with interoperability. As for hypothesis 3, it was not supported, since Kruskal-Wallis test indicates that no significant correlation between functional scores and groups was established ($H = 4.592$, $p = 0.101$), indicating

that the functional intensity level does not vary enough by classification evidence to reject the null hypothesis. Hypothesis 4 is supported when restricted exploratory evidence confirms that nonlinear models are much better than Logistic Regression (classification accuracy was 0.933 and 0.733 respectively) and Random Forest has a high ROC-AUC of 0.977. To summarize, the evidence provided supports the strongest connection between functional intensity and service integration, proving that the nonlinear models are of predictive value, while they fail to establish significant differences between the groups. Since this is pilot research with small sample size, the results of hypothesis 4 should be treated rather as preliminary evidence than proclaimed superiority of the models.

Table 6. Summary of Hypothesis Testing and Empirical Evidence

Hypothesis	**Evidence**	**Conclusion**
H1: functional intensity is positively associated with service access	Spearman ρ=0.727, p=0.002	Supported descriptively/statistically
H2: citizen-facing/interoperability capabilities align with functional intensity	Citizen-facing ρ=0.647, p=0.009; interoperability ρ=0.364, p=0.183	Partially supported
H3: functional score differs by evidence group	Kruskal–Wallis H=4.592, p=0.101	Not supported
H4: nonlinear models outperform logistic regression	Tree/RF/GB accuracy 0.933 vs logistic 0.733; RF AUC 0.977	Supported as pilot predictive evidence

5. Discussion

The findings demonstrate that the relevant KRG digital system has currently been developed with a significant focus towards interoperability, back-end improvement, trustworthiness and accessibility of services. The trend is in line with KRG's joint-platform approach and methodologies existing in the domain of international GovTech where core systems and interoperable backbone systems are considered major preconditions for better services delivered. What makes the presence of interoperability/data coding (93.3%) even more important is that the nature of value in digital government heavily relies on the possibility of data reuse across the boundaries of institutions rather than on the amount of utilized applications (OECD, 2020b; World Bank, 2021).The average Functional_Score 4.60 out of seven shows that the portfolio is multifaceted rather than narrowly-focused on the provision of distinct purposes. Certain processes combine services of citizens, internal workings, transparency and interoperability. Such approach is in line with the boundaries of governmental operations in the digital age as the redesigning of services and the establishment of

common information architectures replace disconnected e-channels (Dunleavy et al., 2006). But the score should not be viewed as the maturity index since it does not establish any benchmarks; it only provides a clear measure based on the coded content revealing how to transform a document evidence into the working variables.Similarly, normality test results justify the statistical approach as Shapiro–Wilk rejected normality due to the nature of the score. This brings about the use of Spearman correlation and Kruskal–Wallis test which improves the methodological validity compared to regular parametric tests. The strong relationship between Service_Access and Functional_Score exists because systems which are made to enhance service access, are expected to aggregate more electronic functions. At the same time the strong relationship with Citizen_ Facing feature follows from the fact that Functional_Score includes component indicators.

The fact that the Kruskal-Wallis test does not show significance, as per ownership-evidence, is also significant in terms of the evidence of functionality. It proves that the level of functionality is not that evident in any category as there are only 15 units divided into three categories in the sample. In fact, it is one of the areas where data governance has to be improved. The comparison proves the capability of machine learning and at the same time the threat it can bring working with a relatively small public-sector research dataset. The most successful results were produced by random forests tool with ROC AUC 0.977 and tree-based models provided 93.3% LOOCV accuracy, which supports the idea of the definition of the functionality of service access via combinations or thresholds of system characteristics. However, it is still impossible to prove that random forests are the best model of KRG public-sector efficiency without using bigger samples. Public value assessment remains another gap on the way towards understanding the effectiveness of digital supply because current official sources have strong results with regard to strategies, named systems, infrastructure, and implementation results but they are weak concerning the data available concerning the public results of yearly performance including average processing time, success percentage, transaction cost, customers' satisfaction, number of complaints, etc., which proves once again the wrongness of believing that digital government should only be evaluated by the number of systems (Bannister and Connolly, 2014; Twizeyimana and Andersson, 2019).

The immediate consequence of KRG's decision-makers is to create a digital-performance data layer across the ministries. Each service can get its distinct identifier which needs to be reported either monthly or quarterly, while the definition will remain stable. This will result in a panel showing digital maturity by institution in different years or services in different months, demonstrating the correlation between digital maturity and achievements. The resulting data would allow for using fixed- or random-

effects panel's methodology and would control for the institutional differences unaffected by time; interrupted series methodology can be used to evaluate the reforms' impact in 2020 and 2022; causal approach can evaluate phased rollout of the system; machine learning can help to define services suffering the most. At last, this research emphasizes one important principle of data-poor governance research: analytical ambition is not achieved through inventing new observations. The multi-year framework presented in this workbook leaves blanks for unverifiable figures on purpose. It reduces the ability to make estimates now but helps to maintain the credibility of the analysis. A stronger paper can be created gradually as official time series become available.

6. Policy Recommendations

Kurdistan Regional Government needs to create a Digital Service Registry that helps enhance its institutional coordination, responsibility, and monitoring of digital services. Evaluation of policies needs to focus on measurable results of policy implementation, including the duration of service delivery, citizens' satisfaction, cost reduction, accessibility, and reliability, rather than on the number of digital platforms available. More attention has to be also paid to interoperability issues, citizens' digital identity, electronic payments, and continuous development of personnel. Kurdistan Regional Government needs to build a database that focuses on measuring the performance of digital government through the indicators connected with the use of services, efficiency with respect to service delivery, quality of services rendered, citizens' experience, inclusiveness, technology, cybersecurity, personnel performance, financing, and governance. Administrative data has to be combined with the digitalization data through the introduction of the mechanisms ensuring privacy and worthy definitions. It will be necessary to conduct audits targeting the quality of data regularly to locate missing values, duplications, out-of-date definitions, delays in reporting.

7. Conclusion

This investigation provided a scientific and reproducible framework for the assessment of statistical intelligence along with the digital transformation in Iraq's Kurdistan Region government institutions, based on available secondary information. The study relied on established reform achievements and its own verified list of 15 different Kurdistan Regional Government digital systems to build functional indicators and then conducted a variety of analyses, from descriptive to correlational. Descriptive analysis showed that the portfolio consists of systems with a high degree of interoperability/functionality in terms of data retrieval and management, back-office digitization, service delivery, and front-office features. According to the average Functional_ Score, which equals 4.60 out of 7, many of the studied systems have a number of digital capabilities. Normality was

rejected through the Shapiro–Wilk test, which permitted the application of Spearman correlation and Kruskal–Wallis test. As a result, only access to services was found to have a strong connection with functional intensity; however, there were no important differences among the technologies used for each of the systems. The research compared four predictive methods using leave-one-out cross-validation. The obtained rates of accuracy for decision tree, random forest, and gradient boosting methods (93.3%) were the same; however, random forest method produced the highest ROC AUC value equal to 0.977. The results indicate the effectiveness of nonlinear models in explaining the interrelations of digital capabilities and features; however, the sample size was too small for the generalization of these findings. Consequently, the results cannot be interpreted as confirmation of the causative links among the studied variables and indicate that the applied models need further improvements to be used in organizations' operational decision-making. The main policy recommendation drawn from this research is that the Kurdistan Regional Government should implement a uniform performance-data architecture during the next development phase of digital transformation. Only if various system inventories are connected to the outcomes (duration of service, transaction volume, satisfaction, inclusiveness, cost, reliability, and productivity of administration) can the efficiency of digital government be properly measured. The proposed institution/service-by-time framework would allow researchers to apply rigorous casual inference methods to the assessment of administrative efficiency. Hence, the study is the foundation of further research development rather than a completion of the undertaken investigation. The research demonstrates how existing information concerning the Kurdistan Regional Government can be turned into a clear analytical dataset, shows some patterns that can be identified today, and defines some additional information necessary for future study.

8. Limitations and Future Research

The first limitation arises from the fact that the study relies on a limited cross-section of only 15 different systems while the numbers reported by the Kurdistan Regional Government appear higher. Thus, trying to create a category with a complete analytical inventory may not be so effective. The next limitation is related to fact that in determining institutional ownership, the researchers are guided by the functions of the systems and thus might miss some confirmation from relevant authorities. The data currently available do not provide a complete picture on service performance by institutions over the years, which makes application of panel regression and causal impact estimation impossible. Rather, the binary coding of the collected data allows ignoring other factors influencing the whole process. However, it is worth noting that the Functional_ Score index does not take into account the

factor that it has not been validated externally. It would be extremely important to gather as much data as possible on different institutions over a certain period of time in the future.

Competing Interests Declaration

The authors declare that they have no financial or non-financial competing interests that are directly or indirectly related to the work submitted for publication.

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Ethics Declaration

Ethical approval and approving ethics committee: Not applicable. This study used only publicly available, aggregate secondary data and did not involve human participants, identifiable personal data, human biological materials, or animals. Therefore, review or approval by an institutional ethics committee was not required. The study was conducted in accordance with accepted principles of research integrity, responsible use of public data, and accurate reporting of secondary sources.

Consent to participate: Not applicable, because no human participants were recruited and no individual-level or identifiable personal data were collected or analyzed.

Artificial Intelligence (AI) Disclosure

During the preparation of this manuscript, the authors used artificial intelligence (AI)-assisted tools solely to improve language clarity, grammar, sentence structure, and academic expression. AI tools were not used to develop the research objectives or conceptual framework, conduct statistical analyses, interpret the empirical results, or generate the study's original findings. All AI-assisted text was reviewed and critically evaluated by the authors, who take full responsibility for the accuracy, originality, integrity, and final content of the manuscript.

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