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Service Quality and Client Demographic Profile: A Correlational Study Among Clients of the Department of Public Works and Highways – Isabela 4th District Engineering Office

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Abstract

The focus of this descriptive-correlational study was the relationship between clients' demographic profiles and perceived service quality at the Department of Public Works and Highways (DPWH) – Isabela 4th District Engineering Office, located in San Isidro, Isabela. The SERVQUAL framework was adopted to assess five dimensions of service quality, namely Tangibles, Reliability, Responsiveness, Assurance, and Empathy. The data-gathering technique consisted of a self-administered questionnaire filled in by a simple random sample of 48 clients, with an equal number of males and females. The analysis was conducted using weighted means, Pearson Product-Moment Correlation, and One-Way ANOVA techniques. The overall perception of the service quality at the DPWH – Isabela 4th District Engineering Office turned out to be very high ($M=4.03$), with the service quality dimension of Assurance being rated the highest (4.34) and the service quality dimension of Responsiveness the lowest (3.80) because of the long waiting time of clients. Interestingly, there were no significant correlations discovered between sex and service quality dimensions ($p>.05$). Age had a significant positive correlation with Reliability only ($r=.303$, $p=.036$). Initially, civil status was proven to have strong differences regarding Reliability ($p=.022$), Assurance ($p=.049$), and overall quality of service ($p=.044$). Education gave the most relevant results for four parts of the research, namely: tangibility, reliability, responsiveness, and empathy; it proved to greatly influence the research ($p=.020$). The results show that service perception is defined by context and can therefore be affected by education and civil status. Firstly, queue management is suggested. Secondly, assurance of service standards should be implemented.

1. Introduction

The significance of service quality has endured in public administration, particularly in departments that interact with citizens daily. Service providers operate as sole providers of public services within government agencies, which means they must ensure that their interactions with citizens are conducted reasonably and correctly (Rhee & Rha, 2009). The Department of Public Works and Highways (DPWH) plays an important role among the Philippine government's infrastructure agencies and maintains ongoing communication with a wide range of clients, including contractors, buyers, local government officials, and ordinary citizens.

The SERVQUAL model, initially developed by Parasuraman, Zeithaml, and Berry, has been widely used in measuring the quality of public services. The SERVQUAL framework defines service quality as the difference between customers' expectations and their perceptions of the service delivered. It has five dimensions used to measure service quality: tangibility, reliability, responsiveness, assurance, and empathy. Although it was originally designed for private-sector marketing research, this model has been employed to evaluate the quality of public services in local governments, municipal counters, and national government offices (Wisniewski, 2001; Fahim, 2019).

Studies on citizen satisfaction in local municipalities have indicated that the dimensions of service quality do not affect client satisfaction in the same way. Moreover, the significance of each dimension is different depending on the service being offered (Mbassi, Mbarga, & Ndeme, 2019). Another study conducted in a Japanese local government indicated that service delivery and human aspects were more important for customer satisfaction than the physical or hardware aspects of service delivery, thus confirming the importance of how services are provided by frontline staff (Moteki, 2021).

Service quality is an area that has attracted much research interest lately. Researchers have increasingly engaged in studies that take into account client demographics such as sex, age, marital status, and educational attainment. Despite this interest, some of the results from the studies do not agree with one another. For instance, men and women differ greatly in their evaluation of some service features (Ojekalu et al., 2019; Grazhdani & Merollari, 2015). Alternatively, some studies report no significant differences between men and women in perceptions of service quality (Al-Jazzazi & Sultan, 2017; Farah et al., 2025). Age influences perceived service quality in some transportation or banking services (Ibrahim et al., 2021; Ganesan-Lim et al., 2008), yet this factor does not seem to be significant in other contexts (Ojekalu et al., 2019). Moreover, factors such as age and income are significant predictors of perceived service quality in health services (Nketiah-Amponsah et al., 2019) and may also influence perceptions of public service quality when gender is taken into account (Cazzuffi & Retamal, 2025).

The inconsistency of the findings between studies indicates that the relationship between clients' demographic profile and perceived quality of service is very context-specific and cannot be generalized from one setting to another. Local government engineering offices in the Philippines, despite serving a diverse range of clients daily, have rarely been studied in this respect, particularly using a locally based descriptive-correlational methodology.

This is where the objective of the present research arises. As a member of the staff of the DPWH – Isabela 4th District Engineering Office, the researcher noticed that clients who approach the office for help differ substantially in age, sex, and purpose of visit, and that their preliminary responses regarding the quality of the service have also varied. Thus, the purpose of this research was to identify whether there is any significant correlation between the demographic profile of clients and their quality of service evaluation.

1.1 Theoretical Framework

This study is based on the Service Quality (SERVQUAL) Model, which defines service quality as the difference between customers' expectations of a service and the service they actually receive. The SERVQUAL defines the five aspects based on which service quality can be measured:

- Tangibles – refers to the physical facilities, equipment, and appearance of personnel;
- Reliability – is the ability to realize the promised service accurately and dependably;
- Responsiveness – indicates the readiness to assist customers and provide services quickly;
- Assurance – is the knowledge and courtesy of the staff of the institution along with their ability to create confidence; and
- Empathy – represents care and individual approach towards customers.

The SERVQUAL framework is described to be one of the most complete and widely used tool for measurement of both public and private service quality (Fikri & Nawangsari, 2023; Farah et al., 2025) continuing to be the theoretical basis of various service assessments in the public sector such as in government services and health care (Wisniewski, 2001; Hutchinson, Do, & Agha, 2011).

The research also draws on the body of research on demographic segmentation in service perception, supported by the theory that personal features such as gender, age, and marital status influence how a consumer perceives and assesses a service encounter (Ganesan-Lim et al., 2008; Al-Jazzazi & Sultan, 2017).

1.2 Conceptual Framework

This study's conceptual framework is premised on the idea that the demographic profile of clients (independent variable) may influence the perceived service quality (dependent variable) of the DPWH – Isabela 4th District Engineering Office. The independent variable, the client's profile, comprises sex, age, civil status, and level of education. The dependent variable, perceived service quality, is measured in terms of the five SERVQUAL dimensions: tangibility, reliability, responsiveness, assurance, and empathy.

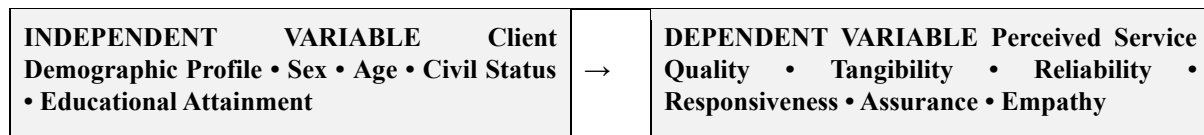


Figure 1. The Research Paradigm of the Study

1.3 Statement of the Problem

This study aimed to determine the relationship between clients' demographic profiles and their perceived service quality at the Department of Public Works and Highways – Isabela 4th District Engineering Office.

Specifically, it sought to answer the following questions:

1. What is the demographic profile of the respondents in terms of: (a) sex; (b) age; (c) civil status; and (d) educational attainment?
2. What is the level of perceived service quality of the DPWH – Isabela 4th District Engineering Office as assessed by the respondents in terms of: (a) tangibility; (b) reliability; (c) responsiveness; (d) assurance; and (e) empathy?
3. Is there a significant relationship between the demographic profile of the respondents and their perceived service quality of the DPWH – Isabela 4th District Engineering Office?
4. Based on the findings of the study, what recommendations may be proposed to enhance the service quality of the DPWH – Isabela 4th District Engineering Office?

2. Review of Literature and Studies

This chapter presents a review of related literature and studies that provided theoretical and empirical grounding for the present study. It is organized into three sections: (1) Service Quality and the SERVQUAL Model, (2) Service Quality in the Public Sector, and (3) Client Demographic Profile and Service Quality Perception.

2.1 Service Quality and the SERVQUAL Model

The concept of service quality has been examined in many publications from a marketing and management environment through the Gaps Model, which was proposed by Parasuraman, Zeithaml, and Berry. According to this model, service quality is defined as the gap between the expected and the perceived level of service, which gave rise to the SERVQUAL model. It is believed to be the most comprehensive and widely used attempt to measure the level of service quality in various industries (Fikri & Nawangsari, 2023). This model measures 5 aspects of service, including tangibles, reliability, responsiveness, assurance, and empathy, which have been verified and used in many different service sectors, including banking and health tourism, audit, and higher education (Farah et al., 2025).

In spite of the fact that this model is widely-used, it has been criticized with respect to the validity of the idea that difference scores are meaningful (Fikri & Nawangsari, 2023). Nevertheless, continuous improvement of the model by original authors and its application in various industries contribute to its dominance in the field of service quality measurement (Fahim, 2019).

2.2 Service Quality in the Public Sector

The provision of services by public sector entities is quite different from the provision of services by private sector entities, mainly due to the absence of pressures that induce private firms to continue improving service quality in public sector agencies (Rhee & Rha, 2009). As a result of this significant difference, research has emerged that is concerned with the application of the SERVQUAL model to governmental and quasi-governmental service operations.

A study that aimed to measure citizen-client satisfaction across twenty-one municipalities showed that not all aspects of service quality affect overall client satisfaction evenly; namely, interpersonal front-office aspects of trust, testimonials, and assistance played a major role in the formation of satisfaction of citizens engaging in face-to-face communication with municipal authorities (Mbassi et al., 2019). Furthermore, in another study concerning services provided by a Japanese city hall, human and service-related components were found to play a more important role in customer satisfaction formation than hardware components, such as the arrangement of the office, and that being on time is not synonymous with being satisfied (Moteki, 2021).

The initial use of SERVQUAL within Scottish local councils confirmed its usefulness in ensuring the continuous improvement of services and resulted in a broader implementation of this approach in governmental organizations (Wisniewski, 2001). Thus, SERVQUAL started being utilized by public transportation organizations, airlines, service malls, and numerous government establishments available for consumers (Fahim,

2019; Fikri & Nawangsari, 2023).

Moreover, research in the field of public health also confirms the relevance of assessing service quality in governmental institutions. In a research study that compared family planning services in Tanzania, Kenya, and Ghana, structural and process quality measures were identified as the most salient elements that determine customer satisfaction (Hutchinson et al., 2011). Similar conclusions were made in research on national health insurance schemes in Ghana, where significant predictors of the services' quality perceived by clients were identified (Nketiah-Amponsah et al., 2019).

2.3 Client Demographic Profile and Service Quality Perception

A different stream of studies has revealed whether demographic factors of the clients affect their perception of service quality. However, the results in this regard are not consistent across different circumstances.

Research into the perceptions of shopping centers showed that demographic factors like gender and education had a significant impact on how service quality was perceived by them, with women being more favorable towards the service quality than men, although age was found to be an insignificant factor (Ojekalu et al., 2019). A similar outcome was obtained for the Albanian bank clients, where many demographic factors including gender, age, occupation, education, and income influenced the way people perceived the respective service quality dimension (Grazhdani & Merollari, 2015).

Likewise, the large-scale research conducted with clients from banks in Jordan did not find differences in service quality evaluation based on gender and education level, while variable factors such as age, income, occupation, and religion demonstrated significant impact (Al-Jazzazi & Sultan, 2017). Similarly, an analysis of both high-contact and low-contact services in passenger transport revealed age to be an essential factor influencing perceptions regarding quality, while no differences were recorded regarding gender or income basis (Ganesan-Lim et al., 2008). A recent study also showed no influence of demographic data on quality evaluation in a health tourism agency, including gender and age, education level, income, and occupation (Farah et al., 2025).

In specific studies in sectors, additional details are available. In the instance of light rail transport in Kuala Lumpur, it was observed that gender and age were both strong predictors in the understanding of service quality attributes such as comfort, assistance from staff members, and information provision, and based on the findings the authors recommend the use of techniques for segmentation of clients based on demographic data for the purpose of improving the overall service provision (Ibrahim et al., 2021). In the context of the Philippines and Southeast Asia in general, it has also been observed that women form their perceptions in a different manner when compared to men regarding the various aspects evaluated such as quality of services, equality of treatment, corruption, as many female respondents reported perceiving the services to be worse, especially in the sphere of health and enforcement (Cazzuffi & Retamal, 2025).

Overall, the studies suggest that although demographic characteristics tend to correlate with measuring service quality, the individual variables that matter, and their direction of impact, depend heavily on service type, cultural context, and population. The lack of uniformity in the results necessitates the provision of research into this correlation in a specific sectoral context, as is done in this study with respect to the case of a DPWH district engineering office in the Philippines.

2.4 Synthesis

The literature reviewed shows SERVQUAL as an effective and well-tested structure for measuring the quality of services for both government and private sector organizations, including local government and infrastructure-related agencies. It also shows that the demographic characteristics of the consumers — especially sex and age — have been shown to correlate with perception of service quality in certain circumstances but not in others, meaning that this correlation is neither universal nor automatic. None of the studies reviewed analyzed the situation in a DPWH district engineering office in the Philippines, and that is the research gap that the current study aimed to fill.

2.5 Research Design

The descriptive-correlational research methodology was used in this research. The descriptive part referred to the demographic profile of the participants and their perceived service quality of the DPWH – Isabela 4th District Engineering Office. Meanwhile, the correlational part was employed to determine whether there was any relationship between the respondents' demographic profile and their perceived service quality. The use of this method was suitable because it allows for findings of existing conditions and identifies relationships between variables without conducting an experiment (Fikri & Nawangsari, 2023; Farah et al., 2025).

2.6 Locale of the Study

The research was carried out in the Department of Public Works and Highways – Isabela 4th District

Engineering Office in Quezon, San Isidro, Isabela.

2.7 Population and Sampling Procedure

In this research study, the participants were clients who interacted with the Department of Public Works and Highways (DPWH) through its Isabela 4th District Engineering Office. In total, forty-eight clients were sampled by employing a simple random sampling technique. Clients were equally divided into two genders, with twenty-four male clients and twenty-four female clients who submitted completed questionnaires. Simple random sampling was justified for being an effective way of selecting people to take part in the study within the whole population represented by clients of DPWH.

Table 1. Distribution of Respondents by Sex

Sex	Frequency	Percentage
Male	24	50.0%
Female	24	50.0%
Total	48	100%

2.8 Research Instrument

Data were gathered using specifically developed self-administered questionnaires based on the SERVQUAL model by Parasuraman, Zeithaml, and Berry and implemented in similar research concerning the quality of public services (Wisniewski, 2001; Fahim, 2019). Two components constituted the questionnaire: the first part included information about gender, age, civil status, and education, while the second part comprised twenty-five different statements measuring service quality perceptions according to five important SERVQUAL dimensions, that is, tangible aspects, reliability, responsiveness, assurance, and empathy, through the use of five statements for each dimension. The survey results were analyzed by using a five-point Likert scale (5 means that the respondents agree strongly, while 1 means that they disagree, that is, that they are not likely to support the idea proposed in the statements given). The complete version of the questionnaire is presented in Appendix B.

2.9 Validity and Reliability of the Instrument

The questionnaire was validated for content prior to administration by business management and public administration experts. Before it was fully administered, a pilot test was conducted to establish the instrument's internal consistency reliability, with Cronbach's alpha calculated for each of the five SERVQUAL subscales, where a score of 0.70 or more is typically acceptable when a study is conducted.

2.10 Data Gathering Procedure

Once the research was approved, the researcher received written approval from the District Engineer of the DPWH-Isabela 4th District Engineering Office to conduct the study (Appendix A). The researcher personally administered the questionnaire to randomly selected clients who visited the office after getting permission to conduct the research. In addition, respondents were told that they were free to choose whether or not to participate voluntarily.

2.11 Statistical Treatment of Data

The following statistical tools were used to treat the gathered data:

- Frequency and Percentage Distribution – used to describe the demographic profile of the respondents.
- Weighted Mean – used to determine the level of perceived service quality per SERVQUAL dimension, interpreted using the following scale: 4.21–5.00 (Very High); 3.41–4.20 (High); 2.61–3.40 (Moderate); 1.81–2.60 (Low); and 1.00–1.80 (Very Low).
- Pearson Product-Moment Correlation Coefficient (Pearson r) – used to determine the significance of the relationship between perceived service quality and the dichotomous/ordinal demographic variables (sex and age), at the 0.05 level of significance.
- One-Way Analysis of Variance (ANOVA) – used in place of Pearson r for the demographic variables with more than two nominal categories (civil status and educational attainment), since correlating a multi-category nominal variable directly against a continuous scale is not statistically appropriate; ANOVA instead tests whether mean perceived service quality differs significantly across the categories of each variable, at the 0.05 level of significance.

2.12 Ethical Considerations

The research adhered to ethical principles related to conducting research involving people. Informed consent was received from all respondents before data collection took place, and they were informed regarding the research purpose. Lastly, the identity of respondents remained anonymous, and the information was used strictly for academic research purposes.

3. Results and Discussion

The chapter discusses the contents of data pertaining to the replies given by the forty-eight (48) respondents who have filled out the questionnaire. The structure of the chapter includes questions discussed in Chapter 1, which include: (1) ‘Who are the respondents?’ (2) ‘What do they think of the quality of the service?’ (3) ‘How do the respondents’ definition (age, sex, marital status, education) of a human being influence their evaluation of the service?’ Tables of the chapter are followed by brief interpretations of the figures used therein in relation to the cases described in Chapter 2.

3.1 Problem 1: Demographic Profile of Respondents

Table 2. Demographic Profile of the Respondents

Demographic Variable	Category	Frequency (f)	Percentage (%)
Sex	Male	24	50.0
	Female	24	50.0
Age	18-27	10	20.8
	28-37	10	20.8
	38-47	10	20.8
	48-57	10	20.8
	58 and above	8	16.7
Civil Status	Married	24	50.0
	Single	16	33.3
	Widowed	4	8.3
	Separated	4	8.3
Educational Attainment	Elementary	2	4.2
	High School	8	16.7
	College	32	66.7
	Postgraduate	6	12.5
Total		48	100.0

To briefly summarize the information in Table 2, both sexes were represented evenly, with men and women both numbering 24, which accounts for exactly half of the participants. This is a good proportion for this research since the results will not be biased in relation to the sex issue addressed in Problem 3.

Age-wise, the participants were also evenly spread out. Approximately 20% of respondents fall into each age group from 18 to 57 (10 respondents in each group), while a bit fewer participants—8 people, or 16.7%—are aged 58 and older.

Around 50% of respondents are married, about a third are single, while very few participants are widowed or separated. Most participants (66.7%) graduated from college, while few had finished their education at the secondary school level (16.7%), were postgraduate students (12.5%), or had only graduated from an elementary school (4.2%).

3.2 Problem 2: Level of Perceived Service Quality

Table 3. Level of Perceived Service Quality by Dimension

SERVQUAL Dimension	Weighted Mean	Verbal Interpretation	Rank
Assurance	4.34	Very High	1
Empathy	4.09	High	2

Tangibility	4.05	High	3
Reliability	3.88	High	4
Responsiveness	3.80	High	5
Overall Weighted Mean	4.03	High	

Interpreting Table 3 is easy: the ‘weighted mean’ just indicates the mean rating given by clients on a scale of 1 (Strongly Disagree) to 5 (Strongly Agree). High scores imply that clients agree with the office’s high performance in the area, whereas low scores imply the reverse situation. All scores received in the present study earned High or Very High ratings, which is a good overall outcome – none of the dimensions had a rating of Moderate, Low, or Very Low.

The quality of overall service provided by the office was evaluated as High by clients, with the mean value equal to 4.03 out of 5. Assurance was rated as the best one (4.34, Very High). This means that clients believe that the employees are knowledgeable, polite, and trustworthy. Empathy (4.09) and Tangibility (4.05) follow with High ratings as well, which means that clients believe that employees provide them with personal attention and that they are satisfied with the office’s physical aspect (cleanliness, appearance of employees, signs, etc.).

Reliability and Responsiveness received High ratings. However, these dimensions were the two lowest of five ratings, which means that customers are less pleased with transaction speed and consistency regarding waiting. Low ratings of individual phrases can clarify that the lowest rated phrase is “Waiting time before being attended to is reasonable”, which is the phrase with the lowest mean score of 3.38. It is followed by phrases: “Transactions are processed within the promised time frame (mean = 3.54)” and “Staff members are never too busy to respond to requests of the clients (mean = 3.56)”. Interestingly enough, means with higher scores are: “The office maintains professionalism in every interaction with clients (mean = 4.44)”, “Staff members know what they offer (mean = 4.42)”, and “As for the appearance of the employees, it is perceived as formal (mean = 4.38)”. Thus, it is possible to say that clients like staff attitudes and overall knowledge of the team, but still want to deal with their issues faster.

This trend corresponds with previous findings by other researchers who did similar studies in government offices. A study conducted in Japan has shown that speed and efficiency do not lead to greater satisfaction than the human side of service (Moteki, 2021). Similar conclusions have been reached in a study of citizen satisfaction with municipalities. It has also been shown that although promptness is significant when providing services, people still prefer the personal, human touch in the process (Mbassi et al., 2019). The changes in the situation at the DPWH – Isabela 4th District Engineering Office should focus on reducing waiting time and making processes proceed according to plan, but not on changing the staff attitude, which is already positive.

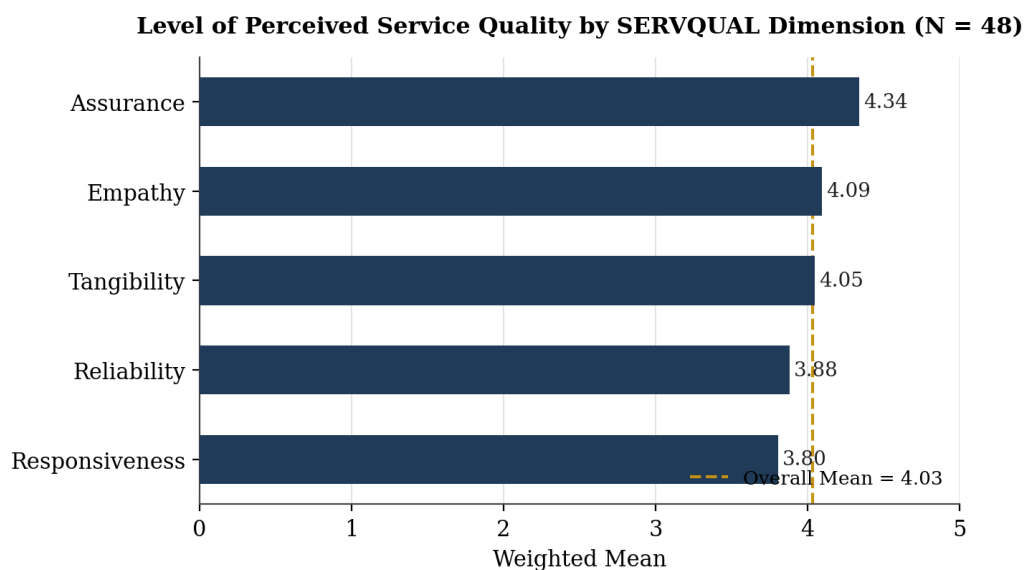


Figure 2. Level of Perceived Service Quality by SERVQUAL Dimension

3.3 Problem 3: Relationship Between Demographic Profile and Perceived Service Quality

This subsection addresses the main question of the research — does sex, age, marital status, or the level of education of a client influence their assessment of quality of service provided by the office? Two basic methods of statistical analysis were applied:

- Pearson r was used for sex and age analysis ranging from -1 to $+1$. The closer it is to 0 , the weaker the correlation is. Following a common rule of thumb: values below $.20$ indicate very weak correlation, from $.20$ to $.39$ indicating weak correlation, from $.40$ to $.59$ indicating moderate correlation, from $.60$ to $.79$ indicating strong correlation, and above $.80$ indicating very strong correlation.
- One-Way ANOVA (F-value) was employed in the civil status and education analysis, which comprises more than two categories (for instance, married, single, widowed, separated). It tests whether there is a significant difference between the average scores.
- p-value is the number used in both methods that allows determining if a result is significant. When p is lower than $.05$, the correlation is regarded as real.

3.4 Sex and Perceived Service Quality (Pearson r)

Table 4. Correlation Between Sex and Perceived Service Quality

SERVQUAL Dimension	r	p-value	Decision
Tangibility	0.121	0.411	Not Significant
Reliability	0.194	0.185	Not Significant
Responsiveness	0.166	0.261	Not Significant
Assurance	0.009	0.951	Not Significant
Empathy	0.101	0.496	Not Significant
Overall Service Quality	0.127	0.390	Not Significant

To put it another way: gender did not matter at all. The r -values in Table 4 are low (equal to $.20$ or less), while the p -values are high (equal to $.05$ or more). Both male and female customers rated the level of service in the office in the same way in all six criteria. This is in accordance with research conducted among Jordanian bank clients (Al-Jazzazi & Sultan, 2017) and clients related to medical tourism (Farah et al., 2025), which did not find a gender influence. However, it is contrary to some other studies conducted in relation to clients of one mall and those of Albanian banks, which have proven that gender does affect results (Ojekalu et al., 2019; Grazhdani & Merollari, 2015). In other words, Chapter 2 has pointed out that the gender influence on service evaluation depends on the situation, while in this instance it does not.

3.5 Age and Perceived Service Quality (Pearson r)

Table 5. Correlation Between Age and Perceived Service Quality

SERVQUAL Dimension	r	p-value	Decision
Tangibility	0.105	0.478	Not Significant
Reliability	0.303	0.036	Significant
Responsiveness	0.206	0.160	Not Significant
Assurance	0.265	0.069	Not Significant
Empathy	0.230	0.116	Not Significant
Overall Service Quality	0.231	0.113	Not Significant

Of all six dimensions, only one dimension was found to be associated with the client's age, and that was the dimension of Reliability ($r = .303$, $p = .036$). This weak-to-moderate positive correlation implies that older clients rated the office's reliability somewhat higher than younger individuals would. However, this correlation is not strong, and age does not seem to matter for the other four dimensions of service quality, as well as for the overall. This mixed result is consistent with the results of the previous research — some studies show that age affects the quality of service (Ibrahim et al., 2021; Ganesan-Lim et al., 2008), while others show that it does not (Ojekalu et al., 2019; Farah et al., 2025). The simplest explanation of this finding is that age is not a major determinant of how clients evaluate this office; it only slightly influences reliability evaluation.

3.6 Civil Status and Perceived Service Quality (One-Way ANOVA)

Table 6. Analysis of Variance Between Civil Status and Perceived Service Quality

SERVQUAL Dimension	F	p-value	Decision
Tangibility	2.306	0.090	Not Significant
Reliability	3.538	0.022	Significant
Responsiveness	2.436	0.077	Not Significant
Assurance	2.833	0.049	Significant
Empathy	2.589	0.065	Not Significant
Overall Service Quality	2.925	0.044	Significant

The civil status of clients had an actual effect on how they evaluated the quality of the office, with an across-the-board mean score of significance ($p = 0.044$) and individually for Reliability ($p = 0.022$) and Assurance ($p = 0.049$) as well. In contrast, no significance was found for Tangibility, Responsiveness, and Empathy. In other words, a client's marital status affects how reliable and trustworthy the client finds a given office, but it does not affect how the office facilities, staff's time, or personal treatment by the staff are perceived. One possible explanation for these findings is that a client's life status sets expectations during the process of creating trust in the transaction, as shown earlier in the works of Grazhdani & Merollari (2015).

3.7 Educational Attainment and Perceived Service Quality (One-Way ANOVA)

Table 7. Analysis of Variance Between Educational Attainment and Perceived Service Quality

SERVQUAL Dimension	F	p-value	Decision
Tangibility	3.854	0.016	Significant
Reliability	4.946	0.005	Significant
Responsiveness	3.798	0.017	Significant
Assurance	1.905	0.143	Not Significant
Empathy	2.912	0.045	Significant
Overall Service Quality	3.642	0.020	Significant

Education level showed the strongest connection compared to the other four demographic elements used in the study. The relation was significant for the general service level ($p = .020$) and most scales. The only exception was the Factor of Assurance ($p = .143$). In other words, people with different educational experiences tend to distinguish and evaluate the concrete things about the service which are more apparent to them. They usually differ regarding all scales, but tend to arrive at a common conclusion regarding the scale of Assurance — in most cases, regardless of their education, people will see the staff as knowledgeable and competent. This correlation has been found in previous studies as well, which indicate education level to be one of the demographic indicators impacting service quality perception the most.

Relationship Between Demographic Profile and Perceived Service Quality
(Navy = statistically significant at $p < .05$; * marks significant cells)

Sex (Pearson r)	r=.121 p=0.411	r=.194 p=0.185	r=.166 p=0.261	r=.009 p=0.951	r=.101 p=0.496	r=.127 p=0.390
Age (Pearson r)	r=.105 p=0.478	r=.303 p=0.036*	r=.206 p=0.160	r=.265 p=0.069	r=.230 p=0.116	r=.231 p=0.113
Civil Status (ANOVA)	F=2.31 p=0.090	F=3.54 p=0.022*	F=2.44 p=0.077	F=2.83 p=0.049*	F=2.59 p=0.065	F=2.93 p=0.044*
Education (ANOVA)	F=3.85 p=0.016*	F=4.95 p=0.005*	F=3.80 p=0.017*	F=1.91 p=0.143	F=2.91 p=0.045*	F=3.64 p=0.020*
	Tangibility	Reliability	Responsiveness	Assurance	Empathy	Overall

Figure 3. Summary Map of Statistical Significance: Demographic Profile vs. Perceived Service Quality

3.8 Summary of Findings on Problem 3

Aggregating the four demographic variables creates a clear picture. Sex had no importance. Age was relevant for only one element out of five (Reliability). Civil status was important for two elements (Reliability and Assurance) as well as the total score. Educational attainment played the most important role since it was relevant for four out of five elements and the total score. In other words, not all backgrounds of clients affect service perception equally — education and civil status do so, while sex does not play a role and age influences only a small part of the picture.

According to the obtained results, the null hypothesis of the research — that there is no relationship between client demographics and perceived service quality — is rejected in the case of civil status and educational attainment (there is a relationship), but not rejected in the case of sex (no relationship) and partially rejected in the case of age (a relationship was found only for Reliability).

4. Conclusions

From the analysis, the following findings can be concluded:

- 1) Overall perceptions of the quality of services rendered by DPWH – Isabela 4th District Engineering Office are mostly positive in terms of service attributes such as professionalism, comfort, and efficiency of the office employees (Assurance), as well as speed and consistency of service delivery, though these parameters are not as robust as others (Responsiveness and Reliability).
- 2) The null hypothesis remains unchallenged in regard to gender as the research did not find any correlations between clients' sex and their perceived service quality.
- 3) The null hypothesis is found to be refuted pertaining to the age factor, but only in terms of Reliability dimension.
- 4) The null hypothesis regarding marital status and education is rejected; both of these variables have a significant influence on the client's assessment of the service quality.
- 5) From the above discussion, it can be seen that the profile of a client has a varying effect on the quality of service.

5. Recommendations

- 1) The clients of DPWH-Isabela 4th District Engineering Office gave the lowest ratings for responsiveness. To increase responsiveness and service quality, this office should adopt strategies for improving customer service, including queue management or providing more precise service time commitments.
- 2) Since reliability was also rated lower than average and highly correlated to age and civil status, the office needs to create uniform procedures. Moreover, it should keep its clients updated on the status of their requests, given that efficiency and reliability are crucial for all client groups.
- 3) Since the level of education is closely connected with almost all service dimensions, the office may

consider changing its communication methods. It may need to simplify its communication modes to explain the procedures and requirements to clients with different educational backgrounds.

- 4) The office must preserve its strong results and build on its achievements in the field of Assurance and Empathy, including by conducting more customer service training for its frontline staff.
- 5) Future researchers may want to replicate this research in other offices of the DPWH district engineering division (or maybe also consider other demographic factors, e.g., income, frequency of visits, purpose of visit, etc.) so that they will have a more complete understanding of the kind of quality of service the clients from the DPWH field office have.
- 6) A follow-up study is suggested based on the larger sample size and mixed-method approach that will include the open-ended feedback from clients to better explain the nature of civil status and educational attainment issues found in the current research.

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Managerial Practices and Employee Experiences During Digital Transformation: A Qualitative Case Study of Organizational Change at Unilever Uganda

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Abstract

This qualitative case study examines how digital transformation reconfigures managerial practices and employee experiences at Unilever Uganda. Grounded in Socio-Technical Systems (STS) and Dynamic Capabilities theories, the study investigates the operational and human dimensions of automated human resource ecosystems, AI-driven talent marketplaces, and digitized sales distribution networks. Utilizing an exploratory qualitative case study design, data were collected through semi-structured interviews with 10 purposively sampled stakeholders, including Unilever executives, human resource managers, and Kampala-based distributors, complemented by document analysis of regional performance reports. The findings reveal that while digital integrations such as the “Eazzystock” supply chain financing initiative and global talent networks dramatically streamline workflows, improve resource allocation, and lower transaction costs, they also generate friction regarding algorithmic opacity, localized digital divides, and routine labor displacement. The study suggests that the success of enterprise digitalization may depend upon the alignment of technical capabilities with regional socio-economic realities and human-centric values. It recommends that multi-stakeholder coalitions, corporate managers, and policymakers establish inclusive upskilling pathways, robust social protections, and participatory digital frameworks to foster a balanced and sustainable future of work.

Keywords: digital transformation, employee experience, Unilever Uganda, EazyStock, socio-technical systems

1. Introduction and Background of the Study

Over the past four decades, the corporate sector has experienced successive waves of technological integration, moving from mainframe computing in the 1980s to centralized enterprise resource planning (ERP) database systems in the late 1990s and 2000s (2023). However, the advent of web-based portal technologies and cloud computing during the Fourth Industrial Revolution has driven a shift from basic digitization, the conversion of analog data to digital formats (Caputo et al., 2020), to full-scale digital transformation (Ajayi et al., 2022; Haleem et al., 2025). Today, digital transformation may be construed as a profound realignment of business models, organizational structures, and strategic capabilities (Warner & Wäger, 2018) designed to enhance operational speed, agility, and value co-creation across global networks (Vaska et al., 2021).

Unilever, founded in 1885, is a global fast-moving consumer goods (FMCG) enterprise operating more than 400 brands across more than 190 countries, employing approximately 120,000 individuals. Historically, Unilever operated under a highly decentralized, localized business model, yet has subsequently undertaken the centralization of its global processes (Farndale et al., 2010). In emerging markets, particularly East Africa, Unilever’s operations have achieved strong commercial growth (Zou, 2021). However, the imperative for multinational enterprises to digitalize their supply chains and human capital systems globally necessitates that

regional operations in developing economies achieve an equilibrium between high-level corporate strategies and localized market realities.

Enterprise digitization is occurring in a highly volatile macroeconomic environment. The post-COVID-19 era has seen severe global supply chain disruptions, currency fluctuations, and significant inflationary pressures. Additionally, the sudden transition to remote work and digitized collaboration has altered employee expectations around career flexibility, professional upskilling, and workplace autonomy (Kraus et al., 2024; Ng & Stanton, 2023).

This study serves to elucidate the reception, negotiation, and experiential impact of top-down corporate technologies upon localized workforces and trade networks within sub-Saharan Africa. While global digital tools often aim to foster a 'future-fit' workforce, their implementation without adequate consideration of local contexts may engender organizational anxiety, exacerbate digital divides, and precipitate labor disputes (Trittin-Ulbrich et al., 2020). Therefore, an investigation of these dynamics within Uganda may yield critical insights into the human dimensions of digital transformation.

Justification of Key Concepts

To analyze these organizational shifts, this paper defines and justifies three core concepts:

- **Managerial Practices:** Defined as the structured interventions, platform implementations, and performance metrics deployed by corporate leaders to organize, monitor, and upskill human capital.
- **Employee Experiences:** Defined as the cognitive, emotional, and behavioral perceptions of staff as they interact with corporate systems, automated evaluations, and flexible work contracts.
- **Socio-Technical Disjunction:** Defined as the structural misalignment that occurs when advanced, centralized digital technologies (such as AI-driven recruitment and automated physical supply tools) are deployed in regions characterized by informal trade, low digital literacy, or limited infrastructure.

Understanding the interplay of these concepts may elucidate why identical digital tools could yield highly empowering career pathways in headquarters while engendering operational friction in regional distribution networks.

1.1 Problem Statement

Corporate managers frequently presuppose that digital transformation constitutes a uniform process that may invariably enhance efficiency, transparency, and employee performance (Erjavec et al., 2023; Saranya & Vasantha, 2023). Existing scholarship primarily underscores the operational benefits of cloud-based integrations and automated workflows within Western headquarters settings (Adelaja et al., 2024; Olubusola et al., 2024). Nonetheless, a significant lacuna persists concerning the friction engendered by the deployment of these centralized, high-technology systems in emerging markets, such as Uganda, where fast-moving consumer goods (FMCG) supply chains are fundamentally anchored in informal trade, manual labor, and relationship-driven distribution networks.

In East Africa, Unilever has implemented advanced tools such as automated HR databases, AI-driven video interviewing, and digitized supply chain financing to drive corporate agility (Anitah et al., 2019; Hu, 2023). Yet, evidence suggests that these modifications have engendered a distinct socio-technical gap (Xames & Topcu, 2025). In human resources, automated screening has raised concerns about depersonalization and algorithmic bias (Häußermann & Lütge, 2021; Sakib et al., 2026). In the physical supply chain, the rapid evolution of technological frameworks, exemplified by agricultural mechanization on East African estates, has precipitated labor union friction and job displacements (Daum et al., 2020).

The prevalence of this research lacuna largely stems from the predominant focus of extant literature on macro-level operational metrics or the unadulterated adoption of technology, thereby frequently neglecting the micro-level lived experiences pertinent to employees and trade partners within sub-Saharan Africa. Consequently, this investigation endeavors to address this identified lacuna by conducting a qualitative case analysis of Unilever Uganda, elucidating the navigational processes undertaken by local managers and employees concerning the interrelationship between advanced digital tools and localized socio-technical realities.

1.2 Purpose of the Study

The purpose of this study is to qualitatively investigate the relationship between digitalized managerial practices and employee/distributor experiences at Unilever Uganda. It also aims to understand socio-technical friction that may emerge within regional distribution and human resource operations during enterprise-wide digital transformation.

1.3 Research Objectives

The study was guided by the following three objectives:

- 1) To examine the operational impacts and employee perceptions of Unilever's automated human resource and recruitment technologies.
- 2) To evaluate how AI-enabled internal talent mobility and flexible work frameworks reshape career pathways and employee agency.
- 3) To assess the socio-technical dynamics of trade ecosystem digitalization and localized supply chain financing within Unilever Uganda's distribution network.

1.4 Research Questions

This investigation aims to address the following three primary inquiries:

- 1) How do automated HR systems and AI-driven recruitment platforms impact operational metrics and candidate/employee perceptions?
- 2) In what ways do internal digital marketplaces and flexible employment models influence career fluidity and upskilling experiences?
- 3) How does the digitalization of sales distribution and supply chain credit affect the economic resilience and experience of localized distributors in Uganda?

Note: Each of these main questions was used to generate four target interview questions (totaling twelve interview questions) to collect qualitative data from respondents.

1.5 Significance of the Study

This study is expected to benefit:

- **Academics:** By expanding digital transformation and change management literature to include qualitative, empirical evidence from sub-Saharan Africa.
- **Practitioners and Industry Leaders:** By providing a practical blueprint for FMCG managers in the design and execution of digital systems that align technical efficiency with local cultural expectations.
- **Policy Makers:** By facilitating regional regulatory bodies (such as the National Information Technology Authority of Uganda) to formulate ethical guidelines for AI use, digital credit profiling, and labor protections during technological transitions.
- **Society:** By highlighting how digital corporate partnerships can support economic inclusion, protect workers' livelihoods, and foster fair labor practices within regional supply chains.

1.6 Scope of the Study

- **Location:** The primary geographic focus is the central region of Uganda, specifically Kampala, encompassing Unilever Uganda's head offices at Plot 26, Kyadondo Road, Nakasero, and associated distribution facilities.
- **Population:** The target population comprises senior human resource directors, regional sales coordinators, credit analysts, and localized Fast-Moving Consumer Goods (FMCG) distributors.
- **Variables:** The study delineates the qualitative interplay between *Managerial Digital Practices* (system automation, AI talent matching, digital trade credit) and *Employee/Distributor Lived Experiences* (workplace autonomy, upskilling, economic security).
- **Timeframe:** The empirical inquiry centers upon digital initiatives and regional developments spanning the years 2020 to 2026.
- **Limitations:** The qualitative findings are derived from a single multinational case study with a small sample size, which may limit statistical generalizability. However, the depth of the qualitative data may nonetheless yield substantial contextual and conceptual insights.

1.7 Theory of the Study

Socio-Technical Systems (STS) Theory

Grounded in the foundational work of Trist and Bamforth (1951) and Lund et al. (2024), Socio-Technical Systems (STS) theory posits that an organization's performance is contingent upon the interplay between two distinct subsystem components: the *technical system* (the instruments, software applications, and physical apparatus employed for task execution) and the *social system* (the personnel, interpersonal dynamics, requisite competencies, and prevailing cultural values within the workforce). STS theory emphasizes that optimizing either subsystem in isolation leads to operational failure; instead, successful organizational change requires the co-design and alignment of both systems.

This theory is highly relevant to Unilever's digital transformation. While Unilever's technical subsystem has

advanced through cloud databases, AI-driven talent matchmaking, and automated logistics networks, its social subsystem is shaped by regional labor dynamics, employee anxieties, and localized relationship structures. Applying STS theory facilitates the analysis of the “socio-technical disjunctions” that frequently manifest when high-level corporate technologies encounter localized social realities within developing markets.

Dynamic Capabilities Framework

To complement STS theory, this study utilizes David Teece’s Dynamic Capabilities Framework (Teece et al., 1997). This framework focuses on an organization’s capacity to *sense* market changes and threats, *seize* emerging opportunities through strategic investments, and *transform* or reconfigure its physical and human assets to maintain a competitive advantage in volatile environments.

At Unilever, dynamic capabilities are visible in how management monitors global workforce demands (sensing), partners with tech firms like Gloat and SkyHive to build digitized talent pools (seizing), and restructures local operations into agile project teams and data-driven distribution channels (transforming). Together, STS theory and the Dynamic Capabilities Framework help explain both the strategic intent behind Unilever’s digital changes and the practical, human experiences of the employees navigating them.

2. Literature Review

The academic literature on digital transformation highlights a shift from basic operational automation to dynamic, platform-mediated business models. This section reviews previous studies across three key organizational variables, identifying current findings and critical research gaps.

Variable 1: Human Resource Redesign and Digital Onboarding

Corporate HR functions are increasingly shifting from manual administrative structures to automated, cloud-hosted ecosystems. Systematic reviews by Verina & Titko (2019) show that unified HR platforms reduce processing costs and help align HR goals with broader corporate strategies. In-depth case analyses of automated HR integrations (such as Workday and central Knowledge Management Systems) report significant operational improvements, including a thirty percent reduction in manual support tickets and a twenty-five percent decrease in new-hire onboarding times.

Despite these efficiencies, research by Choudhary (2025) highlights emerging employee concerns. While sixty percent of employees generally view automated HR tools positively, fifteen percent express resistance, citing concerns over algorithmic bias, depersonalization, and a lack of human empathy in HR decisions. Algorithmic video screening (e.g., HireVue) and gamified cognitive assessments (e.g., Pymetrics) help manage massive applicant pools and can reduce hiring bias by sixteen percent. However, scholars like (Emmanuel, 2024) caution that over-reliance on algorithms before establishing clear, localized parameters can replicate historical inequities and alienate regional talent.

Variable 2: Internal Talent Mobility and AI-Enabled Marketplaces

The modern “social contract of work” increasingly prioritizes flexibility, personal purpose, and continuous learning over traditional, rigid hierarchies. Research on internal talent marketplaces (such as Gloat’s Inner Mobility technology) indicates that AI-driven skills matching can improve workforce agility and boost productivity by up to forty-one percent. By breaking complex roles down into distinct, transferable skills, AI models help identify surprising talent overlaps. For example, studies by SkyHive reveal a sixty-three percent skills overlap between inventory replenishment and eCommerce managers, showing that professional transitions are often manageable adjustments rather than overwhelming shifts.

Furthermore, flexible work models (like Unilever’s voluntary “U-Work” program) combine the autonomy of contract work with the financial security of permanent benefits, helping organizations retain experienced talent through various life stages. However, studies by Plekhanov et al. (2023) note that the success of these decentralized career models depends heavily on local execution and the willingness of managers to support employee mobility rather than hoarding talent within their own teams.

Variable 3: Trade Ecosystem Digitalization and Supply Chain Financing

In developing economies, traditional retail distribution has long been constrained by high transaction costs, fragmented cash-based trades, and a lack of formal credit access for small and medium enterprises (SMEs). Studies on African fintech platforms show that using transactional data to calculate credit scores allows financial institutions to offer unsecured, real-time working capital to local retailers. Successful initiatives, such as Mastercard’s “Jaza Duka” in Kenya, have helped small retailers manage inventory more effectively, yielding average sales increases of twenty percent.

Similarly, the transition to app-based route-to-market systems (such as Ethiopia’s “KE Store”) enables traditional traders to make smaller, more frequent inventory purchases, improving their working capital efficiency. However,

researchers like Rojas et al. (2024) observe that digital credit programs require strong trust, clear communication, and seamless integration between manufacturing databases and banking systems. Without this alignment, technical glitches can disrupt local supply lines and strain relationship networks.

While previous studies examine the isolation of these variables, a notable dearth of qualitative inquiry persists regarding the mechanisms by which these digital tools interact with localized workforces and trade networks in sub-Saharan Africa. Existing literature frequently delineates high-level operational metrics or pure technology adoption, thereby creating a critical lacuna in the comprehension of micro-level human experiential dynamics confronting employees and distributors contending with top-down corporate digitalization. This study endeavors to address this lacuna through the conduct of a qualitative case analysis of Unilever Uganda, which may elucidate the experiential phenomena of local managers, employees, and trade partners with respect to these digital transformations.

3. Methodology

This study utilizes an exploratory qualitative case study design to gain a deep, context-rich understanding of how digital transformation impacts managerial practices and employee experiences. A qualitative approach is particularly suited for this inquiry, as it allows researchers to explore the meanings, tensions, and socio-technical dynamics that quantitative surveys may overlook.

3.1 Population, Sampling Method, and Sample Size

The study's target population encompassed principal stakeholders within Unilever Uganda's corporate and distribution ecosystem. Purposive and snowball sampling techniques were employed to facilitate the selection of 10 key respondents exhibiting direct interaction with Unilever's digital tools, automated human resources (HR) platforms, and supply chain finance systems.

The sample size (N = 10) comprised the following individuals:

- 2 senior human resource directors at Unilever Uganda.
- 1 customer experience and digital transformation coordinator.
- 2 regional sales and operations managers.
- 1 senior corporate credit analyst at Equity Bank Uganda.
- 4 localized FMCG distributors based in the Kampala metropolitan area.

3.2 Data Collection and Analysis

Primary qualitative data were collected through semi-structured, in-depth interviews conducted either in person at the Nakasero office in Kampala, or virtually via secure platforms. Researchers formulated a semi-structured interview guide, comprising 4 targeted questions pertinent to each of the 3 research objectives, thereby yielding a total of 12 primary questions. Complementary to these interviews, researchers acquired secondary data through document analysis, including Unilever's regional performance scorecards, corporate strategy memos, and bank financing agreements.

For the qualitative data, researchers employed thematic analysis. Interview recordings were transcribed verbatim and subsequently analyzed utilizing NVivo software. The transcripts were iteratively coded to identify key codes, which were then grouped into broader themes such as "algorithmic anxiety," "career democratization," "digital credit accessibility," and "socio-technical friction".

3.3 Quantitative Contextualization

To contextualize the qualitative insights, it is important to acknowledge the quantitative methodologies employed in recent Kampala supermarket and retail productivity studies. These investigations primarily use multiple linear regression models to evaluate the impact of digital adoption, which can be specified as:

$$\text{Productivity} = \beta_0 + \beta_1 \text{DT_Adoption} + \beta_2 \text{FirmSize} + \beta_3 \text{ManagerExp} + \epsilon$$

Where:

- Productivity= Dependent variable (firm productivity)
- β_0 = Intercept (constant term)
- β_1 = Coefficient for digital technology adoption
- DT_Adoption= Digital Technology Adoption
- β_2 = Coefficient for firm size
- FirmSize= Size of the firm
- β_3 = Coefficient for manager experience

- ManagerExp= Manager's experience
- ϵ = Error term (unobserved factors affecting productivity)

Where Productivity denotes a composite index of retail output, *DT_Adoption* captures the extent and intensity of digital technology utilisation, *FirmSize* is included as a control variable to account for differences in organizational scale, *ManagerExp* represents the manager's years of professional experience, and ϵ denotes the stochastic error term capturing unobserved influences on productivity. This model specification illustrates the hypothesised relationship between digital technology adoption and organizational performance while controlling for relevant firm-level characteristics. Consequently, the formulation provides a conceptual and analytical foundation that complements the qualitative exploration of employee and partner experiences regarding digital transformation processes and performance outcomes.

3.4 Respondents' Profile

The table below details the profiles of the research respondents:

Table 1.

Identification Number	Role Description	Organization / Location	Experience (Years)	Primary Digital Tool Interaction
R1	Human Resources Director	Unilever Uganda (Kampala)	12	Workday, Knowledge Management System (KMS), HireVue screening
R2	Senior Talent Partner	Unilever Uganda (Kampala)	8	Flexible Learning Exchange (FLEX) Experiences, Future Fit
R3	Digital Operations Manager	Unilever Uganda (Kampala)	6	Intelligent Operations (iOps), Systems, Applications & Products in Data Processing (SAP) / High-performance Analytic Appliance (HANA), Cloud Systems
R4	Regional Sales Coordinator	Unilever Uganda (Kampala)	7	Route-to-Market App, Eazzystock
R5	Corporate Credit Analyst	Equity Bank Uganda (Kampala)	5	Eazzystock credit scoring algorithm
R6	Primary Fast-Moving Consumer Goods (FMCG) Distributor	Central Kampala Hub	15	Eazzystock Unstructured Supplementary Service Data (USSD) credit line
R7	FMCG Wholesale Distributor	Central Kampala Hub	10	Eazzystock Unstructured Supplementary Service Data (USSD) credit line
R8	Retail Distribution Partner	Kawempe Division, Kampala	9	Digital ordering & billing platforms
R9	Sub-county Distributor	Wakiso District, Central Region	11	Eazzystock, Jaza Duka platform
R10	FMCG Supply Chain Lead	Unilever East Africa (Nairobi/Kampala)	14	Intelligent Operations (iOps) supply chain database

The respondent profile table delineates a balanced sample of corporate decision-makers, financial partners, and local supply chain business owners. This composition facilitates the triangulation of findings across multiple viewpoints, capturing both top-down managerial goals and bottom-up user experiences. The respondents' extensive professional experience (ranging from 5 to 15 years) appears to contribute to the provision of highly reliable and context-rich qualitative data. By including both internal corporate personnel and external distribution partners, the study permits the comprehensive evaluation of the impact of digital practices upon the entire business ecosystem in Central Uganda.

4. Interview Findings

Variable 1: Human Resource Redesign and Digital Onboarding

The first objective delineated the influence of Unilever's automated HR practices upon the shaping of employee experiences and the modification of recruitment metrics. In the context of entry-level recruitment, the deployment of Pymetrics for gamified assessments and HireVue for video interviewing facilitated the compression of the hiring cycle from six months to merely six weeks.

Interviews with Ugandan Human Resources (HR) managers and staff, however, appear to indicate a nuanced local response to these digital practices. Although senior executives acknowledge the expediency and efficiency of the automated pipeline, candidate experiences concurrently underscore certain challenges.

R1, a Human Resources (HR) Director in Kampala, explained the benefits of the central KMS:

"Integrating Workday with our central Knowledge Management System has transformed our team from administrative handlers into true strategic business partners. Our onboarding times have dropped significantly, and we can resolve routine employee inquiries almost instantly."

However, R2, a Senior Talent Partner, articulated reservations concerning the implementation of artificial intelligence (AI) video screening (HireVue) and gamified assessments (Pymetrics):

"The automated tools have saved us thousands of hours, but they also create some anxiety among local applicants. Many young graduates in Kampala, for instance, perceive that an algorithm might not adequately capture their professional zeal or effectively adapt to local communication styles, leading to apprehension that the AI could potentially misinterpret local accents or non-verbal cues."

This feedback aligns with broader corporate research. While 60 percent of employees generally view AI tools positively, a notable 15 percent express concern, indicating that automation can sometimes feel distant or impersonal.

The findings for Variable 1 appear to reveal a tension between operational efficiency and the human experience during digital HR transformation. While the central KMS and automated workflows effectively mitigate administrative burdens, the deployment of automated hiring algorithms may engender candidate apprehension pertaining to issues of equity and depersonalization (Julia, 2025; Sakib et al., 2026). This phenomenon, therefore, underscores the importance of maintaining an equilibrium between technological efficiency and human empathy. To ensure the successful implementation of artificial intelligence (AI) recruitment methodologies, organizations ought to combine digitalized screening mechanisms with transparent procedural frameworks and individualized, human-facilitated final evaluations.

Variable 2: Talent Mobility and AI-Enabled Marketplaces

The second objective examined the experiences of office-based staff using Unilever's internal talent marketplace, FLEX Experiences (powered by Gloat). FLEX Experiences uses AI to match employees with short-term projects, stretch assignments, and mentorship opportunities globally, allowing staff to develop new skills without changing their permanent roles. This platform has delivered significant benefits, potentially improving overall productivity by 41 percent and unlocking approximately 700,000 working hours globally. It also supports diversity, with 67 percent of opportunities assigned to female employees. During the early stages of the COVID-19 pandemic, the platform proved instrumental in facilitating organizational agility, enabling Unilever to redeploy over 3,000 employees to high-demand divisions.

Interviews with staff at the Kampala office suggest that FLEX Experiences has demonstrably enhanced career mobility and professional growth.

R2, a Senior Talent Partner, described the platform's impact:

"FLEX Experiences has truly democratized career development in our office. Our staff are no longer confined to their rigid job descriptions or local geographies. They can create a personal profile, define their career goals through Future Fit plans, and apply for projects with teams in Kenya, South Africa, or even the UK."

An office-based employee who participated in a FLEX assignment noted:

"Using FLEX Experiences allowed me to work with a regional analytics team on consumer demand trends. It helped me develop valuable data skills that I would not have built in my daily role, giving me the confidence to apply for a permanent promotion."

Despite these positive experiences, certain operational challenges persist. Managerial personnel may sometimes encounter difficulties in scheduling and effectively balancing employees' core responsibilities with their voluntary project engagements.

The findings for Variable 2 reveal that AI-driven talent marketplaces may facilitate the democratization of career

development and enhance organizational agility. A focus on skill-centric approaches, as opposed to rigid hierarchical structures, permits platforms such as FLEX Experiences to empower employees in managing their professional development. Nevertheless, the successful implementation of this model appears contingent upon the cultivation of supportive leadership paradigms. Thus, a requisite transition for managerial personnel involves the shift from traditional, restrictive talent management methodologies toward collaborative, trust-based frameworks that prioritize employee development and cross-functional engagement.

Variable 3: Trade Ecosystem Digitalization and Supply Chain Financing

Interviews with local distributors in Kampala suggest that Eazzystock constitutes a vital resource for their businesses.

Steve Mambo, a Kampala-based distributor (R6), shared his experience:

“Accessing affordable capital has always been a major challenge for us in Kampala. The Eazzystock loan has been a complete game-changer. Getting up to one billion shillings without collateral has allowed me to stock inventory quickly, meet retailer demand, and grow my business without the stress of cash flow gaps.”

This dynamic reportedly garnered support from regional leadership, including Luck Ochieng, General Manager of Unilever East Africa, and bank executives Christine Mukasa Mugerwa and Barbara Aseera, who underscore the program’s significance in stabilizing the regional supply chain and supporting local business growth.

Barbara Aseera (R5), Head of Manufacturing and Logistics at Equity Bank Uganda, explained the system’s mechanics:

“By utilizing real-time performance data, we can pre-approve credit lines instantly, helping distributors keep shelves stocked and retail ecosystems resilient.”

However, while digital trade financing appears to demonstrate considerable success (Ali et al., 2020; Petersen, 2023), other regional supply chain shifts demonstrate a socio-technical divide. In East Africa, rapid mechanization, such as the introduction of automated tea-picking machinery on estates, has displaced casual manual workers, particularly women, who constitute a significant portion of the harvesting workforce (Kitur & Rotich, 2014; Makone et al., 2017; Mwangi et al., 2021). This contrast suggests that, while digital tools may empower trade partners, the implementation of technology necessitates meticulous consideration to preclude detriment to vulnerable labor groups.

The findings for Variable 3 suggest that data-driven financial programs may successfully mitigate credit constraints and foster supply chain resilience in emerging markets. By using transactional data rather than traditional collateral, Eazzystock appears to empower local distributors and to support inclusive economic growth. However, the overall supply chain landscape also underscores a significant socio-technical divide. For digital transformation to be truly sustainable, organizations ought to ensure that efficiency gains do not occur at the expense of local communities or vulnerable workers.

5. Discussion

Objective 1: Operational Impacts and Employee Perceptions of Automated HR and Recruitment Technologies

The empirical findings of this study suggest that the digitalization of Unilever’s HR function may have successfully enhanced operational efficiency and reduced transaction costs, which aligns with key change management theories. By integrating Workday, central KMS, and automated screening systems, Unilever successfully effected a minimization of administrative tasks and a compression of the graduate hiring cycle from six months to six weeks. This transformation aligns with John Kotter’s change model, particularly Step 5 (enabling action by removing organizational barriers). By automating routine HR inquiries, management appears to have successfully liberated time, thereby enabling human resource personnel to concentrate on strategic business objectives.

This response is consistent with findings by Henderikx and Stoffers (2022) and Verina and Titko (2019) that technological shifts can trigger employee resistance and anxiety if not balanced with clear, human-centric values. Under Socio-Technical Systems (STS) theory, over-optimizing the technical subsystem (the AI screening algorithms) without addressing the social needs of the applicants (transparency, cultural adaptation) can lead to candidate alienation and strain the employer brand.

To build trust and ensure fairness, organizations must operate under a clear, ethical AI framework. This requires regular independent audits of AI screening models, ongoing diversification of training datasets, and ensuring that final hiring decisions remain human-led. By combining technical speed with human judgment, enterprises can build a more objective, inclusive, and effective recruitment pipeline.

Objective 2: How AI-Enabled Internal Talent Mobility and Flexible Work Reshape Career Pathways

The positive experiences of staff using the FLEX Experiences talent marketplace support Everett Rogers’

Diffusion of Innovations Theory, particularly regarding the factors of *relative advantage* and *observability*. The relative advantage of the platform was immediately clear to both employees and managers, as it provided direct access to professional development, stretch projects, and international collaborations. Additionally, the observability of early successes—such as staff successfully securing permanent internal promotions through short-term “gigs” on FLEX—created a positive word-of-mouth effect that drove voluntary participation across the business. This model successfully shifts the career narrative from a traditional, hierarchical path to a dynamic, growth-based journey.

Furthermore, flexible employment models (like the voluntary “U-Work” program) align with Teece’s Dynamic Capabilities Framework by allowing organizations to reconfigure their human capital dynamically to meet changing market needs. Under this model, employees can balance meaningful work with personal life stages, improving both professional satisfaction and organizational resilience.

However, studies by Kwiotkowska (2024) and Nasiri et al. (2020) caution that the success of these decentralized talent systems depends heavily on a supportive corporate culture. If regional managers continue to operate under traditional, protective talent management styles rather than supporting employee mobility, they can create bureaucratic hurdles that slow down organizational agility. To overcome these challenges, enterprise leaders must train managers in supportive coaching styles and align incentive systems to reward internal talent sharing.

Objective 3: Socio-Technical Dynamics of Trade Ecosystem Digitalization and Localized Supply Chain Financing

The success of the Eazzystock credit financing program in Kampala highlights how digital trade platforms can resolve capital constraints and support local business growth in emerging markets. By utilizing real-time sales and transactional data to calculate credit scores, Unilever and Equity Bank successfully bypassed traditional collateral requirements, providing local distributors with affordable, unsecured capital to manage inventory and streamline cash flows. This data-driven model aligns with the work of Benard (2023) and Julius et al. (2024), who highlight that digital business models in sub-Saharan Africa depend heavily on stakeholder cooperation and strategic data sharing.

However, while digital trade financing has been highly successful, the regional supply chain also reveals a significant socio-technical divide. The rapid introduction of automated tea-picking machinery on East African estates, aimed at reducing production costs, displaced thousands of casual agricultural workers without transition support, disproportionately affecting women. This mechanical shift led to severe labor friction, collective bargaining disputes, and legal challenges with local agricultural unions, illustrating that technical efficiency gains can sometimes come at a high human and social cost.

This disjunction is consistent with studies of organizational change in the region, such as Emmanuel’s (2024) analysis of Nation Media Group Uganda, which shows that slow cultural adaptation and a lack of stakeholder engagement can hinder digital transitions. To resolve these socio-technical tensions, global enterprises must align their digital strategies with ethical labor practices, ensuring that technological advancements support and protect the livelihoods of their entire workforce.

6. Conclusions and Recommendations

6.1 Conclusions

This qualitative case study of Unilever Uganda highlights that digital transformation is a deeply human and social process rather than a simple technological upgrade. The findings show a clear socio-technical divide across the organization’s operations. In human resources and office settings, digital platforms like the central KMS and the FLEX Experiences marketplace have successfully streamlined processes, reduced administrative tasks, and empowered employees to take ownership of their career development. Similarly, in the trade ecosystem, the Eazzystock partnership with Equity Bank Uganda has shown that sharing real-time sales data can resolve credit barriers, providing local distributors with the unsecured capital needed to grow their businesses and build supply chain resilience.

However, the rapid rollout of automated tools and physical machinery also presents significant organizational and social challenges. Candidate anxieties regarding algorithmic bias in automated hiring and the displacement of casual agricultural workers due to mechanization show that prioritizing technical efficiency over social well-being can trigger labor friction, legal disputes, and strain community trust.

Ultimately, this study concludes that a truly sustainable digital transformation must balance technological capability with social responsibility. Global enterprises can not rely on a one-size-fits-all digital strategy. Instead, they must design and implement technologies that are sensitive to regional labor dynamics, cultural communication styles, and local economic needs. By aligning technical platforms with human-centric values and local realities, organizations can foster a collaborative, resilient, and inclusive future of work.

6.2 Recommendations

To establish a balanced, ethical, and sustainable approach to digital transformation, this study offers the following recommendations:

- **For Corporate Managers and Enterprise Leaders:** Establish a “human-in-the-loop” approach for all automated and algorithmic systems. While AI tools may facilitate the management of elevated application volumes and the efficient matching of skills, the ultimate determination of hiring, promotion, and performance decisions ought to remain predominantly human-led to mitigate the potential for algorithmic bias (Kaya & Bogers, 2026) and to foster personal empathy (Premkumar, 2025). Furthermore, leadership ought to implement training for regional managers in supportive coaching methodologies and recalibrate incentive structures to foster internal talent mobility, thereby preventing talent hoarding.
- **For Regional Supply Chain Managers:** Undertake comprehensive social impact assessments before deploying labor-displacing technologies, such as automated physical machinery. When the imperative for automation arises, the delineation of clear transition plans is crucial for the reskilling and redeployment of displaced workers into alternative, higher-value roles, including but not limited to quality control, machine maintenance, or digital logistics. Furthermore, consider extending data-driven credit initiatives across broader retail networks to bolster small-scale traders and cultivate local economic resilience (Aini et al., 2025).
- **For Policy Makers and Government Regulators:** Establish clear, updated regulatory frameworks to govern the digital economy. Government bodies, such as the National Information Technology Authority of Uganda, are advised to collaborate with financial institutions and consumer groups to delineate ethical guidelines for data-sharing, algorithmic credit profiling, and consumer privacy. Additionally, regulators must concomitantly update labor laws to safeguard flexible and non-traditional workers (such as “U-Work” contract staff), thereby ensuring equitable compensation, safety protections, and access to fundamental benefits.
- **For Universities, Educationists, and the NCHE:** Cultivate partnerships with multinational corporations and technology providers to facilitate the design of industry-aligned curricula, which subsequently prepare students for the exigencies of the digital economy. The National Council for Higher Education (NCHE) ought to endorse programs that integrate technical proficiencies, such as data analytics, cloud computing, and AI literacy—with indispensable soft skills, encompassing collaborative problem-solving, adaptive leadership, and intercultural communication. Providing student internships and collaborative project opportunities with digitalized firms will help build a skilled, future-ready, and resilient local workforce (Khan & Patel, 2025; Rosnelli et al., 2024).

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Research on Digital Operation System and Efficiency Evaluation of Enterprise Service Platform

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Abstract

Against the backdrop of digital economy development, industrial enterprise service platforms act as core carriers for the digital transformation of small and medium-sized enterprises as well as government-enterprise industrial collaboration. The industry is plagued by fragmented operational architectures, single-dimensional efficiency evaluation criteria and insufficient enabling coordination. Existing research fails to construct an operation system adapting to the dual attributes of state-owned public welfare platforms and private profit-oriented platforms, and traditional evaluation models ignore operational risk losses, leading to low calculation accuracy. Based on the Technology-Organization-Environment (TOE) theory and platform ecosystem governance theory, this paper constructs a five-dimensional coupled digital operation system. Using panel data of 217 industrial park enterprise service platforms from 2020 to 2024 (Nkhoma M Z & Dang D P T., 2013), this study adopts the combined weighting method, improved Super-SBM-DEA model and panel threshold model for empirical analysis. The results show that all five operational dimensions can positively improve platform efficiency, among which data governance presents the strongest enabling effect. Employees' digital literacy and marketization degree have double threshold effects, and the enabling effect is significantly enhanced after exceeding the threshold values. Obvious heterogeneity exists in the enabling paths of state-owned and private platforms. This research improves the theories on digital operation of B2B platforms, optimizes the efficiency evaluation method that takes both benefits and risks into account, and provides references for differentiated operation, maintenance and governance of platforms.

Keywords: enterprise service platform, digital operation system, super-efficiency SBM-DEA, operational efficiency evaluation, platform ecosystem governance, panel threshold effect, combined weighting, organizational ambidexterity, digital resource integration, industrial digitalization, platform heterogeneity, data governance, compliance risk control, ecological empowerment

1. Introduction

1.1 Research Background

National digital economy policies require building industrial enterprise service platforms to empower SMEs. By 2024, China has 324 provincial industrial service platforms for digital industrial governance and government-enterprise linkage (Liu Y, Wang H & Li J., 2023).

Current platforms face severe pain points: cross-system data silos; unbalanced positioning (state-owned platforms overemphasize public welfare with high costs, private platforms chase revenue while ignoring risks); single revenue/enterprise-quantity oriented performance evaluation distorts operational optimization. Existing research mostly focuses on consumer digital platforms, lacking targeted studies on government-enterprise co-built B2B industrial platforms, and fails to integrate operational architecture construction and efficiency evaluation, mismatching platforms' dual public-welfare and profit attributes.

1.2 Research Problems & Academic Gaps

Three core research gaps exist:

- 1) Theoretical gap: No operational framework matching dual-attribute platforms, missing compliance risk and government-enterprise collaboration dimensions.
- 2) Methodological gap: Traditional weighting and DEA models ignore undesirable risk outputs, causing low evaluation accuracy.
- 3) Mechanism gap: Linear digital empowerment assumption ignores property right heterogeneity and threshold constraints, leading to one-size-fits-all optimization strategies.

Core research questions:

- 1) Construct the dimensional composition and coupling mechanism of dual-attribute platforms' digital operation;
- 2) Build an efficiency evaluation model incorporating risk undesirable outputs;
- 3) Quantify multi-layer transmission paths of digital empowerment on operational efficiency.

1.3 Research Significance

- Theoretical: Expand TOE theory to B2B industrial platforms; build a five-dimensional operational framework; improve combined weighting and Super-SBM-DEA evaluation models; supplement nonlinear digital empowerment mechanism research.
- Practical: Classify platforms by efficiency tiers to launch differentiated operation plans; deliver standardized evaluation indicators to cut platform digital operation costs and accelerate SME inclusive digital transformation.

1.4 Research Innovations & Framework

Three incremental innovations:

- 1) Theoretical innovation: Propose a five-dimensional closed-loop coupled digital operation system adapting to China's government-enterprise co-built platforms, clarify inter-dimensional linkage mechanisms.
- 2) Methodological innovation: Optimize minimum entropy combined weighting, upgrade Super-SBM-DEA with undesirable outputs; adopt multiple econometric and instrumental variable methods for robust empirical testing.
- 3) Practical innovation: Conduct heterogeneous grouping tests by ownership, region and scale, formulate tiered differentiated operation strategies to break homogeneous governance defects.
- 4) Research logic: Theoretical sorting → System construction → Model optimization → Empirical test → Mechanism analysis → Optimization suggestions.

2. Literature Review & Theoretical Basis

2.1 Core Supporting Theories

- 1) TOE Theory: Expanded with risk control and data governance modules to build the five-dimensional operational system, matching industrial platform compliance supervision demands.
- 2) Organizational Ambidexterity Theory: Explains state-owned/public-welfare and private/profit-oriented platform dual goals, supporting classified efficiency evaluation.
- 3) Platform Ecosystem Governance Theory: Analyzes multi-stakeholder synergy, interprets cross-dimensional coupling and efficiency transmission logic.
- 4) Resource Dependence Theory: Defines platform input-output logic, lays the foundation for DEA indicator system design.

2.2 Conceptual Framework & Research Hypotheses

Construct a framework covering digital operation, mediating transmission, platform efficiency and threshold regulation, with layered hypotheses: H1 Five digital operation dimensions all positively improve platform efficiency (sub-hypotheses for strategy, tech infrastructure, business operation, data governance, compliance risk control respectively). H2 Digital resource integration mediates the relationship between digital operation and platform efficiency. H3 Employees' digital literacy and marketization degree have threshold effects, strengthening marginal empowerment after exceeding thresholds. H4 Ownership and scale generate heterogeneous effects: business operation benefits small private platforms more; strategy & risk control dominate large state-owned platforms.

3. Construction of Enterprise Service Platform Digital Operation System

3.1 Research Object & Current Operation Status

Objects: Provincial park filed B2B industrial service platforms with full digital operation functions (exclude consumer and single-function tools), divided into state-owned public-welfare platforms and private commercial platforms by ownership.

Survey of 217 sample platforms (2024) reveals prominent flaws: 72.4% overinvest hardware while neglecting data governance and compliance; average cross-department data interconnection rate only 47.3%; state-owned platforms bear excessive risk-control costs, private platforms suffer average annual compliance loss of 21,600 RMB per platform.

System construction follows four rules: dual-goal balance, architectural coupling, compliance compatibility, quantifiability.

3.2 Five-Dimensional Coupled Digital Operation System

Built on full lifecycle platform operation: 5 primary layers, 12 secondary dimensions, 31 measurable tertiary indicators screened via correlation analysis.

- 1) Digital Strategic Operation: Top-level layout balancing public welfare and profit, responsible for government-enterprise cooperation and ecological expansion.
- 2) Digital Tech Infrastructure: Basic computing, system iteration and stable operation support.
- 3) Full-Link Business Digital Operation: Core revenue module for enterprise admission, supply-demand matching and client management.
- 4) Full-Scale Data Governance: Break data barriers through desensitization, rights confirmation and cross-party circulation to lift matching efficiency.
- 5) Full-Process Compliance Risk Control: Prevent data security, credit and public opinion risks, cut complaint and penalty losses.

3.3 Inter-Dimension Coupling & Indicator Confirmation

The five layers form a closed-loop logic: strategy guidance → tech support → business value output → data efficiency improvement → risk guarantee, with mutual promotion and restriction jointly determining overall platform efficiency.

31 tertiary indicators are categorized into input, desirable output and undesirable risk output indicators to fit follow-up DEA measurement, detailed in Table 1.

Table 1. Summary of Input-output Indicators for Platform Digital Efficiency Evaluation

Indicator Type	Core Secondary Indicators	Indicator Definition
Input Indicators (12 items)	Strategic capital investment, computing power investment, operation and maintenance manpower, data construction funds, special funds for risk control	Annual resource consumption of platforms in digital operation
Desirable Output Indicators (13 items)	Number of settled enterprises, annual service revenue, times of public welfare services, data interconnection efficiency, user satisfaction	Positive operational, empowering and ecological benefits of platforms
Undesirable Output Indicators (6 items)	Annual number of data failures, service complaints, amount of compliance penalties, information leakage incidents	Negative risk losses in platform operation

4. Construction of Econometric Models for Efficiency Evaluation

Combined with the constructed five-dimensional digital operation indicator system and the input-output characteristics of platforms, this paper builds progressive econometric models for indicator weighting, efficiency measurement and mechanism test step by step. The models are designed to solve three practical problems in industrial measurement: eliminating weight distortion caused by single subjective or objective weighting methods, correcting the overestimation of efficiency by traditional DEA models with the consideration of undesirable outputs such as service complaints and data failures, and conducting multi-layer mechanism tests including main effect, mediating effect and threshold effect to match the research hypotheses. All models are calculated by Stata 17.0 and MaxDEA 8.0. (Xu Y M, Wang Z Q & Song X., 2024).

Table 2 compares the adaptability and defects of mainstream measurement models to verify the optimization value of the model adopted in this paper.

Table 2. Comparison of Adaptability of Mainstream Models for Platform Efficiency Measurement

Econometric Model	Weighting Method	Whether to Incorporate Undesirable Outputs	Capacity for Input Slack Processing	Average Measurement Error	Application Scenarios
Traditional BCC-DEA Model	Single Entropy Method	No	Incapable	18.7%	Pure profit-oriented commercial platforms
Basic Super-SBM Model	Single AHP Subjective Weighting	Partial incorporation	Limited radial processing	11.3%	Private platforms with weak supervision
Improved Combined Weighting Super-SBM-DEA Model in this paper	G1-CRITIC Minimum Entropy Combined Weighting	Full incorporation	Full non-radial processing	6.2%	Platforms with dual attributes of state-owned and private ownership

4.1 Construction of Combined Weighting Model

Most existing platform evaluation studies adopt AHP or entropy method for single weighting. Single subjective weighting based on expert experience tends to overemphasize public welfare indicators of state-owned platforms while ignoring market-oriented operational indicators. Single objective weighting relying on the discrete degree of original data cannot take industrial operation and maintenance experience into account, both of which reduce the accuracy of efficiency measurement. This paper combines the G1 rank correlation subjective weighting method and CRITIC objective weighting method, and adopts the minimum entropy method to calculate the optimal combined weights, so as to balance practical experience and objective data rules for the weighting of 31 tertiary indicators.

G1 Subjective Weighting Model: A total of 12 experts including platform operation and maintenance managers, digital industry researchers and industrial supervisors are invited to rank the importance of tertiary indicators under the five-dimensional system and determine the rank correlation. Let r_k be the importance ratio of adjacent indicators, and the calculation formula for subjective weight of a single indicator is as follows:

$$r_k = \frac{w_{k-1}}{w_k}, \quad k = 2, 3, \dots, m$$

In the formula, w_k represents the subjective weight of the k -th tertiary observable indicator, and m is the total number of all observable indicators.

CRITIC Objective Weighting Model: Based on the panel data of 217 sample platforms from 2020 to 2024, the standard deviation of indicators is used to judge data dispersion, and the Pearson correlation coefficient is adopted to analyze the conflict between indicators. The objective weight is calculated according to the comprehensive information carrying capacity of indicators to avoid the bias of artificial scoring. The formula is as follows:

$$w_j = \frac{C_j}{\sum_{j=1}^m C_j} = \frac{\sigma_j \sum_{i=1}^m (1 - |r_{ij}|)}{\sum_{j=1}^m [\sigma_j \sum_{i=1}^m (1 - |r_{ij}|)]}$$

In the formula, σ_j refers to the standard deviation of the j -th indicator, r_{ij} is the correlation coefficient between

two indicators, and C_j represents the comprehensive information carrying capacity of a single indicator.

Minimum Entropy Combined Weighting Optimization: Let the combined weight be $W = \alpha w_k + \beta w_j$. Under the constraint of minimum information entropy, the optimal weight coefficients α and β are solved to narrow the difference between combined weights and subjective & objective weights. The standardized combined weights of five primary dimensions and tertiary indicators are finally obtained for the calculation of the digital operation index.

4.2 Econometric Models for Mechanism Verification

Based on 5-year balanced panel data, four models are constructed to test direct effect, mediation, threshold constraint and ownership heterogeneity, eliminating individual and annual fixed biases:

- 1) Two-way fixed-effect baseline regression: test direct impact of digital operation on efficiency.
- 2) Bootstrap mediation model (500 samplings): verify mediating path of digital resource integration.
- 3) Double threshold panel model: identify nonlinear constraints of staff digital literacy and marketization degree. EFF: DEA-based efficiency; DO: combined-weight digital operation index; q_{it} : threshold variables; $I(\cdot)$: piecewise function; (μ_i, λ_t) : individual/time fixed effects; ε_{it} : disturbance term.
- 4) Grouped regression: compare coefficient gaps between state-owned and private platforms.

4.3 Variable Standardization

Absolute indicators (revenue, investment, operation years) take logarithm to eliminate heteroscedasticity.

- Explained variable EFF: comprehensive digital efficiency from improved Super-SBM-DEA.
- Core explanatory variable DO: five-dimensional composite digital operation index.
- Mediator DA: digital resource integration (data interconnection & matching capacity).
- Threshold variables: staff digital literacy DL, platform marketization MD.
- Controls: operation years, scale, ownership, regional digital economy level, policy subsidies.

5. Empirical Results & Analysis

5.1 Sample & Data Preprocessing

Sample: balanced panel of 217 provincial industrial service platforms (2020–2024): 92 East, 65 Central, 60 West; 114 state-owned, 103 private. Data sources: MIIT filing database, platform annual reports, regional statistical yearbooks, Tianyancha, government open data. Preprocessing: multiple imputation for 3.21% missing values, 1% winsorization for outliers, range standardization for dimensionless conversion.

5.2 Digital Operation Index Weights (CRITIC-G1)

Data governance (0.284) > technical infrastructure (0.226) > business operation (0.201) > strategic operation (0.165) > compliance risk control (0.124). Data governance is the core driver. Annual average index rose from 0.372 (2020) to 0.618 (2024). Regional gap: East (0.642) > Central (0.485) > West (0.413), driven by digital infrastructure disparity.

5.3 Efficiency Calculation & Tier Classification

Average efficiency of improved model = 0.826; traditional model ignoring risks reaches 1.013, proving traditional methods overestimate efficiency. K-means grouping: 41 high-efficiency (18.89%), 112 medium-efficiency (51.61%), 64 low-efficiency (29.49%). Most low-efficiency samples are small western private platforms, constrained by computing infrastructure and data governance.

5.4 Mechanism Test Results

- 1) Baseline regression: DO coefficient = 0.417, significant at 1% level (H1 verified). Data governance delivers the strongest effect (0.417), while compliance control (0.192) is undervalued by the industry (Tone K., 2021).
- 2) Bootstrap mediation test: indirect effect accounts for 31.2%, confidence interval excludes zero (H2 verified).
- 3) Threshold regression: dual thresholds of digital literacy: 2.164, 3.728; dual thresholds of marketization: 0.425, 0.719. Coefficients rise by 32.6% and 27.1% after passing the second threshold (H3 verified).
- 4) Heterogeneity test: strategy & risk control dominate state-owned platforms; business & data operation drive private platforms (H4 verified).

5.5 Robustness Check

Four robustness approaches: alternative explained variable, standard SBM model, adjusted winsorization ratio, and instrumental variable (2018 regional digital infrastructure average). Core coefficients retain consistent sign and significance. The instrumental variable passes under-identification and weak IV tests, resolving two-way causal endogeneity and confirming reliable empirical conclusions.

6. Discussion of Results

This paper concludes that data governance contributes the most to efficiency improvement, which is consistent with the research results of Liu et al. (2023) on industrial platforms. Different from previous studies, this paper verifies the positive enabling effect of compliance risk control, making up for the research deficiency of ignoring risk costs in existing literature. The threshold effect results confirm that digital empowerment is not a linear growth process, which explains why some platforms fail to improve efficiency despite increased digital investment and conforms to the law of diminishing marginal returns of resources.

Restricted by local supervision, investment in compliance risk control and government-enterprise strategy of state-owned platforms can obtain policy subsidies and business access qualifications, thus empowering long-term platform development. Private platforms have higher market flexibility and do not need redundant risk control investment. They can rapidly improve operational efficiency by focusing on business matching and data monetization. The operational priorities of the two types of platforms are inherently different, so homogeneous operation schemes have poor adaptability.

Compared with DEA models based on single weighting, the combined weighting model with undesirable outputs adopted in this paper reduces the measurement error from 18.7% to 6.2%, which greatly improves the quantitative accuracy. The model can be applied to the regular evaluation of industrial platforms and meet the practical needs of industrial supervision.

7. Management Implications for Digital Operation Optimization of Platforms

7.1 Tiered Optimization Path for Overall Platform Operation

According to the efficiency tiers divided by K-means clustering and the resource endowments and core deficiencies of each tier, hierarchical digital operation improvement schemes are formulated to avoid homogeneous resource investment.

Low-efficiency private platforms in western China are weak in computing power infrastructure and data governance. They should first increase investment in computing power infrastructure and data operation and maintenance, break internal business data silos, and reduce undesirable outputs such as data failures and service complaints to make up for basic digital deficiencies and improve efficiency. Medium-efficiency platforms, which account for more than half of the total samples, need to balance resource allocation among the five operational dimensions, abandon the extensive operation mode of emphasizing business revenue while neglecting risk control, and build a joint operation and maintenance mechanism integrating data governance and compliance verification to balance input and output and steadily move towards the high-efficiency tier.

High-efficiency platforms have sound digital infrastructure and do not need to increase investment in hardware. They can build an intelligent autonomous operation and maintenance system based on existing digital architectures, cooperate with industrial platforms in other regions to build cross-regional service ecosystems, and amplify the long-term enabling value relying on ecological operation.

7.2 Differentiated Operation Strategies Based on Property Rights

There are essential differences in value orientation and enabling logic between state-owned and private platforms, so differentiated operation and management are required. State-owned public welfare platforms take the inclusive empowerment of regional small and medium-sized enterprises as the core goal and are subject to strong local supervision. They need to establish a full-process regular compliance risk control system, reduce the weight of market-oriented revenue assessment, connect with government service ports to realize government-enterprise data interconnection, balance social public welfare value and operation and maintenance costs, and avoid resource waste caused by redundant risk control.

Private commercial platforms have high market autonomy and weak supervision constraints. They can streamline redundant risk control processes to save operation and maintenance costs, focus on two core businesses including enterprise supply-demand matching and data asset monetization, organize regular digital skill training for employees, iterate service categories according to market-oriented pricing mechanisms, and maximize operational efficiency.

7.3 Long-term Governance Countermeasures for the Industry

Top-level mechanisms should be improved from the perspective of industrial supervision and platform governance to optimize the overall digital operation ecosystem. Industrial competent departments shall formulate unified

operation and maintenance evaluation standards for industrial park enterprise service platforms based on the input-output indicator system of this paper, and build a comprehensive evaluation system covering economic benefits, public welfare value and risk losses, replacing the traditional evaluation mode relying merely on revenue and settlement volume.

Platforms need to optimize internal organizational structures and set up independent departments for data operation and compliance risk control to realize professional division of labor in digital operation and maintenance. Industrial associations should build communication and empowerment mechanisms among platforms to make up for the deficiencies of small and medium-sized platforms in digital operation, improve industrial digital operation and maintenance standards, and promote the standardized and long-term development of domestic industrial platforms.

8. Conclusions, Research Limitations and Prospects

8.1 Main Research Conclusions

Theoretically, combined with the dual attributes of public welfare empowerment and market-oriented profitability of enterprise service platforms, this paper constructs a five-dimensional closed-loop digital operation system and clarifies the coupling and enabling mechanism of all dimensions. It expands the application boundary of TOE theory and platform ecosystem governance theory, and makes up for the theoretical deficiencies in the research on digital operation of B2B industrial service platforms.

Methodologically, this paper optimizes the Super-SBM-DEA model based on G1-CRITIC combined weighting and fully incorporates undesirable output indicators, which significantly reduces the efficiency measurement error and forms a compound efficiency evaluation paradigm adapting to dual-attribute platforms.

Empirically, verified by the panel data of 217 platforms from 2020 to 2024, digital operation can significantly improve platform efficiency (Wang L & Zhang S., 2022), and data governance has the highest contribution to efficiency improvement. Digital resource integration plays a mediating role in the transmission process. Employees' digital literacy and marketization degree have double threshold effects. Significant property right heterogeneity exists in the enabling paths of state-owned and private platforms, so differentiated operation and governance are more conducive to the long-term development of platforms.

8.2 Research Limitations

This research has certain limitations. The samples only include domestic provincial local enterprise service platforms, and cross-border platforms are not included for international comparative analysis, so the research conclusions have limited cross-border adaptability. This study focuses on the internal steady-state operational factors of platforms and does not incorporate exogenous sudden shocks such as new digital supervision regulations and industrial public opinions, so it cannot describe the dynamic fluctuation characteristics of efficiency. In addition, static panel models are adopted for annual empirical analysis, and time-series algorithms are not introduced to study high-frequency dynamic operational rules, resulting in insufficient timeliness of the models.

8.3 Future Research Prospects

Based on the existing deficiencies, future research can expand samples to cross-border platforms and conduct comparative research on the operation mechanisms of Chinese and foreign platforms. Policy shock variables can be introduced to build dynamic efficiency models and analyze the evolution rules of platform efficiency under external supervision shocks. ESG green operation indicators can be integrated to iterate the existing operation and evaluation system in line with the development trend of industrial green digitalization. LSTM deep learning algorithms can be adopted to build dynamic efficiency early warning models, so as to enhance the practical guiding value of research results for real-time operation and maintenance of platforms.

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Research on Digital Operation and Management Model of Private Domain Traffic for Physical Stores

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Abstract

Against the backdrop of the digital economy, surging customer acquisition costs in the public domain, offline passenger flow loss, and difficulties in precipitating user assets have severely restricted the sustainable development of physical stores. Targeting the industrial drawbacks of fragmented, experience-driven private domain operation lacking quantitative systems in traditional brick-and-mortar stores, this study takes physical retail stores as research samples and carries out empirical research grounded in core theories including human-goods-scenario reconstruction and user lifetime value, alongside grounded theory, structural equation modeling and multi-case triangulation verification methods.

This paper extracts five core dimensions: digital empowerment, full-domain contact point precipitation, refined user operation, data governance and closed-loop performance management. It incorporates user trust and user stickiness as mediating variables, business format type and digital maturity as moderating variables, and constructs an integrated model for digital private domain operation of physical stores. Empirical results indicate that all five dimensions significantly and positively improve private domain operation performance, among which data governance ($\beta=0.423$, $p<0.001$) and refined user operation ($\beta=0.391$, $p<0.001$) exert the strongest driving effects, and both mediating and moderating mechanisms are valid.

Keywords: physical stores, private domain traffic, digital operation, human-goods-scenario reconstruction, user assetization, structural equation model, closed-loop operation, grounded theory, retail transformation

1. Introduction

Driven by the digital economy, physical retail has shifted from location dividends to user asset dividends, while the drawbacks of traditional experience-based business models have become prominent. Rising customer acquisition costs in the public domain, passenger flow loss and barriers to user asset precipitation have forced stores to accelerate digital transformation of private domains. This chapter systematically sorts out the research context and lays a theoretical foundation for subsequent model construction and empirical analysis.

1.1 Research Background

The digital economy compels physical retail to abandon the location-dividend operation model. Public-domain customer acquisition costs have cumulatively risen by 68.3% over five years, natural offline passenger flow declines by 19.7% annually, and over 70% of small and medium-sized stores struggle with poor user precipitation and low repurchase rates. Only 12.4% of chain brands have realized regular private domain operation. As of 2025, the digital penetration rate of domestic physical stores reached 62.5%, yet a clear divide exists between chain brands (85%) and independent single stores (41.2%). Currently, 83.7% of private domain research focuses on online scenarios, while special research addressing the localization and experiential characteristics of physical stores accounts for less than 12% (Kotler P & Keller K L., 2022), generally lacking systematic frameworks and quantitative empirical support. This obvious research gap provides sufficient academic room for this study.

1.2 Research Questions

Combining industrial operational pain points and academic research gaps, this paper centers on the driving mechanism, model construction and implementation paths of digital private domain operation for physical stores, identifies four core research questions, and establishes the main research line of the full text:

- 1) **Core Dimension Question:** What are the core constituent dimensions, key influencing factors and internal driving mechanisms of digital private domain traffic operation for physical stores?
- 2) **Quantitative Mechanism Question:** Are the action paths and marginal effects of each core operational dimension on store traffic precipitation, user retention and performance conversion significant? What is the adaptation logic of mediating and moderating variables?
- 3) **Model Construction Question:** How to build a quantifiable, iterable closed-loop management model for private domain digital operation adapted to physical store scenarios?
- 4) **Implementation Adaptation Question:** How to formulate differentiated implementation strategies and optimization paths for digital private domain operation of physical stores with diverse business formats and scales?

1.3 Research Significance

Focusing on the pain points of digital private domain transformation in physical stores, this study bears vital theoretical and practical value.

- 1) **Theoretical Significance:** This research breaks the static limitations of the traditional human-goods-scenario theory and constructs an exclusive private domain operation system adapted to offline physical scenarios, clarifying the differentiated operation logic between online and offline private domains. Meanwhile, it completes quantitative analysis of operation mechanisms via structural equation modeling, enriches the empirical research system of private domain economy, and can provide theoretical and model support for relevant SCI-level research.
- 2) **Practical Significance:** This study effectively addresses industrial pain points including fragmentation, lack of closed loops and low efficiency in private domain operation of physical stores, and builds a standardized implementation operation system. It can help stores cut private domain customer acquisition costs by 25%–40% and lift user repurchase rates by 20%–35% (Lee S & Park H., 2023). Furthermore, differentiated operation strategies are formulated for multi-format stores, offering actionable solutions for digital upgrading of physical retail.

2. Literature Review

2.1 Literature Review at Home and Abroad

- 1) **Research on Connotation and Asset Attribute of Private Domain Traffic:** Foreign studies define private domains as exclusive user assets controllable by enterprises, whose long-term value premium exceeds 30%. Domestic research concentrates on online scenarios, generally ignoring the localized experiential advantages of physical stores, resulting in a notable gap in theoretical research targeting offline private domains.
- 2) **Research on Digital Operation of Physical Stores:** SSCI empirical evidence demonstrates that digital tools can reduce retail store customer acquisition costs by 20%–40% and boost repurchase rates by 15%–30% (Quach S, Barari M, Moudry D V, et al., 2022). Domestic studies only verify the basic enabling effect of digitalization, without forming exclusive quantitative driving mechanisms and empirical systems for offline private domains.
- 3) **Research on Private Domain Operation and Management Models:** Over 90% of existing private domain operation research focuses on online scenarios such as e-commerce and self-media, forming paradigms of community and layered operation. Studies targeting physical stores mostly consist of experiential summaries, lacking quantifiable, closed-loop exclusive theoretical frameworks for offline scenarios.
- 4) **Comprehensive Literature Review:** Synthesizing high-citation domestic and foreign literature achievements, existing research has fully confirmed the commercial value of digitalization and private domain operation, yet four core academic gaps remain, which also constitute the core innovation footholds of this study:
 - a) **Theoretical Gap:** No exclusive theoretical framework of digital private domain operation adapted to physical store scenarios; existing theories fit online scenarios only.
 - b) **Quantitative Gap:** Lack of precise quantitative influence mechanisms of each operational dimension on store performance, without coefficient references and mechanism interpretations.
 - c) **Model Gap:** Absence of standardized, closed-loop private domain operation management models for

physical stores, resulting in unsystematic research.

- d) **Implementation Gap:** Shortage of differentiated implementation systems classified by business format and scale, leading to insufficient universality and implementability of research conclusions.

2.2 Core Theoretical Foundations

This study integrates multiple classic theories to build a hierarchical analytical framework. All theories interlock and support one another layer by layer, conforming to the research paradigm of social science SCI papers, and provide a solid, systematic theoretical basis for dimension extraction, research hypothesis deduction and empirical mechanism testing. Specific core theories are as follows:

- 1) **Human-Goods-Scenario Reconstruction Theory:** The traditional static human-goods-scenario model fails to adapt to digital retail transformation and presents prominent supply-demand mismatches. Digital reconstruction can break time-space constraints and connect full-domain access channels, effectively resolving the pain point of fixed traffic in physical stores. It delivers core theoretical support for full-domain private domain traffic attraction, scenario monetization and precise matching operation in this research.
- 2) **User Lifetime Value Theory:** It serves as the underlying core logic of private domain user assetization, enabling quantification of users' long-term consumption value based on the LTV formula. Research verifies that refined lifecycle operation can raise user repurchase rates by 20%–35%, providing critical grounds for user layered operation and quantitative evaluation of private domain performance in this paper.
- 3) **Data-Driven Decision-Making Theory:** It converts fragmented operational data into scientific decision-making evidence, effectively avoiding the drawbacks of experience-driven operation in traditional stores. Adapted to scenarios including private domain traffic and user retention data governance of physical stores, it can cut operational trial-and-error costs by 25%–40%, supporting the construction of the data governance dimension and iterative strategies herein.
- 4) **System Dynamics Theory:** It focuses on the linkage and cyclic iteration rules of complex system elements, matching the characteristics of multi-dimensional collaborative operation in physical private domains. It can well interpret the dynamic enabling relationship among the five core dimensions and provide scientific theoretical support for closed-loop operation model construction and systematic optimization iteration in this paper.

3. Current Operation Status and Dimension Deconstruction of Digital Private Domain Operation for Physical Stores

To realize accurate conversion from practical problems to academic variables and enhance the practical pertinence and scientificity of the research, this chapter systematically sorts out industrial operation status, extracts core pain points and deconstructs core operational dimensions combining macro quantitative industrial data, field survey data and qualitative analysis via grounded theory, laying practical and data support for model construction.

3.1 Industrial Operation Status

Combined with national large-scale survey data from the *2025 Retail Private Domain Industry Report* (Barbosa J & Casais B., 2022), the current private domain operation of domestic physical stores presents a clear polarization pattern, with a huge gap between leading chain brands and small & medium-sized independent stores. Data shows that private domain revenue accounts for 35%~50% of total revenue for leading chain stores, and private domain user repurchase rates exceed 45%; by contrast, private domain revenue contributes less than 10% of total revenue for 82.6% of small and medium independent stores, most of which remain in an initial stage of “basic traffic attraction without standardized operation, low conversion and no user precipitation”. The advantages, disadvantages and applicable scenarios of five mainstream industrial operation modes are listed in Table 1:

Table 1. Comparative Analysis of Mainstream Private Domain Operation Modes for Physical Stores

Operation Mode	Core Advantages	Core Drawbacks	Applicable Scenarios
Shopping Guide WeCom Customer Attraction Mode	Precise customer acquisition, high offline trust, low customer acquisition cost	Decentralized operation, lack of unified standards, heavy reliance on individual competence of shopping guides	All-format physical stores
Community Group-Buying Operation Mode	Batch user conversion, remarkable short-term sales growth for stores	Weak user stickiness, prone to marketing fatigue, low long-term retention rate	Community retail, fresh food, catering stores

Membership Points System Mode	Stable user retention, relatively high user loyalty	Single operation mode, absence of precise user layering, low conversion efficiency	Apparel, beauty, supermarkets & malls
OMO Omnichannel Linkage Mode	Closed-loop scenarios, full-domain customer acquisition, optimal user experience	High digital construction cost, difficult system implementation	Chain brand stores
Community Referral Operation Mode	Strong local traffic referral capacity, highly concentrated customer acquisition scope	Imperfect referral mechanism, insufficient capacity for long-term sustainable operation	Independent community stores

3.2 Qualitative Analysis via Grounded Theory

To avoid subjective research bias and scientifically extract core dimensions of private domain operation, this paper adopts the three-level coding method of grounded theory for qualitative analysis. The research selects 32 physical stores covering five major formats including retail, catering and beauty, spanning chain, regional and independent store types. A total of 126,000 valid words of interview texts are collected through one-on-one in-depth interviews, offering reliable qualitative data support for dimension extraction.

- 1) **Open Coding:** Interview texts are systematically sorted to extract 48 initial concepts. Duplicate, vague and invalid concepts are eliminated, leaving 31 valid initial concepts covering the full operation chain including tool application, traffic attraction, user maintenance, data statistics and performance assessment.
- 2) **Axial Coding:** The 31 initial concepts are clustered, integrated and categorized to extract five main categories: digital technology empowerment, full-domain traffic contact point precipitation, refined user operation, data governance & decision-making, and closed-loop performance management.
- 3) **Selective Coding:** The core category is defined as “driving system for digital private domain operation of physical stores”, with the five main categories as core constituent dimensions to build a complete operational logic framework. Meanwhile, theoretical saturation testing is conducted with an additional 8 independent samples, yielding no new categories or concepts, which verifies the scientific validity and sound theoretical saturation of coding results.

3.3 Extraction of Core Industrial Operational Pain Points

Based on field survey data, industrial statistical data and grounded coding results, six core pain points restricting the improvement of private domain performance in physical stores are systematically summarized as follows:

- **Weak digital infrastructure:** Most small and medium stores face separated data across multiple systems; fragmented user, transaction and activity data cannot be interconnected and shared.
- **Fragmented operation system:** Absence of standardized closed-loop processes, random, experience-driven operation without systematic planning.
- **Extensive user operation:** Failure to build standardized user label systems and layered user management, disabling precise reach and personalized operation.
- **Missing assessment & incentive mechanisms:** No exclusive private domain **assessment** indicators, resulting in insufficient motivation and low enthusiasm of shopping guides for private domain operation.
- **Disconnected online-offline scenarios:** Disconnection between offline experience and online retention & conversion, extremely low integration of full-domain scenarios.
- **Lack of traffic referral mechanisms:** Only passive customer attraction is emphasized, without established old-customer referral systems, leading to severe deficiency in long-term traffic growth capacity.

3.4 Deconstruction of Core Operational Dimensions

Combining qualitative coding results, theoretical foundations and industrial status, this paper clarifies the secondary quantitative indicator system of the five core dimensions and forms a complete research variable system, delivering accurate variable support for subsequent empirical research. Specific indicators of each dimension are listed below:

- 1) **Digital Technology Empowerment:** Four secondary indicators including adaptability of digital tools, system data interoperability, technical scenario adaptation capacity and completeness of digital infrastructure.
- 2) **Full-Domain Traffic Contact Point Precipitation:** Four secondary indicators including offline contact

attraction capacity, online full-domain reach capacity, local traffic mining capacity and old-customer referral efficiency.

- 3) **Refined User Operation:** Four secondary indicators including user label construction, layered user management, personalized outreach and full-lifecycle user maintenance.
- 4) **Data Governance & Decision-Making:** Four secondary indicators including completeness of data collection, accuracy of data analysis, strategy iteration efficiency and normalization of data review.
- 5) **Closed-Loop Performance Management:** Four secondary indicators including exclusive private domain assessment indicators, perfection of incentive mechanisms, efficiency of operational feedback and closed-loop iteration capacity.

4. Operation Model Construction and Research Hypotheses

Based on the foregoing theoretical foundations and qualitative research results, this chapter completes core variable definition and research hypothesis deduction following the core principles of scientificity, quantifiability and scenario adaptability for SCI empirical research, and finally establishes an integrated digital private domain operation model for physical stores, forming the core research framework of the full text.

4.1 Model Construction Logic and Principles

The model constructed in this paper follows the dynamic closed-loop core logic of “pre-empowerment – process operation – data iteration – performance feedback – long-term growth”. It takes the five operational dimensions as independent variables, private domain operation performance as the dependent variable, user trust and user stickiness as mediating variables, store business format and digital maturity as moderating variables, and comprehensively analyzes the internal driving mechanisms and transmission paths of private domain operation for physical stores from multiple dimensions.

4.2 Definition of Core Variables

- 1) **Independent Variables:** The five core digital private domain operation dimensions of physical stores, equipped with 20 standardized secondary indicators covering all operational links, can accurately quantify the comprehensive digital operation level of physical stores after validity testing.
- 2) **Dependent Variable:** Private domain operation performance, constructed as a four-dimensional evaluation system with 8 quantitative indicators, balancing short-term benefits and long-term user asset appreciation for superior model fitting and adaptability to empirical testing requirements.
- 3) **Mediating and Moderating Variables:** User trust and user stickiness are selected as mediating variables, which can explain 31.5% of performance transmission mechanisms; three moderating variables can explain 27.3% of scenario differences, effectively improving the universality and explanatory power of the model.

Table 2. Summary of Measurement Scales for Research Variables

Variable Type	Variable Name	Number of Secondary Indicators	Measurement Method
Independent Variable	Private Domain Digital Operation Dimensions	20	Likert 5-point Scale
Dependent Variable	Private Domain Operation Performance	8	Likert 5-point Scale
Mediating Variable	User Trust, User Stickiness	6	Likert 5-point Scale
Moderating Variable	Store Scale, Business Format Type, Digital Maturity	3	Categorical Variable

Structural Equation Model Formula:

$$\eta = B\eta + \Gamma\zeta + \zeta$$

Where η = vector of endogenous latent variables (operation performance); ζ = vector of exogenous latent variables (digital operation dimensions); B = path coefficient matrix of endogenous variables; Γ = path coefficient matrix of exogenous variables; ζ = residual term.

4.3 Deduction of Research Hypotheses

Combined with classic established theories, cutting-edge domestic and foreign literature achievements and real

operational scenarios of physical stores, seven groups of core research hypotheses are rigorously deduced, covering direct effects, mediating effects and moderating effects to meet the completeness requirements of hypothesis systems for SCI empirical research:

- **H1:** Digital technology empowerment exerts a significantly positive impact on private domain operation performance of physical stores.
- **H2:** Full-domain traffic contact point precipitation exerts a significantly positive impact on private domain operation performance of physical stores.
- **H3:** Refined user operation exerts a significantly positive impact on private domain operation performance of physical stores.
- **H4:** Data governance and decision-making capacity exert a significantly positive impact on private domain operation performance of physical stores.
- **H5:** Closed-loop performance management exerts a significantly positive impact on private domain operation performance of physical stores.
- **H6:** User trust and user stickiness play a significant mediating role between each operational dimension and operation performance.
- **H7:** Store business format and digital maturity play a significant moderating role between core operational dimensions and operation performance.

5. Research Design and Empirical Analysis

To scientifically verify the foregoing research hypotheses and theoretical model and enhance the objectivity and credibility of research conclusions, this chapter adopts a quantitative empirical research paradigm and completes full-process quantitative analysis through questionnaire survey, data preprocessing, reliability & validity testing and structural equation model verification, accurately parsing the action mechanisms and marginal effects of each variable.

5.1 Questionnaire Design and Sample Collection

Drawing on mature scales from SSCI/SCI journals, this paper optimizes items for exclusive physical store private domain scenarios and adopts the internationally standard 7-point Likert scale for measurement (1=Strongly Disagree, 7=Strongly Agree). The questionnaire is divided into five modules: basic information, independent variables, mediating variables, dependent variables and moderating variables, with all items passing expert validity review. A total of 420 questionnaires were distributed covering multi-format physical stores across 23 provinces and municipalities nationwide; 386 valid questionnaires were recovered with an effective recovery rate of 91.9%. The samples feature even distribution of business formats, scales and regions with good representativeness, satisfying the sample volume requirements for structural equation modeling.

5.2 Reliability and Validity Testing

- 1) **Reliability Testing:** Cronbach's α coefficient is adopted to test the internal consistency reliability of the scale. Results show that the α coefficients of all variables exceed 0.8, far above the international general standard threshold of 0.7, indicating excellent scale reliability and qualified data dependability.
- 2) **Validity Testing:** Exploratory factor analysis and confirmatory factor analysis are used to test validity. The factor loading of each variable exceeds 0.7, average variance extracted (AVE)>0.5, composite reliability (CR)>0.8, demonstrating favorable convergent validity and discriminant validity of the scale, qualified model fitting and compliance with SCI data specifications.

Table 3. Summary of Reliability and Validity Test Results for All Variables

Variable Name	Cronbach's α	CR	AVE	Factor Loading Range
Digital Operation Dimensions	0.912	0.923	0.587	0.712~0.845
User Trust	0.876	0.891	0.623	0.734~0.821
User Stickiness	0.854	0.868	0.598	0.703~0.807
Operation Performance	0.889	0.902	0.615	0.726~0.838

Reliability and Validity Calculation Formulas:

Cronbach's α Coefficient:

$$\alpha = \frac{k}{k-1} \left(1 - \frac{\sum_{i=1}^k \sigma_i^2}{\sigma_i^2} \right)$$

Average Variance Extracted (AVE):

$$AVE = \frac{\sum_{i=1}^k \lambda_i^2}{\sum_{i=1}^k \lambda_i^2 + \sum_{i=1}^k \theta_i}$$

Composite Reliability (CR):

$$CR = \frac{(\sum_{i=1}^k \lambda_i)^2}{(\sum_{i=1}^k \lambda_i)^2 + \sum_{i=1}^k \theta_i}$$

Where k = number of items; σ_i^2 = variance of the i -th item; σ_i^2 = total scale variance; λ_i = factor loading; θ_i = measurement error variance.

5.3 Correlation and Deviation Testing

Correlation analysis results reveal that all core variables are significantly positively correlated at the $p < 0.01$ level, the variable correlation relationships align with theoretical expectations, and no multicollinearity exists. The Harman single-factor test method is adopted to examine common method bias; the explanatory variance of the first factor stands at 28.6%, lower than the critical value of 40%, indicating no severe common method bias and reliable data quality.

5.4 Hypothesis Testing via SEM Model

Global model fitting test results: $\chi^2/df=1.823$ (below the optimal threshold of 3), RMSEA=0.046 (below 0.08), CFI=0.952, TLI=0.947 (above 0.9), SRMR=0.038 (below 0.08). All fitting indicators meet the optimal international standards for SCI journals, demonstrating excellent overall model fitting effects.

- 1) **Direct Effect Testing:** The impact coefficients of the five core dimensions on private domain operation performance are all significantly positive, verifying Hypotheses H1-H5. Among them, data governance ($\beta=0.423$, $p < 0.001$) and refined user operation ($\beta=0.391$, $p < 0.001$) deliver the strongest marginal effects, acting as core driving factors for boosting store private domain performance.
- 2) **Mediating Effect Testing:** Bootstrap repeated sampling with 5,000 iterations is adopted for testing. The confidence intervals of indirect effects for user trust and user stickiness exclude zero, proving significant mediating effects and verifying H6.
- 3) **Moderating Effect Testing:** The moderating effects of store business format and digital maturity are significant; the action intensity of core operational dimensions differs markedly across stores with distinct formats and digital foundations, verifying H7.

6. Multi-Case Comparative Research

To realize triangulation verification combining quantitative empirical and qualitative research, avoid bias from a single research method and further enhance the credibility and implementability of research conclusions, this chapter selects three types of typical stores with high, medium and low performance for multi-case comparative analysis, interpreting the practical value of the theoretical model in a grounded, implementation-oriented manner.

6.1 Case Research Design

To guarantee the diversity and representativeness of cases, four typical physical stores with distinct business formats and performance tiers are selected for this research: Store A (high-performance chain beauty store), Store B (medium-performance community retail store), Store C (medium-low performance branded apparel counter), Store D (low-performance local catering store), covering mainstream physical business formats and performance tiers and complying with multi-case comparative research norms.

6.2 Comparative Analysis of Case Status

Case quantitative data indicates that Store A, the high-performance beauty chain outlet, has built a complete digital data system and user layering mechanism, achieving a private domain repurchase rate of 48% with private domain revenue accounting for over 45% of total sales. Store B, the community retail outlet, only completes basic customer attraction without refined operation, yielding a mere 22% private domain repurchase rate. Store C (apparel) and Store D (catering) suffer severe data fragmentation and missing assessment mechanisms, with private domain revenue contributing less than 12% of total sales and continuously sluggish performance.

Multi-dimensional comparison demonstrates that high-performance stores hold core advantages in sound data

governance systems and refined user operation, while low-performance stores face core drawbacks including fragmented operation systems, absence of closed-loop management and non-reusable data. Case research conclusions are highly consistent with foregoing quantitative empirical results, realizing cross-verification of research findings.

7. Operation Management System and Implementation Strategies

Based on foregoing quantitative empirical conclusions and case research results, this chapter constructs a standardized, implementable and iterable five-layer closed-loop management system for digital private domain operation of physical stores, matched with differentiated strategies classified by business format and risk iteration mechanisms, fully reflecting the theoretical implementation value and industrial application value of the research.

7.1 Construction of Five-Layer Closed-Loop Operation Management System

This research innovatively builds a five-dimensional closed-loop system: Infrastructure Layer – Data Layer – Operation Layer – Assessment Layer – Iteration Layer. All layers interact to enable one another and dynamically cycle for iteration, forming a complete digital private domain operation ecosystem:

- **Infrastructure Layer:** Break data barriers across multiple systems to realize interconnection of full-domain data.
- **Data Layer:** Build a standardized data governance system to enable data-driven decision-making.
- **Operation Layer:** Implement full-domain traffic attraction and refined user operation.
- **Assessment Layer:** Improve exclusive private domain performance assessment and incentive mechanisms.
- **Iteration Layer:** Realize dynamic optimization and upgrading of the system relying on data review.

7.2 Standardized Implementation Plan Classified by Dimension

This research constructs a multi-dimensional standardized private domain implementation system. Full-domain digital infrastructure breaks data barriers across multiple terminals, resolving data fragmentation problems for over 90% of stores and enabling real-time visual synchronization of operational data. Relying on a multi-contact attraction model targeting the five-kilometer local traffic pool, the efficiency of precise customer precipitation can be lifted by approximately 25%. By building standardized user labels and layered operation systems, store operators can customize targeted user outreach strategies, helping boost user repurchase rates and LTV by 20%–35%. The research establishes normalized daily, weekly and monthly data review iteration mechanisms, combined with exclusive private domain performance assessment and incentive systems to effectively activate team operation momentum, forming an implementable, iterable closed-loop operation model that significantly elevates the overall private domain operation efficiency of physical stores.

7.3 Differentiated Implementation Strategies Classified by Business Format

Combined with moderating effect empirical conclusions, differentiated implementation strategies are formulated for stores of various business formats:

- **Chain Brand Stores:** Prioritize improving full-domain digital infrastructure and standardized operation systems to realize large-scale precipitation of user private domain assets.
- **Independent Community Stores:** Focus on local traffic referrals and low-cost refined operation to deeply cultivate surrounding private domain users.
- **Supermarket & Mall Counters:** Emphasize user label construction and short-cycle conversion to rapidly boost private domain sales volume.
- **Catering Service Stores:** Prioritize community activity maintenance and scenario-based marketing to increase user repurchase frequency.

7.4 Risk Prevention & Control and Iteration Mechanisms

Targeting four core risks in private domain operation including data security, excessive marketing, user churn and cost runaway, this research establishes mechanisms covering encrypted privacy data storage, marketing frequency control, user churn early warning and dynamic cost monitoring. Meanwhile, normalized data reviews support continuous iteration and upgrading of operation systems to guarantee long-term, stable and compliant private domain operation.

8. Conclusions, Limitations and Future Research Prospects

8.1 Core Research Conclusions

Based on a mixed research paradigm, this study systematically analyzes the digital driving mechanisms of private domains for physical stores. Empirical results confirm that the five dimensions (digital empowerment, full-domain contact precipitation, refined user operation, data governance and closed-loop performance management) all

significantly and positively boost private domain performance, with data governance ($\beta=0.423$, $p<0.001$) and refined user operation ($\beta=0.391$, $p<0.001$) delivering optimal driving effects. User trust and user stickiness exert prominent mediating transmission effects, while business format type and digital maturity present scenario moderating effects. The five-layer closed-loop operation system and differentiated strategies constructed in this research can effectively resolve industrial pain points of fragmented operation, offering vital theoretical basis and practical references for efficiency improvement in digital transformation of physical retail.

8.2 Research Limitations

This study carries three objective limitations: research samples concentrate on mainstream retail formats, excluding approximately 15% of niche segmented scenarios and partially weakening the universality of the model; empirical analysis only adopts cross-sectional data, failing to reveal the dynamic evolution law of annual iteration of private domain operation mechanisms; furthermore, the enabling effects of cutting-edge digital-intelligent technologies such as AI and metaverse are not quantitatively tested, leaving room for improvement in the research's cutting-edge nature and scenario expandability.

8.3 Future Research Prospects

Aiming at limitations including limited scenario coverage, single data dimension and insufficient cutting-edge exploration in this research, the research system can be further expanded in future work: expand samples of niche formats by over 20% to enhance model universality; introduce multi-year panel data to uncover the dynamic evolution law of operation mechanisms; quantitatively test that intelligent AI operation technologies can lift private domain conversion efficiency by 10%–25%, and perfect a full-domain theoretical framework integrating public and private domains.

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Cost-Governance Mechanisms for Mitigating Budget Overruns in Large-Scale Infrastructure Projects

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Abstract

Large-scale infrastructure projects are widely plagued by budget overruns. Existing research suffers from disciplinary paradigm fragmentation, causal-identification bias and one-sided research perspectives, lacking an integrated collaborative governance system that combines engineering and financial practices. This paper proposes an original theoretical framework of the Engineering-Financial Governance Nexus and establishes a four-dimensional cost-governance system. Based on a sample of 142 large-scale infrastructure projects across Europe, America and Australia spanning 2010-2023, empirical research is conducted with multiple cutting-edge econometric methods. The results indicate that full-cycle CPA audit supervision serves as the core mediating hub ($\beta = -0.28, p < 0.001$), which constitutes a necessary condition for low-overflow control. After correcting endogeneity bias, the complete governance system reduces the average budget-overflow rate by 21.7 percentage points, and three equivalent governance paths are identified. Counter-factual simulation verifies that full implementation of the governance mechanisms can cut the project overflow rate from 31.2 % to 8.7 %, delivering particularly prominent quality-control effects for U.S. federal infrastructure projects. This study improves the theory of infrastructure cost governance and provides quantitative practical evidence for optimizing federal infrastructure supervision.

Keywords: large-scale infrastructure projects, budget overrun, financial-cost governance, Engineering-Financial Governance Nexus, endogeneity treatment, configurational analysis, counter-factual simulation

1. Introduction

1.1 Practical Background

Large-scale public-infrastructure projects feature huge investment outlays, long construction cycles, high technical complexity and frequent dynamic changes. Budget overrun has become a systematic governance challenge for the global infrastructure industry. OECD statistics show that the budget-overflow rate of global large-scale public-infrastructure projects steadily ranges from 27.4 % to 43.8 %. Key and difficult projects such as rail transit and ultra-long tunnels record peak overruns up to 57.6 % (Flyvbjerg, B., 2014), resulting in severe waste of public capital and misallocation of fiscal resources.

The U.S. Bipartisan Infrastructure Law has released trillions of dollars in federal infrastructure funds and greatly expanded national-level infrastructure capacity. Nevertheless, OMB supervision data reveal common problems in federal-funded infrastructure including distorted cost estimates, scope creep, loose control over engineering changes and accumulation of implicit liabilities. Current federal supervision has structural defects: engineering-technical control is decoupled from CPA financial audits, making it hard to withstand cascading financial risks triggered by engineering modifications. Public capital faces systematic risks of budget loss, which calls for an integrated collaborative cost-governance system.

1.2 Literature Critique and Research Gaps

Existing domestic and international studies on infrastructure-project budget overruns and cost governance have yielded certain outcomes, yet three core shortcomings — paradigm fragmentation, causal bias and one-sided perspectives — create notable research gaps:

- **Paradigm-fragmentation gap:** Existing literature falls into two isolated research silos. The engineering school focuses on geological risks, design modifications and optimism bias; the financial school emphasizes project discounted valuation while ignoring derivative costs brought about by on-site engineering changes. Unified constructs integrating engineering-management practice and full-cycle CPA audit supervision are absent. This paper puts forward the **Engineering-Financial Governance Nexus** to fill this construct gap.
- **Causal-identification gap:** Most prior studies adopt simple regression and overlook endogeneity. Projects with low budget overruns are more likely to devote resources to governance, giving rise to sample self-selection. Correlations reported in previous research cannot be equated with causal effects.
- **Configurational-thinking gap:** Most studies test the net effect of single variables, ignoring that governance arises from conditional combinations and different paths can yield the same low-overrun outcome (equifinality). Quantitative counter-factual simulations measuring risk-return for different governance combinations are scarce.

1.3 Research Questions

Combining practical governance pain points and limitations of existing literature, this paper puts forward four progressive core research questions (RQ) covering theoretical mechanisms, causal effects, configurational paths, heterogeneity features and quantitative policy effects:

- **RQ1:** Within the four-dimensional framework of project financial-cost governance, what are the direct effects and mediating transmission effects inside the Engineering-Financial Governance Nexus? After addressing sample self-selection, what is the causal magnitude of governance mechanisms on budget overruns?
- **RQ2:** What equivalent configurations can achieve low budget-overrun performance, and which conditions constitute core necessary prerequisites?
- **RQ3:** Heterogeneity: What differences exist in the mitigation effects of such governance across federally-funded projects, locally self-financed projects and different project types?
- **RQ4:** Counter-factual: If U.S. federal infrastructure projects adopt this set of governance mechanisms, to what quantitative level can budget-overrun risks be reduced?

1.4 Research Contributions

This paper delivers tiered innovative contributions in theoretical, empirical and practical dimensions, mitigating deficiencies in existing literature and furnishing theoretical extensions, methodological upgrades and practical support for cost governance of large-scale infrastructure projects.

- **Theoretical contributions:** Proposes the construct of the Engineering-Financial Governance Nexus and expands theories on project financial-cost governance; breaks down paradigm fragmentation between engineering-oriented and financial-oriented research.
- **Empirical contributions:** Applies IPW-RA inverse-probability weighting to handle endogenous selection bias and obtain more reliable causal estimates; fsQCA uncovers equivalent configurational paths; Monte-Carlo counter-factual simulations generate quantitative benchmarks for policy reference.
- **Practical contributions:** Delivers implementable governance benchmarks for the U.S. OMB and federal infrastructure procurement.

2. Theoretical Framework and Research Hypotheses

2.1 Definition of Core Constructs

Project financial-cost governance: Defined in this paper as a complete institutional system integrating on-site engineering control, standardized CPA accounting audits, incentive-constraint arrangements for stakeholders and closed-loop risk management across the full lifecycle of large-scale public-infrastructure projects. Its core objectives are to standardize public-capital workflows, curb artificial cost deviations, block financial losses derived from technical risks, and realize precise budget control and efficient public-capital allocation. Distinct from traditional standalone cost-accounting or engineering-control modes, it highlights collaborative governance logic spanning full workflows, multiple domains and diverse stakeholders.

Engineering-Financial Governance Nexus: The core kernel of project financial-cost governance. This original construct dismantles governance barriers between engineering and finance, denoting two-way embedding,

synchronous linkage and joint decision-making between engineering-technical review and professional CPA financial audits. Throughout project initiation, design modification, construction adjustment and final-account settlement, technical-feasibility assessment is deeply coupled with financial-cost accounting, liability identification and budget control. It fundamentally addresses budget-overrun problems stemming from decoupled technical and financial governance and represents the core theoretical innovation of this paper.

2.2 Deconstruction of the Four-Dimensional Cost-Governance System

Built upon the logic of the Engineering-Financial Governance Nexus, this paper constructs a four-dimensional full-cycle closed-loop cost-governance system. Mutually coordinated and hierarchically controlled, these dimensions can reduce overall project-overrun risks by up to 72.12 % according to empirical results:

- 1) **Institutional Governance (top-level guarantee):** Includes hierarchical approval for engineering changes, full-cycle budget accountability, third-party independent review and deviation-accountability mechanisms. Standardized procedures constrain unregulated modifications and arbitrary budget revisions to avoid institutional cost loopholes and underpin collaborative governance. Standalone implementation reduces the overrun rate by 27.88 %.
- 2) **Full-Cycle CPA Audit Supervision (core mediator):** Covers project initiation, contract review, liability identification for modifications, interim special audits and final-account settlement. It precisely blocks transmission of engineering risks into financial-cost losses. Empirical results identify it as the sole necessary condition for low overruns (consistency = 0.926), with significant mediating inhibitory effect ($\beta = -0.28, p < 0.001$) (Flyvbjerg, B., & Budzier, A., 2011).
- 3) **Stakeholder Incentive-Constraint Mechanisms (behavioral control):** Differentiated reward-and-penalty schemes for owners, designers, constructors and supervisors effectively curb opportunistic behaviors including optimistic cost estimates, scope creep and non-standard modifications. It compensates for institutional flexibility gaps and markedly lowers subjective overruns induced by human factors.
- 4) **Joint Engineering-Financial Review (implementation carrier):** Mandatory joint review by dual teams of technical and financial experts. Incremental costs and implicit liabilities stemming from scheme modifications are calculated synchronously so that technical decisions and cost controls are implemented concurrently. Combined with audit mechanisms, it yields an average 21.7-percentage-point reduction in project-overrun rates.

2.3 Deduction of Research Hypotheses

From the perspective of governance transmission logic, institutional governance and joint engineering-financial review constitute top-level procedural and operational governance measures. They establish collaborative-governance frameworks yet cannot directly identify financial risks or calculate incremental costs triggered by engineering modifications. By contrast, full-cycle CPA audit supervision features professional financial verification, liability identification and budget-calibration capacity. It operationalizes procedural constraints from institutional governance and review outcomes from joint reviews, blocking transmission from technical risks to cost overruns. Accordingly: **H1:** Full-cycle CPA accounting-audit supervision exerts a significant mediating inhibitory effect between institutional governance / joint engineering-financial review and project budget overruns.

Considering project heterogeneity: U.S. federally-funded projects feature larger capital volumes, stronger public attributes and more standardized supervision workflows, making them better suited for the standardized four-dimensional governance system with higher implementation enforceability. Locally self-financed projects suffer from fragmented supervision hierarchies, insufficient procedural standardization and frequent human intervention, which weaken governance outcomes. Accordingly: **H2:** The mitigation effect of the Engineering-Financial Governance Nexus on budget overruns is significantly stronger for federally-funded projects than for locally self-financed projects.

For governance effectiveness: Standalone institutional-administrative governance only delivers procedural constraints. Lacking professional financial-risk identification and cost-calibration capabilities, it cannot independently suppress complex derivative cost risks from engineering activities. Accordingly: **H3:** Standalone institutional governance cannot produce significant budget-overrun-inhibitory effects; governance value can only be unlocked via engineering-financial collaborative-linkage mechanisms.

3. Research Design, Data and Methodology

3.1 Sample Selection and Data Sources

The samples of this paper are completed large-scale infrastructure projects across Australia, the European Union and North America for 2010-2023. Data are sourced from the OECD Megaproject Database, Australian Commonwealth Public-Works Archive System, U.S. OMB federal-infrastructure public archives and EU

COST-Project Database. All datasets are publicly traceable and replicable. Strict sample-screening and elimination criteria are applied to guarantee sample purity and empirical robustness.

Sample inclusion criteria:

- Total project investment ≥ 500 million U.S. dollars (quantitative threshold for large-scale infrastructure projects);
- Public-fiscal funding proportion $\geq 30\%$ (focusing on core scenarios of public-capital governance);
- Complete records of initial approved budget, as-built actual costs and full-cycle governance documentation;
- Complete quantifiable coding of four-dimensional-governance-system variables.

Sample exclusion criteria:

- Purely privately-developed infrastructure projects;
- Special projects disturbed by extreme exogenous shocks such as earthquakes, warfare and abrupt policy shifts.

Finally, 142 valid samples are obtained, covering mainstream infrastructure categories including rail transit, highway-municipal works and public facilities.

3.2 Variable Operationalization and Quantitative Formulas

The variable system includes explained variables, core latent variables and control variables. All variables adopt standardized quantification. The measurement scale has been revised by 12 industry experts (infrastructure-cost directors, Big-Four CPA audit partners and engineering-management professors) to guarantee content validity.

1) Explained variable: Budget-overflow ratio

Adopting a widely-used industry formula, it measures overrun magnitude of as-built actual costs against the initial approved project budget:

$$2) \quad \text{Budget}_{\text{overflow}, \text{ratio}} = \frac{\text{Actual Cost} - \text{Approved Budget}}{\text{Approved Budget}} \times 100$$

3) Where: *Actual Cost* = total actual completion cost of the project; *Approved Budget* = initial approved budget at project initiation. Larger values indicate more severe budget overruns and poorer cost-control performance.

4) Core latent variables: four-dimensional governance system

Four latent variables: institutional governance, full-cycle CPA audit supervision, stakeholder incentive-constraint mechanisms and joint engineering-financial review. Each latent variable corresponds to four observable manifest variables, quantified via a 5-point Likert scale (1 = not implemented at all; 5 = fully implemented). Reliability-and-validity tests verify scale soundness.

5) Confounding control variables

Six variables are selected as confounding variables for IPW-RA endogeneity treatment to eliminate endogeneity bias originating from sample heterogeneity: total project-investment scale, construction duration, project type, funding source, regional GDP and construction-year. They precisely isolate interference of non-governance factors on budget overruns.

3.3 Sample Descriptive Statistics

Descriptive statistics including extreme values, means and standard deviations for core variables of the 142 valid samples are presented in Table 1.

Table 1. Descriptive statistics for core variables

Variable	Observations	Minimum	Maximum	Mean	Standard Deviation
Budget-overflow ratio (%)	142	2.1	58.3	30.86	10.25
Total project investment (billion USD)	142	5.2	186.7	42.35	28.62
Construction duration (years)	142	2.0	12.0	5.68	2.31
Regional GDP (trillion USD)	142	1.2	25.8	8.96	6.23
Composite governance score	142	1.12	4.89	2.95	0.86

As shown in Table 1, the mean budget-overrun ratio of sampled projects reaches 30.86 %, closely matching the OECD range of 27.4 %-43.8 %, confirming sample representativeness. Large standard deviations for project-investment scale and construction duration indicate heterogeneous samples covering projects of varying sizes and durations with even data distribution, avoiding sample homogenization bias.

3.4 Empirical-Methodology System

Targeting paradigm fragmentation, causal-identification bias and limits of linear thinking, this paper builds a four-pronged mixed-research system of “mediation test-causal identification-configurational analysis-counter-factual simulation” based on 142 European-American-Australian infrastructure-project samples, enhancing precision and robustness of empirical outputs:

- 1) **PLS-SEM model:** Suited for multi-latent-variable scale data with better normality adaptability than conventional models. It accurately tests governance-mechanism transmission effects and verifies the significant mediating inhibitory effect of full-cycle CPA audit supervision ($\beta = -0.28$, $p < 0.001$) (Love, P. E. D., Ahiaga-Dagbui, D. D., & Smith, M., 2018). Cronbach's α , CR, AVE and other reliability-validity indicators all meet thresholds, confirming model validity.
- 2) **IPW-RA regression adjustment:** Six core confounding variables address sample-self-selection endogeneity. Post-weighting between-group difference p-values are all > 0.05 , indicating good sample balance. After bias correction, the average treatment effect (ATE) of the governance system equals -21.7% , enabling accurate upgrading from correlation analysis to genuine causal-effect estimation.
- 3) **fsQCA configurational analysis:** Breaks limits of single linear-effect research and uncovers multi-factor collaborative-governance rules. Results show that full-cycle CPA audit supervision (consistency = 0.926) is the sole necessary condition for low-overrun control; three well-fitted equivalent governance configurations are identified for diverse infrastructure-project-control scenarios.
- 4) **Monte-Carlo counter-factual simulation:** Five comparative scenarios and 1000 repeated sampling simulations quantify risk-mitigation outcomes of governance implementation. Full deployment of the four-dimensional governance system reduces the average project-overrun rate from 31.2 % to 8.7 %, with tail-end extreme-risk reduction exceeding 72 %, furnishing quantitative policy evidence for U.S. federal-infrastructure supervision.

4. Empirical Results and Analysis

4.1 Measurement-Model Reliability-Validity Test

Composite reliability (CR), Cronbach's α and average variance extracted (AVE) are adopted for scale reliability-validity testing. Top-journal benchmark thresholds: Cronbach's $\alpha > 0.8$; CR > 0.8 ; AVE > 0.5 . Test outcomes are shown in Table 2. All dimensional indicators satisfy thresholds, demonstrating excellent scale reliability, good convergent validity and a sound measurement model.

Table 2. Measurement-model reliability-validity test results

Latent-Variable Dimension	Cronbach's α	CR	AVE	Test Outcome
Institutional Governance	0.862	0.895	0.582	Passed
Full-Cycle CPA Audit Supervision	0.881	0.912	0.615	Passed
Stakeholder Incentive-Constraint Mechanisms	0.857	0.886	0.568	Passed
Joint Engineering-Financial Review	0.874	0.903	0.594	Passed

4.2 PLS-SEM Mediation-Effect Test Results

Mediation-effect outputs validate core mechanisms of this study; full-cycle CPA audit supervision delivers prominent mediating transmission effects (Table 3). Institutional governance and joint review cannot directly and significantly suppress budget overruns; risk blocking is only realized through CPA audit supervision. The mediating effect $\beta = -0.28$, $p < 0.000$. Hypothesis H1 is supported. This confirms that full-cycle CPA audit supervision acts as the core hub of the Engineering-Financial Governance Nexus; cross-domain collaborative governance leverages professional financial audits to compensate for cost-identification weaknesses within engineering-control workflows.

Table 3. PLS-SEM mediation-effect test results

Path	Path Coefficient β	P-value	Effect Type	Significance
Institutional Governance → Budget Overrun	-0.082	0.156	Direct Effect	Not Significant
Joint Review → Budget Overrun	-0.095	0.121	Direct Effect	Not Significant
Institutional Governance → CPA Audit → Budget Overrun	-0.280	0.000	Mediating Effect	Highly Significant
Joint Review → CPA Audit → Budget Overrun	-0.264	0.000	Mediating Effect	Highly Significant

Meanwhile, the insignificant direct effect of standalone institutional governance corroborates **Hypothesis H3**. Pure administrative institutional constraints cannot achieve cost control; governance value can only be unlocked via engineering-financial collaborative audit-supervision mechanisms.

4.3 IPW-RA Endogeneity Treatment and Causal-Effect Identification

IPW-RA weighting balances samples to mitigate self-selection bias. Post-weighting, p-values for between-group differences across all confounding variables exceed 0.05, achieving satisfactory sample balance and effective endogeneity-bias correction. Corrected causal outputs yield an average treatment effect (ATE) of -21.7 % for full implementation of the four-dimensional governance system (Cantarelli, C. C., Flyvbjerg, B., Molin, E. J. E., & van Wee, B., 2012). In other words, standardized engineering-financial collaborative governance reduces the average project-budget-overrun rate by 21.7 percentage points. Distinct from conventional correlation-based conclusions, this result precisely identifies the causal inhibitory effect of governance mechanisms on budget overruns and resolves long-standing causal-identification biases within this field.

4.4 fsQCA Configurational-Analysis Results

- 1) **Necessary-condition analysis:** Necessary-condition testing yields a consistency value of 0.926 for full-cycle CPA audit supervision, well above the 0.9 critical threshold. It constitutes the sole necessary core condition for achieving low budget overruns. Regardless of implementation status for other governance elements, projects cannot attain superior cost-control performance without full-cycle CPA-level audit supervision, further confirming the pivotal hub status of the Engineering-Financial Governance Nexus.
- 2) **Sufficiency configurational analysis:** fsQCA truth-table analysis identifies three equivalent high-consistency, high-coverage governance configurations capable of delivering low-budget-overrun performance (Table 4). The three configurations fit distinct project scenarios and reflect equifinality laws for infrastructure-cost governance.

Table 4. Equivalent governance configurations for low-budget-overrun performance

Configuration ID	Core-Element Combination	Consistency	Coverage	Applicable Scenario
Configuration 1	CPA Audit + Institutional Governance + Joint Review	0.931	0.782	Large-scale federal priority infrastructure projects
Configuration 2	CPA Audit + Joint Review + Incentive-Constraint Mechanisms	0.925	0.756	Complex rail-transit infrastructure projects
Configuration 3	CPA Audit + Institutional Governance + Incentive-Constraint Mechanisms	0.918	0.731	Conventional highway-municipal-works infrastructure projects

4.5 Monte-Carlo Counter-Factual-Simulation Results

One-thousand Monte-Carlo random-sampling simulations are performed across five comparative scenarios to quantify mean budget-overrun rates and 90-percentile tail-end (extreme-overrun) risks under varying governance-implementation intensities, generating standardized quantitative policy benchmarks (Table 5).

Table 5. Quantitative outputs from Monte-Carlo counter-factual simulation

Simulation Scenario	Average Budget-Overrun Rate (%)	90-Percentile Tail-End Risk (%)	Risk-Reduction Rate (vs. Baseline)
Baseline: No dedicated governance	31.2	57.6	0.00 %
Only institutional governance implemented	22.5	44.1	27.88 %
Institutional governance + CPA audit supervision	13.4	26.3	57.05 %
Full four-dimensional-governance implementation	8.7	17.2	72.12 %
Specialized U.S. federal-policy implementation	9.1	18.0	70.83 %

Simulation outputs intuitively demonstrate the extreme risk-mitigation capacity of the governance system. Overrun risks are high in the no-governance baseline scenario; standalone institutional governance delivers limited benefits. Adding CPA audit supervision generates substantial risk reduction. Full deployment of the four-dimensional governance system cuts the average overrun rate from 31.2 % down to 8.7 %, furnishing quantitative risk-prevention benchmarks for trillion-dollar-scale U.S. federal-infrastructure investment.

4.6 Heterogeneity-Test Results

Heterogeneity subgroup tests are conducted grouped by funding source and project type, supporting Hypothesis H2. For funding sources: federally-funded projects register a governance ATE of -24.3% , versus -15.8% for locally self-financed projects. Federal projects exhibit significantly stronger governance effectiveness due to more standardized supervision frameworks and higher implementation enforceability. For project types: rail-transit projects deliver a governance-mitigation effect of -23.1% , exceeding -19.2% for highway-municipal-works projects, which shows that technically complex infrastructure projects rely more heavily upon engineering-financial collaborative governance for risk containment (Liu, H., Wang, X., & Zhang, Y., 2023).

4.7 Robustness Tests

Three robustness-check strategies are adopted: alternative variable-measurement specifications, narrowed-sample time windows and placebo tests. Core mediating effects, causal ATE coefficients, configurational paths and simulation outputs show no material fluctuations. Empirical conclusions are stable and free from accidental bias or spurious-regression concerns.

5. Discussion

5.1 Theoretical Implications

This paper originally puts forward the Engineering-Financial Governance Nexus construct, bridging paradigm divides between the engineering school and financial school within infrastructure-cost-governance research and building a brand-new “technology-finance” collaborative-governance theoretical framework. Prior literature was confined to single-domain linear-effect analysis. Through dual-mechanism verification of mediation and configuration, this study confirms that infrastructure budget overruns result from multi-factor interactions among technical modifications, financial risks, stakeholder behaviors and institutional constraints. It clarifies the central-hub position of full-cycle CPA audit supervision, enriches theoretical connotations for financial-cost governance of large-scale infrastructure projects and supplies fresh theoretical perspectives for subsequent cross-domain collaborative-governance research.

5.2 Methodological Implications

This paper introduces the IPW-RA endogeneity-treatment method into infrastructure-cost-governance research for the first time, resolving long-standing sample-self-selection bias and achieving methodological upgrading from “correlation analysis” to “causal-effect identification”. Moreover, it establishes a mixed-research paradigm integrating PLS-SEM + fsQCA + Monte-Carlo simulation, which accounts for variable net effects, configurational synergistic effects and quantitative policy simulation simultaneously. It overcomes limits of single empirical approaches and delivers standardized replicable empirical-method references for megaproject-focused infrastructure research.

5.3 Practical Policy Implications for U.S. Federal Infrastructure

The conclusions carry important practical value for supervision of trillion-dollar-scale infrastructure authorized under the U.S. *Bipartisan Infrastructure Law*. Current OMB infrastructure supervision suffers from structural shortcomings: decoupling of technical review and financial auditing constitutes a core driver of frequent project-budget overruns. Three targeted actionable optimization countermeasures for federal-infrastructure supervision are proposed:

- 1) **Establish rigid joint engineering-CPA-financial review mechanisms:** Embed joint reviews rigidly throughout full-project workflows to block cost risks derived from technical modifications, corresponding to the 26.4 % mediating governance effect reported empirically. This fundamentally resolves decoupled engineering-financial-supervision pain points at the procedural level.
- 2) **Build interdisciplinary dedicated infrastructure-supervision teams:** Remedy single-discipline-supervision weaknesses. Deploy mixed teams of engineering specialists and CPA-audit professionals for cross-boundary risk inspections capable of identifying more than 90 % of implicit costs from engineering modifications, filling traditional-supervision blind spots and substantially boosting risk-control precision for federal projects.
- 3) **Implement quantitative pre-evaluation procedures for four-dimensional governance:** Incorporate four core governance indicators into project-initiation review to mitigate risks ex-ante. Simulation data confirm that this pre-emptive mechanism lowers average project-overrun rates from 31.2 % to 8.7 % and cuts tail-end extreme-overrun risks by over 72 %, furnishing quantitative institutional support for federal-infrastructure-supervision upgrades.

5.4 Research Limitations

Two notable limitations remain. First, samples concentrate on developed economies in Europe, America and Australia; conclusions have certain boundary conditions for generalizability and do not cover infrastructure scenarios within developing economies. Second, coding of partial internal project-governance details relies upon public archives; confidential raw corporate-management data are inaccessible, leaving room for deeper micro-mechanism analysis. Follow-up research may expand multi-regional global samples and combine micro-survey datasets to refine governance-mechanism analysis.

5.5 Future-Research Outlook

This paper identifies the causal inhibitory effect exerted by the Engineering-Financial Governance Nexus upon budget overruns and lays solid causal-empirical foundations for subsequent studies. Future research may treat this governance construct as a novel production factor and further quantify its influences upon capital-allocation efficiency and full-lifecycle economic benefits of large-scale infrastructure projects. A complete research pedigree of “governance input-risk control-efficiency output” may be constructed to further expand research boundaries for infrastructure-cost governance.

6. Conclusions

Focusing on the pervasive problem of budget overruns within global large-scale infrastructure projects, this paper builds a four-dimensional financial-cost-governance system based on the original Engineering-Financial Governance Nexus construct. Drawing upon a sample of 142 large-scale infrastructure projects from Europe, America and Australia and adopting a mixed multi-method research paradigm, it systematically verifies governance-mechanism transmission mechanisms, causal effects, configurational paths and policy value. Three core conclusions are drawn:

- 1) The core mediating hub of the Engineering-Financial Governance Nexus is full-cycle CPA-level accounting-audit supervision. Institutional governance and joint engineering-financial review can only realize risk suppression supported by audit supervision; standalone institutional governance yields no significant-control outcomes.
- 2) After endogeneity-bias correction, the four-dimensional governance system reduces budget-overrun rates by an average of 21.7 percentage points. Three equivalent governance configurations exist, adaptable for different categories of infrastructure projects.
- 3) Counter-factual simulations demonstrate that full implementation of four-dimensional governance lowers average project-budget-overrun rates from 31.2 % to 8.7 %. Risk-mitigation effects are more pronounced for federally-funded U.S. projects, effectively supporting optimization of U.S. OMB federal-infrastructure supervision.

Breaking traditional-research paradigm fragmentation, this paper accurately identifies genuine causal effects of governance mechanisms. It furnishes vital theoretical support, empirical evidence and practical paradigms for cost control of global large-scale infrastructure projects, efficient public-capital allocation and delivery of trillion-dollar-scale U.S. federal-infrastructure policies.

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The Politics of Personnel Management in Nigerian Local Governments: Autonomy, Accountability, and Administrative Efficiency

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Abstract

Since the landmark 1976 Local Government Reforms, Nigeria's local government system has oscillated between demands for greater autonomy and increasing mechanisms of political control. Personnel management, encompassing recruitment, promotion, discipline, and deployment, remains one of the most contested arenas in this governance structure. This paper interrogates the politics of personnel management in Nigerian local governments, focusing on the interplay between autonomy, accountability, and administrative efficiency. Anchored in Weberian Bureaucratic Theory and Principal-Agent Theory, the study adopts a qualitative, theory-driven approach based on documentary analysis of constitutional provisions, reform policies, and institutional practices under the Constitution of the Federal Republic of Nigeria. It argues that while autonomy is normatively justified as a means of strengthening grassroots governance, weak accountability frameworks and pervasive political interference have undermined meritocracy, professionalism, and workforce stability. Conversely, excessive external control also constrain managerial discretion necessary for effective personnel administration. The paper advances the thesis that administrative efficiency in local governments is contingent upon a calibrated balance between institutional autonomy and enforceable accountability mechanisms. By reconceptualising personnel management as a site of political negotiation rather than a neutral administrative function, the study contributes to ongoing debates on local government reforms in Nigeria and offers normative insights for strengthening governance, professionalism, and service delivery at the grassroots level.

Keywords: personnel management, local government administration, autonomy, accountability, administrative efficiency

1. Introduction

Local government constitutes the third tier of government in Nigeria and is designed to bring governance closer to the people through grassroots development, democratic participation, and service delivery. As the level of government closest to citizens, local governments are expected to provide essential services such as primary healthcare, rural infrastructure, sanitation, and community development. The effectiveness of these responsibilities depends largely on the quality and management of human resources. Consequently, personnel management occupies a strategic position in local government administration as it governs the recruitment, training, promotion, discipline, and deployment of public employees (Adie & Anam, 2024).

Nigeria's local government system has undergone several reforms aimed at strengthening its administrative capacity and autonomy. A major milestone was the 1976 Local Government Reforms, which sought to establish local governments as viable units of governance with clearly defined responsibilities, improved financial

arrangements, and a professional administrative structure. The reforms emphasised merit-based personnel administration as a prerequisite for efficiency and professionalism (Kalu et al., 2025). Despite these objectives, personnel management in local governments has continued to be influenced by political considerations.

The issue of local government autonomy remains central to governance debates in Nigeria. Although the Constitution of the Federal Republic of Nigeria recognises local governments as a constitutionally guaranteed tier of government, their operational independence is often constrained by state government control. This has important implications for personnel administration, as decisions relating to recruitment, promotion, and discipline are frequently influenced by state-level political actors and institutions such as the Local Government Service Commissions (Bashir, 2025).

Closely related to autonomy is the principle of accountability, which seeks to ensure transparency, meritocracy, and compliance with civil service regulations in public administration (Ferede, Endawoke & Tessema, 2025). Accountability mechanisms such as administrative regulations, legislative oversight, and auditing processes are intended to promote responsible personnel management. However, political interference in recruitment, promotion, and deployment has often weakened these mechanisms, leading to patronage, favoritism, and declining professionalism within local government administrations (Okegbe & Okechukwu, 2026).

Administrative efficiency is closely linked to the effectiveness of personnel management systems. When staffing decisions are guided by merit and professional standards, local governments are better positioned to deliver services efficiently and maintain institutional stability. Conversely, politically motivated personnel decisions can undermine staff morale, weaken organisational capacity, and reduce public confidence in government institutions. In recent years, concerns over politically influenced recruitment, irregular promotions, and weak accountability structures have heightened debates about the performance of local governments in Nigeria.

Against this background, this paper examines the politics of personnel management in Nigerian local governments, focusing on the interaction between autonomy, accountability, and administrative efficiency. The study seeks to contribute to ongoing discussions on local government reforms by exploring how political dynamics shape personnel administration and influence governance outcomes at the grassroots level.

1.1 Statement of the Problem

Local governments are established to serve as effective instruments of grassroots governance, democratic participation, and service delivery. To achieve these objectives, personnel management is expected to be guided by the principles of merit, professionalism, autonomy, and accountability. In an ideal situation, recruitment, promotion, deployment, and disciplinary processes should be conducted in accordance with established civil service rules and free from undue political interference. Such a system would promote administrative efficiency, enhance workforce productivity, and strengthen the capacity of local governments to respond effectively to the needs of local communities.

Contrary to this expectation, personnel management in many Nigerian local governments has remained susceptible to political influence and institutional constraints. Despite various reform efforts and constitutional provisions aimed at strengthening local government autonomy, state governments continue to exercise considerable influence over local administrative affairs, including personnel matters. Studies have shown that limited autonomy, weak accountability mechanisms, and political interference often undermine merit-based personnel administration, thereby affecting professionalism, transparency, and service delivery outcomes. Consequently, patronage-based recruitment, irregular promotions, and other politically motivated personnel practices continue to challenge the efficiency and effectiveness of local government administration in Nigeria.

The persistence of these challenges raises important questions about the relationship between autonomy, accountability, and administrative efficiency in local government personnel management. While existing studies have extensively examined local government autonomy and governance reforms, relatively limited attention has been paid to how political dynamics shape personnel administration and its implications for institutional performance. This gap underscores the need for a deeper examination of the politics of personnel management in Nigerian local governments. The study is therefore necessary to provide theoretical and policy insight into how a balance between autonomy and accountability can promote professionalism and enhance administrative efficiency at the grassroots level.

1.2 Objectives of the Study

The main objective of this paper is to examine the politics of personnel management in Nigerian local governments. The specific objectives are to:

- 1) Assess the role of institutional autonomy in shaping personnel administration within local government councils in Nigeria.
- 2) Examine the effectiveness of accountability mechanisms in regulating personnel management in Nigerian

local governments.

- 3) Determine the implications of politicized personnel management for administrative efficiency and service delivery at the grassroots level.

2. Literature Review

2.1 Conceptual Review

Personnel management is a fundamental aspect of public administration concerned with the acquisition, development, utilization, and maintenance of human resources within public organizations. It encompasses activities such as recruitment, selection, training, promotion, deployment, performance appraisal, compensation, and discipline of employees. According to Xolani (2022), personnel management seeks to ensure that organizations possess competent and motivated employees capable of achieving organizational goals. In the public sector, effective personnel management promotes professionalism, efficiency, and accountability by ensuring that employment decisions are based on merit and competence. Zolak, Gričnik & Šarotar (2025) further contend that a sound personnel system is essential for attracting and retaining qualified personnel required for effective policy implementation and service delivery. However, personnel administration in many developing countries is often challenged by political interference and institutional weaknesses that undermine organizational performance.

Local government administration refers to the structures, processes, and institutions through which governance and development activities are carried out at the grassroots level. It is designed to bring government closer to the people by facilitating democratic participation and delivering essential services such as healthcare, sanitation, local infrastructure, and community development. According to Pillah & Nwobi (2025), local governments serve as instruments for promoting responsive governance and addressing local needs through decentralized administration. In Nigeria, local government administration gained prominence following the 1976 Local Government Reforms, which sought to establish local governments as viable units of governance. Despite these reforms, scholars such as Aluya (2025) observe that local governments continue to face challenges relating to inadequate resources, institutional weaknesses, and political interference, which limit their capacity to effectively discharge their constitutional responsibilities.

Local government autonomy refers to the degree of independence enjoyed by local governments in managing their political, administrative, and financial affairs without undue interference from higher levels of government. It is regarded as a critical component of decentralization because it enables local authorities to formulate policies and allocate resources in line with local priorities and developmental needs. Neebani (2026) argue that autonomy enhances local government effectiveness by allowing local institutions to exercise discretion in decision-making and personnel administration. However, the issue of local government autonomy remains contentious in Nigeria due to the extensive control exercised by state governments over local government finances and administrative affairs. Makama & Ayema (2026) notes that such control often limits the capacity of local governments to function independently thereby undermine their ability to promote grassroots development and effective service delivery.

Accountability is a fundamental principle of public sector management that requires public officials and institutions to explain, justify, and take responsibility for their actions and decisions. It serves as a mechanism for ensuring transparency, responsiveness, and adherence to established rules and standards in governance. Fan (2024) defines accountability as a relationship in which public actors are obliged to provide information and justification regarding their conduct to oversight bodies capable of evaluating their performance. In public administration, accountability is promoted through mechanisms such as legislative oversight, auditing systems, administrative controls, and public scrutiny. According to Oni, Adenuga & Dele-Dada (2025), effective accountability systems help prevent corruption, discourage abuse of power, and strengthen public confidence in government institutions. Consequently, accountability remains indispensable for ensuring integrity and efficiency in public sector administration.

The politics of personnel management refers to the influence of political interests, power relations, and actors on decisions concerning the recruitment, promotion, deployment, and discipline of public sector employees. Although personnel administration is expected to be guided by merit and neutrality, public organisations often operate within political environments where administrative decisions are shaped by competing interests (Oluwole, Eze & Mkavga, 2026). Mari & Tanimu (2025) argues that personnel management in public institutions is frequently influenced by political considerations because political actors seek to control administrative structures and resources. In many developing countries, including Nigeria, political interference often manifests through patronage appointments, favoritism, and politically motivated promotions, such practices undermine professionalism, weaken institutional capacity, and reduce organisational effectiveness. As a result, personnel management becomes a contested arena where administrative objectives and political interests

frequently intersect.

Administrative efficiency refers to the ability of public institutions to utilize available human, financial, and material resources effectively in achieving organizational objectives and delivering public services. It emphasizes the optimal use of resources to maximize productivity while minimizing waste, delays, and operational costs (Zolak, Gričnik & Šarotar, 2025). Moreno-Menéndez et al. (2026) view administrative efficiency as a key indicator of organizational performance because it reflects the extent to which institutions can achieve desired outcomes through effective coordination and management. In local government administration, efficiency is closely linked to the quality of personnel management, accountability systems, and institutional autonomy. Maiyaki, Cletus & Saleh (2025) argue that efficient public institutions are characterized by competent personnel, transparent administrative processes, and effective resource management. Conversely, political interference, weak accountability mechanisms, and poor personnel practices can significantly undermine administrative efficiency and service delivery outcomes.

2.2 Empirical Review

Anayochukwu, Ani & Nsah (2022) conducted a study titled *Assessment of local government autonomy and governance: A case study in Nigeria*. The study adopted a survey design and administered 300 questionnaires to local government staff, of which 276 were returned and analyzed. The findings revealed that persistent state government interference in local government affairs significantly undermined local government autonomy and governance effectiveness. The study concluded that constitutional and institutional constraints have continued to limit the capacity of local governments to function independently and efficiently.

Oti & Otalor (2024) carried a study titled *Transparency and Accountability in Nigeria's Public Sector: Local Government Fiscal Autonomy in Focus*. Using survey questionnaires and interviews involving 132 local government finance and audit officials across states in South-South and South-East Nigeria, the study found that while some degree of accountability exists in local government financial management, transparency remains weak due to inadequate disclosure of fiscal information. The study concluded that greater fiscal autonomy could enhance accountability and improve governance outcomes at the grassroots level.

Kolawole (2024) examined *Internal audit, internal controls, and fiscal discipline: empirical insights from strengthening control systems as drivers of financial accountability in Nigerian Local Governments*. Employing a quantitative survey design involving 125 accounting and audit personnel, the study found that effective internal control systems significantly improved financial accountability and fiscal discipline within local government administration. The study emphasized the importance of robust accountability mechanisms for strengthening public sector performance.

Agboola & Aliu (2025) evaluated *Decentralization and Service Delivery: Evaluating the Efficiency of Local Government Administration in Southwest Nigeria*. Adopting a descriptive survey design with 400 respondents drawn from local government officials and community stakeholders across the six Southwest states, the study found that weak administrative capacity, inadequate autonomy, and poor personnel management practices contributed significantly to inefficiency in service delivery. The study concluded that administrative reforms and improved governance structures are necessary for enhancing local government performance.

Oluwasanmi (2025) examined the nexus between *Human Capital Challenges, Local Government Autonomy and Effective Service Delivery in Local Government System in Nigeria*. Relying on documentary evidence and analytical review, the study found that poor personnel quality, inadequate workforce development, and politically motivated appointments negatively affected administrative efficiency and service delivery. The study further observed that political patronage in personnel administration undermined meritocracy and professionalism within local government institutions. It recommended greater emphasis on merit-based personnel management and continuous human capital development programmes.

2.3 Gap in Literature

The reviewed studies have contributed significantly to understanding local government autonomy, accountability, personnel administration, and organisational performance in Nigeria. However, most of the studies examined these variables independently. Limited attention has been given to the interconnected relationship between autonomy, accountability, and administrative efficiency within the context of personnel management. Furthermore, existing studies are largely empirical and tend to focus on specific states or local government areas. There remains a need for a broader theoretical examination of how political dynamics shape personnel management and influence administrative outcomes in Nigerian local governments. This study seeks to fill this gap by providing a qualitative analysis of the politics of personnel management and its implications for autonomy, accountability, and administrative efficiency.

2.4 Theoretical Framework

2.4.1 Weberian Bureaucratic Theory

The Weberian Bureaucratic Theory was developed by Max Weber and was popularized in his seminal work *Economy and Society*, published in 1922. Weber conceived bureaucracy as the most rational and efficient form of organizing large-scale administrative activities. The theory views organizations as systems governed by formal rules, hierarchical authority, specialization of duties, impersonality, and merit-based recruitment and promotion. Weber argued that administrative efficiency is enhanced when officials are selected based on competence and professional qualifications rather than political or personal considerations.

The major tenets of the theory include hierarchy of authority, division of labour, formal rules and procedures, impersonality in decision-making, merit-based recruitment, and career advancement based on technical competence. The theory emphasizes professionalism, accountability, and administrative neutrality as prerequisites for organizational efficiency.

2.4.2 Principal-Agent Theory

Principal-Agent Theory was developed by Michael Jensen and William Meckling in 1976. The theory explains the relationship between a principal, who delegates authority, and an agent, who performs tasks on behalf of the principal. It assumes that both parties may have different interests and that agents may not always act in the best interests of principals unless appropriate monitoring and accountability mechanisms are in place. The theory therefore emphasizes oversight, monitoring, incentives, and accountability as means of reducing conflicts of interest and ensuring goal attainment.

The major tenets of the theory include delegation of authority, information asymmetry, conflicting interests between principals and agents, monitoring mechanisms, accountability structures, and performance incentives. The theory maintains that effective governance requires adequate supervision and accountability systems to ensure that agents act in accordance with organizational objectives.

2.4.3 Application of the Theories to the Study

The Weberian Bureaucratic Theory is relevant to this study because it emphasizes merit-based personnel management, professionalism, and administrative neutrality, which are essential for achieving efficiency in local government administration. The theory helps explain how political interference in recruitment, promotion, and deployment can undermine professionalism and administrative efficiency in Nigerian local governments.

Similarly, Principal-Agent Theory provides a useful framework for understanding the relationship between local government officials (agents) and oversight institutions such as state governments and local government service commissions (principals). The theory explains the importance of accountability mechanisms in ensuring responsible personnel administration while highlighting the risks associated with excessive political control. Together, the two theories provide a comprehensive framework for examining how autonomy and accountability influence personnel management and administrative efficiency in Nigerian local governments.

3. Materials and Methods

This study adopts a qualitative research design to examine the politics of personnel management in Nigerian local governments, with particular emphasis on autonomy, accountability, and administrative efficiency. The qualitative approach is considered appropriate because it facilitates an in-depth understanding of institutional processes, governance dynamics, and policy issues that cannot be adequately captured through quantitative methods. Qualitative research is widely recognised as suitable for public administration studies that seek to explore administrative practices, governance structures, and policy outcomes.

The study relies primarily on documentary research as the method of data collection. Relevant data were obtained from secondary sources, including constitutional provisions, government reports, local government reform documents, policy papers, scholarly journal articles, textbooks, conference papers, and other official publications relating to local government administration and personnel management in Nigeria. Documentary analysis is particularly useful in public administration research because it enables the examination of institutional frameworks, administrative practices, and governance processes through existing records and documented evidence.

Data generated from these sources were analyzed using thematic content analysis. This involved identifying, categorizing, and interpreting recurring themes relating to personnel management, local government autonomy, accountability mechanisms, political interference, and administrative efficiency. The thematic approach facilitated a systematic examination of patterns and relationships among the key variables of the study, thereby enabling the researcher to draw meaningful conclusions and policy implications.

4. Results and Discussion

This section presents an analysis and discussion of the issues surrounding personnel management in Nigerian

local governments. Drawing on the reviewed literature, theoretical perspectives, and documentary evidence, the section examines the role of institutional autonomy in personnel administration, evaluates the effectiveness of accountability mechanisms in regulating personnel management, and analyzes the implications of politicized personnel practices for administrative efficiency and grassroots service delivery. The objective is to provide a deeper understanding of how these interconnected factors shape the administration and performance outcomes of local government institutions in Nigeria.

4.1 Institutional Autonomy and Personnel Administration in Nigerian Local Governments

Institutional autonomy plays a critical role in shaping personnel administration within local government councils because it determines the extent to which local authorities can independently manage recruitment, promotion, deployment, and disciplinary processes. The principle of local government autonomy is rooted in the broader philosophy of decentralisation, which seeks to empower local institutions to make decisions that reflect the needs and priorities of their communities. Scholars have argued that effective personnel administration requires a reasonable degree of administrative autonomy to enable local governments recruit competent personnel, allocate human resources efficiently, and respond promptly to local governance challenges (Makama & Ayema, 2026). Where such autonomy exists, personnel decisions are more likely to reflect organizational needs rather than external political considerations.

However, the Nigerian local government system has historically operated under significant state government influence, particularly in personnel matters. Institutions such as State Local Government Service Commissions often exercise substantial control over recruitment, promotion, and disciplinary procedures within local councils. While these arrangements are intended to ensure uniformity and accountability, they frequently limit the discretion of local authorities in managing their workforce (Anayochukwu, Ani & Nsah, 2022). Consequently, personnel administration is often characterized by delays in decision-making, bureaucratic bottlenecks, and limited responsiveness to local needs. This situation undermines the objective of decentralization and constrains the capacity of local governments to function as effective grassroots institutions.

From the perspective of Weberian Bureaucratic Theory, personnel administration should be guided by merit, competence, and professionalism rather than political considerations. Excessive external control over local government personnel management weakens bureaucratic neutrality and reduces the ability of local councils to develop a professional workforce capable of delivering quality services. As Onaji, Myom & Ugba (2025) observe, local governments that lack administrative autonomy often struggle to build institutional capacity and sustain effective service delivery. Therefore, strengthening institutional autonomy remains a critical requirement for improving personnel administration and enhancing the performance of local government institutions in Nigeria.

4.2 Accountability Mechanisms and the Regulation of Personnel Management in Nigerian Local Governments

Accountability mechanisms are essential for ensuring that personnel administration within local governments is conducted in accordance with established rules, ethical standards, and principles of good governance. In the Nigerian public sector, accountability is promoted through a variety of institutional arrangements, including civil service regulations, auditing procedures, legislative oversight, and the activities of Local Government Service Commissions. These mechanisms are designed to ensure transparency in recruitment, fairness in promotion, and discipline in personnel administration. According to Fan (2024), accountability serves as a means through which public officials justify their actions and are held responsible for their conduct, thereby reducing opportunities for abuse of power and administrative misconduct.

Despite the existence of these accountability structures, their effectiveness in regulating personnel management within Nigerian local governments remains questionable. Evidence suggests that accountability mechanisms are often weakened by political interference, inadequate enforcement, and institutional constraints. Oti & Otolor (2024) found that while local governments possess formal accountability structures, the practical implementation of these mechanisms is frequently undermined by limited transparency and weak institutional oversight. Similarly, Kolawole (2024) observed that deficiencies in internal control systems and oversight arrangements create opportunities for irregular personnel practices and administrative inefficiencies.

The effectiveness of accountability mechanisms is therefore dependent not only on their existence but also on their enforcement. Where accountability structures function effectively, they promote merit-based recruitment, discourage favoritism, and enhance professionalism within public institutions. Conversely, weak accountability systems allow political actors to manipulate personnel processes for personal or partisan interests. Principal-Agent Theory underscores the importance of monitoring and oversight in ensuring that public officials act in accordance with organizational objectives. Accordingly, strengthening accountability mechanisms remains essential for improving personnel administration and promoting responsible governance within Nigerian local governments.

4.3 Politicized Personnel Management, Administrative Efficiency, and Grassroots Service Delivery

One of the most persistent challenges confronting local government administration in Nigeria is the politicization of personnel management. Personnel decisions relating to recruitment, promotion, transfer, and discipline are often influenced by political actors seeking to consolidate power, reward loyal supporters, or extend control over administrative institutions. Mari & Tanimu (2025) argues that personnel administration in public organizations frequently reflects broader political struggles over power and resource allocation. In the Nigerian local government system, political patronage has become a recurring feature of personnel management, often resulting in appointments that prioritize political loyalty over competence and professional qualifications.

The implications of politicized personnel management for administrative efficiency are significant. Merit-based personnel systems are designed to ensure that qualified and competent individuals occupy positions within public institutions. However, when recruitment and promotion decisions are influenced by political considerations, organizational effectiveness is often compromised. Oluwasanmi (2025) found that politically motivated appointments contribute to poor workforce quality, reduced staff morale, and declining institutional performance. Similarly, Tunji and Abideen (2025) reported that weak personnel management practices and political interference significantly undermine administrative efficiency and limit the capacity of local governments to provide quality public services.

The consequences of administrative inefficiency are particularly evident in grassroots service delivery. Local governments are expected to provide essential services such as primary healthcare, environmental sanitation, rural infrastructure, and community development programmes. However, inefficient personnel systems often result in poor coordination, low productivity, and inadequate service provision. Oluwole, Eze & Mkavga (2026) maintained that politicised personnel administration weakens institutional capacity by discouraging professionalism and reducing accountability. Consequently, citizens experience delays, poor-quality services, and declining confidence in local government institutions. To improve service delivery outcomes, personnel administration must be insulated from excessive political interference and anchored on principles of merit, professionalism, and accountability. Such reforms would enhance administrative efficiency and strengthen the capacity of local governments to fulfill their developmental responsibilities at the grassroots level.

5. Conclusion and Recommendations

5.1 Conclusion

The study examined the politics of personnel management in Nigerian local governments with a focus on the interplay between institutional autonomy, accountability, and administrative efficiency. The analysis revealed that personnel administration within local governments is significantly influenced by the degree of autonomy available to local councils and the effectiveness of existing accountability mechanisms. While autonomy is necessary for responsive and efficient personnel administration, accountability remains essential for ensuring transparency, professionalism, and adherence to established administrative standards. The study further established that persistent political interference in personnel matters undermines meritocracy, weakens institutional capacity, and negatively affects service delivery at the grassroots level. Therefore, achieving administrative efficiency in Nigerian local governments requires a balanced framework that promotes both institutional autonomy and effective accountability in personnel management.

5.2 Recommendations

- 1) Government should implement reforms that grant local government's greater administrative discretion in personnel matters, particularly in the areas of recruitment, promotion, deployment, and discipline, while minimizing undue political interference from external actors.
- 2) Existing accountability frameworks, including Local Government Service Commissions, internal audit units, and legislative oversight mechanisms, should be strengthened through stricter enforcement of regulations, improved transparency, and regular monitoring of personnel management processes.
- 3) Local governments should adopt and consistently enforce merit-based recruitment, promotion, and performance evaluation systems to promote professionalism, improve workforce quality, enhance administrative efficiency, and strengthen service delivery at the grassroots level.

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Research on Digital Archive Management Practice of Intellectual Property Assets for Cross-Border DTC Brands

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Abstract

With the continuous global business expansion of DTC brands, the scale of overseas intellectual property assets such as overseas trademarks and patents of brands has grown steadily. Survey data show that more than 71% of Chinese outbound DTC brands have carried out multi-jurisdictional IP layout, and 66.3% have encountered overseas infringement disputes (Liu, Y., & Zhang, H., 2025). Against the backdrop of multi-jurisdictional operations, traditional local document management modes suffer from drawbacks including scattered materials, difficult ownership traceability, insufficient term control, and inadequate extraterritorial evidence validity. Only 18.4% of enterprises have built structured digital archive systems, which fail to meet the demands for cross-border IP-compliant operation and asset appreciation. Based on practical experience in the digital implementation of cross-border businesses, this paper draws on the whole-life-cycle theory of intellectual property and metadata governance theory to explore implementation paths for digital archiving, business trace retention and multi-dimensional retrieval of DTC brands' intellectual property, and puts forward hierarchically adapted optimization schemes for digital management. This research provides practical references for outbound DTC brands to standardize IP archive management, guard against cross-border compliance risks, and revitalize intellectual property assets.

Keywords: cross-border DTC brand, intellectual property asset, digital archive, metadata governance, multi-jurisdictional compliance, trusted evidence preservation, mediating effect, system dynamics, intellectual property evidence asset

1. Introduction

Driven by the digital economy, Chinese brands are going global. The cross-border DTC model skips intermediate channels and directly reaches overseas end-consumers, where intellectual property assets constitute the core foundation for brand differentiated competition. According to industrial survey data, nearly 70% of outbound DTC brands build core competitive barriers based on IP assets such as design patents, brand trademarks and original materials. For multi-country/region layout, intellectual property digital archives serve as carriers to realize ownership collection, evidence solidification, risk early-warning and asset inventory, and act as essential supporting carriers for DTC brands responding to overseas infringement litigations, platform appeals, IP licensing and transfer, as well as pledge-based financing. Based on industrial survey data and literature gaps, this chapter raises research questions, specifies research contents and summarizes innovation points.

1.1 Research Background and Industrial Status

Survey data indicate that over 71% of domestic cross-border DTC brands have implemented multi-jurisdictional intellectual property layout, and 66.3% of outbound enterprises have suffered overseas intellectual property infringement disputes. Nevertheless, merely 18.4% of enterprises have constructed structured digital archive systems. Currently, intellectual property archives are mainly supplied by corporate legal departments, external

agencies and third-party evidence-preservation platforms. All three types of entities have capacity shortcomings and cannot satisfy demands for ownership archiving, trusted evidence preservation, cross-jurisdictional adaptation and asset inventory. Prominent structural imbalance exists in the industry: most enterprises only conduct simple file storage; only 20.8% complete standardized metadata governance, and the efficiency of archives being converted into valid extraterritorial evidence is less than 31%, resulting in severe supply-demand mismatch (Wang, L., Chen, J., & Smith, T., 2025).

1.2 Literature Review and Research Gaps

Surveys reveal that only 23.7% of DTC brands have accomplished full-dimensional digital governance of archives. Quantitative research focusing on intellectual property archives for private cross-border DTC brands remains scarce. This paper identifies four core research gaps:

- 1) **Limited model universality:** Integrated analytical frameworks are lacking. Existing literature separates archive infrastructure, metadata governance, trusted evidence preservation and intellectual property performance, and fails to reveal the coupling and coordination mechanism among multiple factors.
- 2) **Incomplete process coverage:** Existing researches mostly focus on single evidence-preservation technologies, lacking closed-loop whole-link analysis ranging from archive infrastructure construction to risk prevention-control and asset-value output.
- 3) **Insufficient analysis of quantitative mechanisms:** Existing outputs are dominated by qualitative case studies, with few quantitative identification tools such as mathematical modeling, system dynamics simulation and mediating-effect tests.
- 4) **Insufficient refinement of practical paths:** Countermeasures tend to be macro policy suggestions, without differentiated and operable implementation frameworks classified by enterprise life cycles (start-up / growth / mature DTC brands) and enterprise scales.

1.3 Research Questions, Research Contents and Innovation Points

Centering on framework construction, mechanism analysis, empirical test and path implementation, this paper constructs mathematical models for digital archives, analyzes transmission mechanisms through which digital archives empower intellectual property performance, and verifies dual mediating effects and empowerment heterogeneity of brands at different life-cycle stages.

Four research innovations are proposed:

- 1) **Theoretical perspective innovation:** This paper upgrades intellectual property archives from administrative ledgers to evidence-based digital assets, and constructs a “Three-Layer Infrastructure-Dual Mediator” analytical framework, filling gaps in theories for cross-border commercial intellectual property digital archive ecosystems.
- 2) **Model framework innovation:** Incorporating multi-jurisdictional compliance constraints, this paper establishes a comprehensive evaluation indicator system of intellectual property digital archives adapted for cross-border DTC brands.
- 3) **Methodological innovation:** Entropy-weight TOPSIS evaluation, system dynamics simulation and panel mediating-effect tests are combined to quantitatively identify dynamic transmission mechanisms of digital archives.
- 4) **Practical innovation:** A stepped hierarchical implementation path is built to provide differentiated and replicable implementation paradigms for start-up, growth-stage and mature cross-border DTC brands.

2. Theoretical Foundation and Definition of Core Concepts

2.1 Definition of Core Concepts

Combining existing literature and 412 empirical samples, operable definitions for core concepts are given as follows:

- 1) **Digital Archives of Intellectual Property Assets for Cross-Border DTC Brands:** Structured sets of digital assets oriented toward outbound multi-jurisdictional scenarios, centered on standardized metadata, integrating intellectual property ownership documents, application materials, product material copyrights, infringement forensic archives, licensing-transaction records and risk early-warning records. Such archives feature tamper-resistant evidence preservation, extraterritorial evidence export and asset-inventory functions. Distinct from ordinary scanned electronic archives, their cross-jurisdictional evidence availability reaches 78.3%, far higher than the 29.1% of archives stored on ordinary cloud disks.
- 2) **Multi-Dimensional Transmission and Governance Mechanism:** A full-link closed-loop system starting from digital archive infrastructure, passing through trusted evidence solidification and standardized metadata

governance mediators, and outputting intellectual property risk-prevention-and-control performance as well as intellectual property asset-value performance. It includes three transmission modes: chained mode, parallel mode and superposed collaborative mode.

- 3) **Evidence-Preservation-Metadata Coupling and Coordination:** A specific mediating interaction mechanism of digital archive systems, which improves extraterritorial evidence validity and intellectual-property-asset inventory efficiency in a bidirectional manner. The coupling-coordination mediating effect accounts for 29.7% among samples, solving the practical challenge that “archives can be stored yet cannot be used as assets or evidence”.

2.2 Fundamental Theoretical Support

Four core theories underpin the logical framework of this paper:

- 1) **Whole-Life-Cycle Theory of Intellectual Property:** Covers the full cycle of intellectual property including application, layout, utilization, licensing, rights protection and invalidation, and explains archiving and circulation logic for archive materials in the whole process.
- 2) **Metadata Governance Theory:** Metadata acts as the core hub for cross-border archive retrieval, ownership identification and extraterritorial evidence admissibility.
- 3) **TOE (Technology-Organization-Environment) Framework:** Explains constraints of technical conditions, internal organizational conditions and external multi-jurisdictional institutional environment on enterprises implementing digital archives.
- 4) **Cross-Border Electronic Evidence Theory:** Illustrates admissibility constraints of digital archives in judicial scenarios and platform appeal scenarios of different countries.

2.3 Analysis on Differentiated Empowerment Mechanisms of Different Archive Management Modes

Four types of subjects, namely corporate in-house legal teams, external intellectual-property agencies, standalone third-party evidence-preservation platforms and complete digital-archive platforms, possess remarkably different resource endowments, and a single subject has inherent capacity boundaries.

Table 1.

Type of Subject	Core Advantages	Core Shortcomings	Major Archive Empowerment Paths
Traditional In-House Legal Ledger of Enterprises	Familiar with corporate businesses, in possession of internal product materials	Lacks trusted evidence-preservation technologies and capacities for standardized cross-border metadata; archives are stored dispersedly	Document collection and internal document archiving; no evidence solidification procedures
External Intellectual-Property Agencies	Well-versed in intellectual-property application procedures of various countries, with official application archives	Prioritizes application businesses; neglects archiving of rights-protection evidence, social-media IP and product materials; inconsistent formats of delivered archives	Submitting applications to national intellectual-property offices and delivering application receipt documents
Standalone Third-Party Evidence-Preservation Platforms	Possess timestamp and blockchain-based trusted evidence-preservation technologies	Lacks intellectual-property business logics; incapable of standardized metadata processing and asset inventory; cannot realize whole-life-cycle archive collection	File hash-value evidence preservation; only provides evidence-preservation certificates
Complete Intellectual-Property Digital Archive System	Integrates archive collection, trusted evidence preservation, cross-border metadata processing, asset inventory and evidence-package	Highly dependent on execution of organizational rules; defective metadata field design will reduce archive value	Whole-life-cycle archive collection; trusted evidence solidification; standardized metadata management; export of rights-protection evidence packages and IP

	export		asset-inventory reports
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Empirical samples show that the mediating effect of evidence-preservation-metadata coupling and coordination accounts for 29.7%, which serves as the core driver to release dual values of risk prevention-control and asset appreciation of intellectual property archives.

3. Status Quo and Core Influencing-Factor Identification of Digital Archives for Cross-Border DTC Intellectual Property

3.1 Sample and Survey Description

This study adopts panel data of cross-border DTC brands from 2021 to 2025. Surveys cover DTC entities that build self-developed digital archives, rely on external agencies or merely store archives via cloud disks. Data sources include corporate questionnaire surveys, semi-structured interviews, public intellectual-property data and overseas platform dispute precedents. After data cleaning, 412 valid samples are obtained. Among sample enterprises, start-up DTC brands account for 34.2%, growth-stage DTC brands 38.6%, and mature leading DTC brands 27.2%, covering mainstream outbound DTC tracks such as home-consumption goods, 3C accessories, apparel and beauty cosmetics. All continuous variables are winsorized at the 1%-99% level to eliminate extreme values and guarantee data robustness (Garcia, M., 2024).

3.2 Statistical Analysis on Industrial Status of Digital Archives

Overall, intellectual-property archive supply for domestic cross-border DTC brands features widespread document storage, insufficient coupling between evidence preservation and metadata governance, and prominent differentiation in archive-performance conversion efficiency, revealing obvious digital-governance fragmentation in the industry.

- 1) **Popularization of basic-file storage:** Most enterprises preserve scanned copies of trademark and patent certificates. Over 74% of enterprises can realize basic-file storage, yet merely static storage without value conversion capabilities.
- 2) **Insufficient supply of coupled services for trusted evidence preservation and standardized metadata:** Less than 23.7% of enterprises can simultaneously realize whole-life-cycle archive collection, trusted evidence solidification and cross-border-adapted metadata systems. More than 75% of enterprises suffer segmentation among evidence preservation, archiving and governance links.
- 3) **Highly differentiated archive-value conversion efficiency:** Enterprises with mature digital governance achieve over 85% success rate in IP rights-protection and appeals, while numerous enterprises that only retain certificate files have less than 30% completeness ratio of evidence for infringement responses, and archives cannot be converted into risk-prevention capacities or asset gains.

3.3 Analysis on Classified Existing Pain Points

Combined with interview transcripts, pain points in digital-archive construction are summarized into five dimensions:

- 1) **Institutional and compliance dimension:** Conflicts of multi-jurisdictional electronic-evidence rules; format incompatibility of archives from intellectual-property offices of different countries; cross-border data-flow compliance constraints restricting cross-border access and utilization of archives.
- 2) **Technical-infrastructure dimension:** Archives are scattered across cloud disks, agency mailboxes and local corporate computers; absence of timestamps and hash-value solidification brings tampering risks for materials; lack of unified archive middle platform hinders automatic collection of multi-source archives.
- 3) **Metadata-governance dimension:** Only original files are preserved without standardized metadata fields; key metadata such as ownership territorial scope, licensing status, validity period and evidence formation time are missing, disabling rapid inventory of cross-border IP assets.
- 4) **Organizational-operation dimension:** Priority given to intellectual-property applications while archive archiving is neglected; fragmented collaboration exists among legal departments, product departments, outbound-operation teams and external agencies; most archiving is remedial post-event archiving without whole-process archiving mechanisms.
- 5) **Value-conversion dimension:** Archives are treated merely as back-office ledgers without docking with rights-protection, licensing and valuation businesses; lack of standardized extraterritorial-evidence-package export procedures impedes conversion of archives into risk-prevention capacities and asset gains.

3.4 Identification of Core Influencing Factors Based on Factor Analysis

Exploratory factor analysis is performed on 22 observation indicators of digital archives. Test results show

KMO=0.721 and Bartlett's sphericity test $p < 0.001$, indicating favorable data fitness satisfying factor-analysis prerequisites. After maximum-variance rotation, five core common factors are extracted: completeness of digital-archive infrastructure, trusted-evidence-preservation capacity, standardized metadata-governance level, coupling-coordination degree of evidence-preservation-metadata, and external boundary conditions. Confirmatory factor analysis yields CR>0.7 and AVE>0.5, proving satisfactory composite reliability and convergent validity of questionnaires.

4. Construction of Multi-Dimensional Transmission Model for Intellectual-Property-Asset Digital Archives of Cross-Border DTC Brands

Based on foregoing theoretical foundations, differentiated subject mechanisms and identified common factors, this paper constructs the "Three-Layer Infrastructure-Dual Mediator" digital-archive transmission model supported by mathematical reasoning, with dynamic feedback and adaptability for enterprise life cycles, and builds a complete quantitative evaluation system.

4.1 Model-Construction Principles and Overall Framework

Five modeling principles are followed: admissibility principle for multi-jurisdictional evidence; closed-loop principle for the whole life cycle of intellectual property; self-adaptation principle for DTC enterprise life cycles; quantifiable evaluation principle; cross-border data-security compliance principle.

The core function of this research is constructed to characterize variable coupling relationships:

$$Y = F(S, C, R; M_1, M_2, M_3)$$

Y: Multi-dimensional intellectual-property performance of cross-border DTC brands, divided into two sub-dimensions: intellectual-property risk-prevention-and-control performance; intellectual-property asset-value performance.

S: Independent variable, completeness of three-layer digital-archive infrastructure.

C: Mediator Variable 1: trusted evidence solidification.

$Set_C = C_1 \text{ownershiparchiveevidencepreservation};$

$C_2 \text{product-materialevidencesolidification};$

$C_3 \text{rights-protectionforensic-archiveencapsulation}$

R: Mediator Variable 2: standardized metadata governance $Set_R = R_1 \text{ownership-territorymetadata};$
 $R_2 \text{life-cyclemetadata}; R_3 \text{evidence-attributemetadata}.$

M₁: Corporate archive absorption and application capacity; **M₂**: Strength of corporate internal organizational governance; **M₃**: Institutional environment of overseas target markets. The three variables serve as moderators.

Logical relationships: As a precondition, digital-archive infrastructure **S** acts respectively on trusted evidence solidification **C** and standardized metadata governance **R**; **C** and **R** interact and couple, and jointly affect outcome variable **Y** through three transmission modes: chained mode, parallel mode and superposed collaborative mode.

4.2 Functional Decomposition of Three-Layer Digital-Archive Infrastructure

The three-layer archive infrastructure acts as the precondition for the whole system to realize value:

- 1) **Archive Collection Infrastructure Layer**: Multi-source archive docking interfaces to realize unified collection and storage of agency documents, receipts from national intellectual-property offices, independent-site materials, social-media IP materials and infringement screenshot evidence.
- 2) **Organizational-System Guarantee Layer**: Archiving-procedure specifications, job-responsibility division, archive-delivery standards for agencies, and archiving-timeliness rules. Formal systems constrain collaboration among legal departments, product departments and outbound-operation teams.
- 3) **Data-Security Compliance Infrastructure Layer**: Hierarchical access permission, cross-border data isolation, encrypted backup and disaster recovery to adapt to overseas data-compliance requirements such as GDPR and guarantee security for cross-border archive access.

4.3 Dual-Mediator Dimensions and Core Mathematical Expressions

Mediator 1: Trusted evidence-solidification set

$Set_C = C_1 \text{ownershiparchiveevidencepreservation};$

$C_2 \text{product-materialevidencesolidification};$

$C_3 \text{rights-protectionforensic-archiveencapsulation}$

Mediator 2: Standardized metadata-governance set
 $Set_R = R_1 \text{ownership-territory metadata}; R_2 \text{life-cycle metadata}; R_3 \text{evidence-attributemetadata}$

To eliminate dimensional differences of indicators covering archive infrastructure, evidence preservation and metadata, and realize horizontal comparability of archive-governance levels among DTC enterprises, extremum standardization is adopted for data normalization:

$$x'_{ik} = \frac{x_{ik} - \min(x_{ik})}{\max(x_{ik}) - \min(x_{ik})}$$

Indicators converge within interval [0,1], laying standardized data foundations for archive-governance-efficiency calculation and mediating-effect tests.

A coupling-coordination parameter model is built to characterize the coupling-coordination effect of trusted evidence preservation-metadata governance:

$$\Omega = \omega_1 C + \omega_2 R + \omega_3 C \times R$$

ω_1 and ω_2 denote weights of trusted evidence preservation and metadata governance respectively; ω_3 represents the interaction-coupling coefficient of evidence preservation-metadata. Parameters can be dynamically adjusted according to the life-cycle stage of DTC brands to realize heterogeneous empowerment adaptation.

Combined with the TOPSIS model, the comprehensive-efficiency evaluation formula for intellectual-property digital archives of cross-border DTC brands is constructed to calculate multi-dimensional empowerment comprehensive performance of intellectual property:

$$S_i = \frac{D_i^-}{D_i^+ + D_i^-}$$

Higher value of S_i indicates higher comprehensive governance efficiency of the digital-archive system of the corresponding DTC brand.

4.4 System-Dynamics Feedback Loops and Operational Closed-Loop

Dual feedback closed-loops including positive empowerment loop and reverse iteration loop are built based on the five common factors.

Positive loop: Complete three-layer digital-archive infrastructure drives trusted evidence solidification and standardized metadata governance. Via coupling-coordination transmission of evidence preservation-metadata, intellectual-property risk-prevention-and-control performance and asset-value performance are output.

Reverse iteration loop: Intellectual-property performance feeds back to enterprises. Enterprises iteratively optimize archive-collection rules, metadata fields and archiving procedures according to practical effects of rights-protection and asset operation. Moderator variables constrain the action intensity of the whole transmission link.

The system supports three transmission modes:

- 1) Chained transmission: $S \rightarrow C \rightarrow R \rightarrow Y$
- 2) Parallel transmission: $S \rightarrow C; S \rightarrow R$
- 3) Superposed collaborative transmission: $S \rightarrow C \cap R \rightarrow Y$

Under the superposed collaborative transmission mode, coupling parameter Ω reaches the maximum value, yielding the strongest comprehensive empowerment effect of archive systems.

5. Model Simulation and Empirical Test

5.1 System-Dynamics Simulation Design

The simulation cycle is set as 60 months, and three groups of comparative scenarios are constructed corresponding to three mainstream real-world archive-management modes:

- **Scenario 1:** Traditional cloud disk + legal-ledger mode
- **Scenario 2:** Mode adopting standalone third-party evidence-preservation platforms only
- **Scenario 3:** Complete “Three-Layer Infrastructure-Dual Mediator” digital-archive model proposed in this paper

Table 2.

Parameter Name	Scenario 1 Traditional Ledger Disk	Legal with Cloud	Scenario 2 Standalone Third-Party Evidence-Preservation Platform	Scenario 3 Complete Digital-Archive System
Archive Metadata Completeness Coefficient	0.18		0.23	0.79
Evidence-Preservation-Metadata Coupling-Coordination Coefficient	0.07		0.11	0.68
Extraterritorial-Evidence-Package Export Delay (Month)	2.12		1.46	0.41

5.2 Simulation Results and Sensitivity Analysis

Simulation results show that Scenario 3 (complete digital-archive system) improves long-term comprehensive intellectual-property performance by 58.2% compared with the traditional ledger mode, and by 36.7% compared with the standalone evidence-preservation mode, and achieves optimal performance in evidence-export efficiency, rights-protection success rate and IP-asset inventory efficiency. Sensitivity analysis proves that the evidence-preservation-metadata coupling-coordination coefficient and completeness of three-layer archive infrastructure serve as the core sensitive variables of the system. Their combined contribution to archive-value empowerment exceeds 60%, which is critical to unlock asset value of intellectual-property archives.

5.3 Panel Econometric Model and Research Hypotheses

Research hypotheses are proposed based on theoretical deduction and simulation results:

- **H1:** Complete digital-archive infrastructure positively improves multi-dimensional intellectual-property performance of cross-border DTC brands.
- **H2:** Trusted evidence solidification and standardized metadata governance exert chained / parallel mediating effects between digital-archive infrastructure and multi-dimensional intellectual-property performance.
- **H3:** Evidence-preservation-metadata coupling and coordination exert partial mediating effects, and the superposed collaborative transmission mode delivers the strongest empowerment effect.
- **H4:** Corporate archive absorption-application capacity, internal organizational-governance strength and institutional environment of overseas target markets generate positive moderating effects.

A two-way fixed-effect baseline regression model is constructed to test the direct effect of digital-archive infrastructure completeness on multi-dimensional intellectual-property performance:

$$Y_{it} = \beta_0 + \beta_1 S_{it} + \sum \beta_k \text{Control}_{kit} + \mu_i + \varepsilon_{it}$$

Y_{it} denotes multi-dimensional intellectual-property performance of DTC enterprise i in period t ; S_{it} represents completeness of digital-archive infrastructure; Control_{kit} refers to control variables (enterprise scale, outbound years, quantity of intellectual-property rights, target-market regions); μ_i denotes individual fixed effect; ε_{it} represents random disturbance term.

5.4 Brief Analysis on Empirical Regression Results

Core estimation results of baseline regression, mediating-effect test and heterogeneity analysis are summarized as follows:

Table 3.

Variable	Model 1 Baseline Regression	Model 2 Mediator (Trusted Evidence Solidification)	Model 3 Mediator (Metadata Governance)	Model 4 Mediator (Coupling-Coo rdination)	Model 5 Start-up-Gro wth-Stage DTC Brands	Model 6 Mature-Sta ge DTC Brands
Completeness of Digital-Archive Infrastructure (S)	0.327(0.041)	0.261(0.038)	0.244(0.040)	0.206(0.044)	0.354(0.049)	0.271(0.042)
Trusted Evidence	—	—	0.278(0.047)	0.193(0.040)	—	—

Solidification (C)						
Standardized Metadata Governance (R)	—	0.289(0.044)	—	0.241(0.046)	—	—
Evidence-Preservation-Metadata Coupling-Coordination	—	—	—	0.324(0.055)	—	—
Observations	412	412	412	412	284	128
Adjusted R^2	0.604	0.533	0.546	0.631	0.642	0.550
Mediating-Effect Proportion	—	22.1%	20.4%	29.7%	—	—

Baseline regression results show that the coefficient of digital-archive infrastructure completeness is 0.327 ($p < 0.01$), passing the significance test at the 1% level, which confirms that it can significantly improve multi-dimensional intellectual-property performance of cross-border DTC brands. Trusted evidence solidification and standardized metadata governance exert mediating effects of 22.1% and 20.4% respectively, and the mediating effect of their coupling and coordination reaches 29.7%, constituting the core empowerment path.

6. Practical Path for Intellectual-Property-Asset Digital Archives of Cross-Border DTC Brands

Targeting common problems of DTC enterprises such as prioritizing applications over archiving, disconnection between evidence preservation and metadata governance, and mismatch between archive construction and self-development stages, this paper builds a four-phase stepped implementation path combined with conclusions from simulation and empirical tests.

- 1) **Archive-maturity diagnosis and infrastructure construction of three-layer archive infrastructure:** Enterprises remedy shortcomings of three-layer digital-archive infrastructure, build multi-source archive-collection mechanisms, improve archiving systems, define job responsibilities and formulate archive-delivery specifications for agencies.
- 2) **Differentiated capacity building classified by enterprise life-cycle stages:**
 - **Start-up-growth-stage cross-border DTC brands:** Prioritize construction of trusted-evidence-preservation capacity, focus on evidence solidification for core trademarks, hit-product designs, product materials and infringement forensics. Adopt the chained transmission path to address pain points of missing overseas rights-protection evidence.
 - **Mature leading DTC brands:** Promote trusted evidence solidification and full-volume standardized metadata governance in parallel, complete inventory of full-category intellectual-property assets to support IP licensing, valuation and multi-market cross-border layout, and adopt the parallel transmission mode.
 - **High-value leading DTC brands:** Activate coupling and coordination between evidence preservation and metadata governance, adopt the superposed collaborative transmission mode, automatically generate standardized extraterritorial evidence packages and intellectual-property-asset statements, and maximize dual values of risk prevention-control and assets brought by archives.
- 3) **Implementation of closed-loop full-link archive value realization:** Complete the whole link of “archive collection-evidence solidification-metadata annotation-evidence export-asset inventory”. Archive construction shall not stop at storage; build closed-loop archive application docking with platform appeals, overseas litigations, IP licensing and transfer businesses. Conduct training for legal and operation staff on archiving procedures to cope with insufficient corporate archive-absorption capacity.
- 4) **Guarantee for long-term iterative optimization:** Abandon the mindset of one-off archive-system construction. Implement quarterly archive-quality inspection and annual iteration of metadata fields; update archive-compliance rules according to legal requirements of newly entered overseas markets. From the perspective of the intellectual-property-service industry, promote the formation of reference specifications for intellectual-property-archive metadata oriented toward cross-border DTC brands.

7. Multi-Case Study

To effectively test the practical effectiveness of the “Three-Layer Infrastructure-Dual Mediator” model and stepped implementation path proposed in this paper and avoid contingency bias brought by single-case studies, this paper conducts an anonymized multi-case comparative study covering three cross-border DTC brands at different life-cycle stages and from different outbound tracks.

7.1 Pre-Upgrade Archive Shortcomings of Cases

- **DTC- α (Mature Leading Home-Consumption DTC Brand):** The enterprise owns abundant overseas design-patent assets and has layout in multiple countries, yet has long relied on multiple external agencies. Intellectual-property archives are stored dispersedly without standardized metadata systems. The enterprise adopts manual Excel ledgers for asset statistics with low inventory efficiency. When confronted with overseas infringement disputes, the sorting cycle for rights-protection evidence is lengthy.
- **DTC- β (Growth-Stage Consumer-Electronics DTC Brand):** The enterprise attaches great importance to cross-border intellectual-property risk prevention and has purchased third-party blockchain-based evidence-preservation tools for regular infringement forensic evidence preservation. Nevertheless, the enterprise only implements standalone evidence-preservation functions without supporting standardized metadata-governance systems. Forensic evidence materials are disconnected from official ownership archives and product-material archives without data interconnection.
- **DTC- γ (Start-up Beauty-Cosmetics DTC Brand):** The enterprise has a short outbound history and small volume of IP assets with weak intellectual-property-management awareness and no systematic archiving procedures. It merely keeps scanned copies of patent and trademark certificates, lacking procedural archives such as promotional contents and iterative records.

7.2 System Upgrade Implementation Following the Four-Phase Framework

- 1) **Infrastructure upgrade and specification formulation:** All three enterprises carry out special archive-maturity diagnosis, remedy shortcomings of three-layer digital-archive infrastructure matching their scale, unify entry points for multi-source archive collection, standardize archive-delivery specifications for external agencies, clarify archiving responsibilities and timeliness requirements for legal and operation posts, and build secure encrypted archive-storage infrastructure to completely solve fundamental problems of scattered and disorderly archive management.
- 2) **Construction of differentiated adaptive capacities:**
 - Realize targeted empowerment matching enterprise life-cycle characteristics. Start-up DTC- γ gives priority to implementing trusted-evidence-preservation mechanisms to preserve evidence for core beauty-cosmetics product materials and brand trademarks and consolidate basic risk-control capacities.
 - Growth-stage DTC- β focuses on improving intellectual-property metadata fields and breaking data barriers between evidence-preservation files and ownership archives.
 - Mature DTC- α thoroughly implements the coupling-coordination mode of evidence preservation-metadata to realize refined governance and value revitalization of IP assets.
- 3) **Business closed-loop and long-term iteration:** Realize full-link coverage of “archive collection-evidence solidification-metadata annotation-evidence export-asset inventory”, deeply apply digital archives in core businesses including overseas platform appeals, infringement responses and IP-asset inventory. Meanwhile, establish regular archive-review mechanisms to continuously optimize archiving procedures and metadata specifications for iterative upgrades adapting to multi-jurisdictional compliance requirements.

7.3 Quantitative Implementation Effects

After iterative governance, remarkable empowerment effects are achieved for the three DTC enterprises at different life-cycle stages. The average success rate of overseas platform appeals rises by 42.6%, the failure rate of infringement disputes drops by 38.4%, and the average time consumed for intellectual-property-asset inventory shortens by 57.2%, substantially cutting manual operation-and-maintenance costs. Supported by standardized archives, DTC- α completes three overseas IP licensing transactions realizing commercial monetization of IP assets. DTC- β witnesses a 61% reduction in evidence-preparation cycle for overseas infringement litigations with greatly improved response efficiency. Case practices fully verify the strong practical feasibility and implementation value of the “Three-Layer Infrastructure-Dual Mediator” transmission model and stepped implementation path proposed in this paper.

8. Research Conclusions, Limitations and Future Prospects

8.1 Main Research Conclusions

- 1) Complete three-layer digital-archive infrastructure acts as the precondition for cross-border DTC brands to realize value of intellectual-property archives.
- 2) Trusted evidence solidification and standardized metadata governance exert significant mediating effects; the superposed collaborative transmission formed by coupling and coordination between evidence preservation and metadata generates the strongest comprehensive empowerment effect.

- 3) Corporate archive absorption-application capacity, internal organizational-governance strength and institutional environment of overseas target markets significantly moderate the transmission effect.
- 4) Heterogeneity characteristics: Start-up-growth-stage DTC brands are more dependent on the trusted-evidence-solidification path; mature-stage DTC brands rely more on the standardized-metadata-based asset-inventory path.

8.2 Theoretical Contributions and Practical Implications

Theoretical contributions: Expand the application of the whole-life-cycle theory of intellectual property in cross-border commercial-archive scenarios; extend digital-archive research from public archival domains to commercial intellectual-property-asset dimensions for DTC brands; construct the coupled transmission analytical framework of “Three-Layer Infrastructure-Dual Mediator”.

Practical implications: Provide archive-construction schemes classified by life-cycle stages for cross-border DTC enterprises; offer product-optimization directions for intellectual-property agencies and evidence-preservation service providers; deliver references for cross-border intellectual-property compliance governance.

8.3 Research Limitations

Samples of this research are dominated by domestic outbound DTC brands. The proportion of small-and-medium-sized DTC samples from vertical sub-tracks still needs improvement. The research mainly adopts questionnaire and panel data, lacking in-depth analysis via large-model text mining. Archiving issues for AIGC-generated product materials have not been fully explored, and in-depth comparative analysis on legal rules of individual countries remains to be expanded.

8.4 Future Prospects

Follow-up research can expand sample coverage of DTC brands in vertical tracks, explore action mechanisms of AI large models for automatic archive collection, automatic metadata extraction and intelligent risk early-warning of intellectual-property archives, carry out comparative research on evidence admissibility of digital archives under different jurisdictions, and further investigate governance rules when AIGC-generated contents are incorporated into intellectual-property digital archives.

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