

# A Human-Machine Collaborative Model for Improving Administrative Efficiency in Wenzhou Universities in China

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## Abstract

As digital transformation continues to advance within local universities, the enhancement of administrative efficiency has emerged as a critical concern for institutional development. Human-machine collaboration (HMC) has been identified as a promising approach to addressing this challenge in the governance of higher education. It is against this backdrop that the present study examines the relationship between HMC and administrative efficiency, and proposes a localized governance model for universities in Wenzhou, China. A quantitative cross-sectional research design was employed, utilizing survey data collected from 280 administrative staff across 11 universities in Wenzhou. The study applied descriptive statistics, Pearson correlation, regression analysis, and the Priority Needs Index Modified (PNI Modified) to identify key areas for improvement and construct a hierarchical model of efficiency enhancement. The findings indicate that HMC is significantly associated with administrative efficiency ( $r = 0.680$ ,  $p < 0.001$ ), and regression analysis further confirms a strong predictive relationship ( $\beta = 0.680$ ,  $p < 0.001$ ). Priority analysis identifies three critical areas requiring improvement: smart task recognition, automated workload distribution, and real-time system adjustment. These priorities reflect a progressive mechanism linking process optimization to performance outcomes. Based on these findings, the study proposes the "AEGIS–Wenzhou Model," which offers a structured and context-sensitive framework for improving administrative efficiency. The study contributes to socio-technical systems theory by elucidating the role of adaptive integration in HMC, and offers practical implications for advancing digital governance in local higher education institutions.

**Keywords:** administrative efficiency, human-machine collaboration, localization model, local universities, priority needs index, digital governance

## 1. Introduction

The expansion of higher education and the growing complexity of institutional governance have rendered administrative efficiency a critical determinant of educational quality and organizational performance. Protracted administrative processes, pronounced information silos, and the substantial costs associated with cross-departmental collaboration remain persistent impediments to the modernization of university governance. Although information systems have been widely adopted across higher education institutions, empirical evidence suggests that technological adoption alone does not necessarily yield commensurate gains in efficiency; in certain instances, it may instead amplify management complexity (Dwivedi et al., 2021).

Despite the pervasive integration of information systems within university settings, administrative efficiency remains suboptimal, particularly with respect to cross-departmental coordination and institutional decision-making. This disparity points to a fundamental misalignment between the degree of technological adoption and the realization of governance effectiveness (Rattanapun & Hansanontha, 2026; Wang et al., 2025).

The advent of artificial intelligence and big data technologies has given rise to the concept of human-machine collaboration (HMC). In contrast to automation paradigms premised on the substitution of human labor by technological systems, HMC foregrounds the complementary integration of human judgment and machine computation. Through socio-technical integration mechanisms, this approach offers a theoretically grounded and practically viable perspective for efficiency optimization in complex organizational environments (Shneiderman,

2022). Nevertheless, extant research has predominantly concentrated on enterprise contexts or research-intensive universities, and no systematic framework or operational guidance has thus far been established for the implementation of HMC within regional, multi-type local universities (Tran, 2024).

Compounding this limitation, the existing literature lacks systematic frameworks capable of integrating human-machine collaboration into administrative governance within such institutional contexts. This constitutes a significant gap in scholarly understanding of how HMC may be effectively operationalized to enhance administrative efficiency in local higher education institutions.

Situated within this context, the present study focuses on public and private undergraduate and junior college institutions in Wenzhou, China. It seeks to examine how, and through which mechanisms, human-machine collaboration contributes to improvements in administrative efficiency, with particular attention directed toward three research questions: (1) What is the prevailing level of human-machine collaboration in universities in Wenzhou? (2) Which dimensions of human-machine collaboration represent the most critical priorities for improvement? And (3) How may an effective governance model be constructed to enhance administrative efficiency within the context of regional higher education institutions?

This study advances three principal contributions to the field. First, at the theoretical level, it extends socio-technical systems theory by situating human-machine collaboration within the domain of university governance. Second, at the methodological level, it integrates correlation analysis with the Priority Needs Index (PNI) to construct a structured analytical pathway linking existing conditions, priority needs, and governance model development. Third, at the practical level, it proposes a localized and operationalizable governance model that furnishes empirical guidance for the enhancement of administrative efficiency in regional higher education institutions.

## 2. Literature Review

### 2.1 Theoretical Foundation

The analytical framework for examining human-machine collaboration in university administration is grounded in three complementary theoretical traditions: Sociotechnical Systems Theory, Activity Theory, and Human-Centered Artificial Intelligence (HCAI). These theories collectively provide systematic support for the present study from the perspectives of organizational structure, practical context, and normative principles, respectively.

Sociotechnical Systems Theory, originally introduced by Trist and Bamforth (1951), posits that human actors serve as the connective element between technological structures and social systems through coordinated activity. The theory argues that enhanced organizational performance derives from the optimized alignment of social and technical subsystems, rather than from the isolated strengthening of either component. This foundational proposition was subsequently extended to the study of information systems by Bostrom and Heinen (1977), who contended that the design of technical systems must be congruent with an organization's structure and management processes in order to avoid the inefficiencies and failures that arise from misaligned configurations. This perspective enables a systematic examination of the interaction patterns among technological tools, organizational structures, and human behavior within higher education administration. Building on this foundation, Orlikowski (1992) introduced the concept of the "duality of technology," which expanded the notion of socio-technical synergy by incorporating organizational dynamism. This framework reconceptualizes technology not as a static artifact but as something continuously reshaped through organizational practice, thereby offering a dynamic theoretical basis for understanding the ongoing development of human-machine collaboration in university administrative systems (Bond et al., 2024).

Activity Theory, rooted in the cultural-historical school of psychology, was systematically elaborated by Engeström (2000) into a six-component analytical model comprising subject, object, tools, rules, community, and division of labor. Within this framework, tools assume a mediating function; technology is no longer treated as an exogenous variable but is instead embedded within the system of purposeful action, fundamentally reconfiguring the normative rules that govern practice. Engeström's subsequent theory of expansive learning further demonstrated that organizations drive the transformation of activity systems through the updating of tools and the reorganization of structures (Engeström, 2014). This theoretical lens is particularly pertinent to understanding how changes in university information systems generate structural constraints and dynamic adjustment mechanisms within administrative workflows.

Advances in artificial intelligence have, in turn, provided the normative foundations for Human-Centered Artificial Intelligence (HCAI) as a theoretical framework for redesigning human-machine interaction. HCAI holds that intelligent systems must preserve meaningful human control over critical decisions and cultivate trust through transparency and interpretability. Incorporating HCAI theory into the analysis of university administration serves to

mitigate the risks associated with technological determinism and provides a value-oriented normative basis for the construction of human-machine collaborative governance mechanisms.

In synthesis, Sociotechnical Systems Theory supplies a macro-structural perspective on organizational design; Activity Theory elucidates the mediating mechanisms operative at the level of practice; and Human-Centered Artificial Intelligence establishes the normative and value principles that should govern intelligent system deployment. Together, these three theoretical traditions constitute the integrated theoretical foundation upon which the present study analyzes the mechanisms of human-machine collaboration in university administration and its consequent impact on administrative efficiency.

## 2.2 Review of Human-Machine Collaboration (HMC) Related Research

Artificial intelligence and data analytics technologies have been widely adopted across public sector organizations and educational institutions, and human-machine collaboration has progressively emerged as a significant area of inquiry within organizational governance research. A substantial body of literature affirms that human-machine collaboration exerts a positive influence on administrative efficiency, principally through the optimization of task allocation, the strengthening of decision support mechanisms, and the improvement of collaborative processes (Raisch & Krakowski, 2021). While machines demonstrate considerable advantages in processing repetitive, high-volume computational tasks, human actors retain an indispensable role in situational judgment, value-based deliberation, and cross-departmental communication (Gonzalez et al., 2026).

Empirical studies within the domains of public governance and education management further indicate that human-machine collaboration can both reduce the duration of administrative process cycles and lower human error rates while simultaneously improving service response speed (Van Rooy, 2024). Nevertheless, findings across the literature are not entirely consistent. Research by Glikson and Woolley (2020) suggests that where system design lacks flexibility or fails to adequately incorporate user participation, human-machine collaboration may paradoxically intensify organizational burdens, resulting in what has been characterized as "technological accumulation rather than efficiency improvement" (Haesevoets et al., 2021).

Within the specific context of university administrative management, existing studies have largely focused on isolated systems or individual cases as units of analysis, and have yet to produce a systematic analytical framework for examining coordination mechanisms across institutional settings (Agbabiaka et al., 2025). This fragmentation in the literature underscores the need for a more integrative and context-sensitive approach to the study of human-machine collaboration in higher education administration.

Drawing on a comprehensive review of the relevant literature, the present study conceptualizes human-machine collaboration as a multidimensional governance mechanism encompassing task allocation, decision support, and collaborative efficiency. Particular emphasis is placed on the adaptability of this mechanism across varying organizational contexts.

**Table 1.** HMC Summary of Definition, Domain, Criteria

Variable	Definition	Domain/Element	Criteria	Sources
HMC	Hybrid intelligence system integrating human judgment and machine computation	Task allocation	Based on task complexity, workload should be flexibly allocated in conjunction with professional division of labor	Gonzalez et al. (2026); Raisch & Krakowski (2021)
	Complementary collaboration between human and AI agents in decision processes	Decision support	AI decision-making assistance effectiveness; real-time dynamic adaptation capability	Haesevoets et al. (2021); Van Rooy (2024)
	Governance mechanism embedded in public management context	Collaboration efficiency	Efficiency improvement; cognitive burden reduction; quality optimization	Van Rooy (2024); Glikson & Woolley (2020)

### 2.3 Review of Administrative Efficiency (AE) Related Research

Research on administrative management efficiency in universities originated within the tradition of scientific management theory and organizational efficiency studies, and has progressively converged with public sector performance evaluation frameworks (Pollitt & Bouckaert, 2017). Earlier scholarship concentrated primarily on administrative cost control and process standardization. More recent studies, however, have demonstrated that the adoption of digital governance principles has reoriented the field toward the integration of information systems, data-driven decision-making, and the enhancement of service quality (Khatir & Madani, 2024).

The conceptualization of administrative efficiency in higher education extends considerably beyond cost reduction and time savings. In the university context, administrative efficiency encompasses service quality, organizational equity, and inter-departmental coordination capacity. The quality assurance dimension, in particular, includes the consistency of administrative service delivery, error controllability in operational processes, the fluency of cross-departmental cooperation, and the reliability of support provided to research activities and the learning needs of faculty and students. Given the multi-departmental structure and non-profit orientation of universities, the pathways through which efficiency is improved differ substantially from those applicable to commercial enterprises. A singular focus on cost minimization risks compromising service quality, a characteristic that has been substantiated in research on university resource allocation (Chen et al., 2024). Accordingly, administrative management in higher education institutions necessitates a deliberate balance between operational efficiency and governance values.

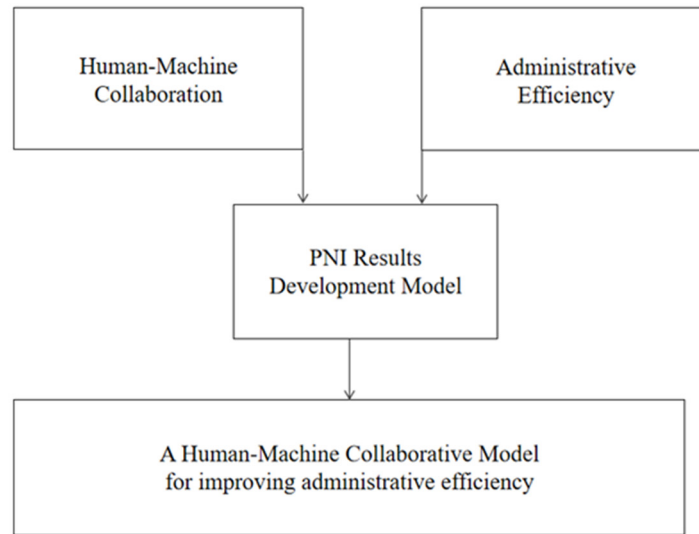
Recent empirical studies have demonstrated that digital tools can optimize time management and resource allocation efficiency within universities; however, their practical effectiveness is largely contingent upon institutional capacity for organizational transformation and the availability of adequate supporting systems. Persistent challenges — including fragmented information systems, insufficient cross-platform interoperability, and entrenched data silos — continue to constitute significant constraints on the improvement of university administrative efficiency (Fernández et al., 2023).

Informed by the foregoing review, the present study conceptualizes administrative management efficiency as the core performance outcome variable within the framework of university administrative governance. It is operationalized across three dimensions - time management, cost control, and quality assurance - to assess the contributory role of human-machine collaborative mechanisms in enhancing administrative efficiency in higher education institutions.

**Table 2.** AE Summary of Definition, Domain, Criteria

Variable	Definition	Domain/ Element	Criteria	Sources
AE	Performance of shortening process cycles and improving response speed via optimal resource allocation.	Time Management	Process cycle shortening; on-time task completion; time utilization efficiency.	Khatir & Madani (2024); Fernández et al. (2023)
	Efficiency indicators for reducing costs while ensuring service quality (public sector framework-based).	Cost control	Cost control level; resource allocation efficiency; budget rationality.	Chen et al. (2024); Pollitt & Bouckaert (2017)
	Capability to balance efficiency and governance value via stability, error reduction and coordination.	Quality Assurance	Service stability; error rate reduction; cross-departmental smoothness.	Chen et al. (2024); Damián Núñez et al. (2025)

Conceptual framework shows as following



**Figure 1.** Conceptual Framework Diagram

### 3. Research Methods

#### 3.1 Research Design

This study employs a quantitative cross-sectional research design, utilizing a stratified sampling procedure and questionnaire survey to collect data on the perceptions of university administrative staff regarding Human-Machine Collaboration (HMC) and Administrative Efficiency (AE).

The sample size of 280 was determined on the basis of Yamane's (1967) formula for finite populations ( $N = 790$ ,  $e = 0.05$ ), which yielded a minimum requirement of 266 respondents. A total of 280 responses were therefore collected to ensure statistical adequacy and to account for the potential exclusion of invalid data.

HMC, constituting the core independent variable, is operationalized across three dimensions informed by sociotechnical systems theory and collaborative intelligence research. Task allocation measures the extent to which information systems support the identification of administrative tasks and the distribution of workload. Decision support reflects the informational assistance role of such systems in administrative decision-making processes. Collaborative efficiency assesses improvements in the speed and quality of administrative affairs processing under conditions of human-machine collaboration. AE, as the dependent variable, is measured across three corresponding dimensions grounded in university administrative practice: time management, reflecting the timeliness of administrative processes; cost control, capturing the rationality of resource utilization; and quality assurance, indicating the overall level of service quality. All items were rated on a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The instrument was adapted from established scales in the literature and subsequently refined following a pilot survey ( $n = 30$ ). Cronbach's alpha coefficients for all dimensions exceeded 0.80, indicating satisfactory internal consistency (Sürücü & Maslakci, 2020; Babamiri et al., 2024). The questionnaire incorporated both current-state and ideal-state evaluation items to provide the data necessary for subsequent Priority Needs Index (PNI) calculations.

#### 3.2 Data Analysis Methods

The analysis of the data was performed in three steps. To examine the characteristics of the samples, first, descriptive statistics were applied to analyse the sample characteristics. Second, Pearson correlation analysis was used to study the association between HMC and AE. Third, priority areas to be improved were identified by using the Priority Needs Index Modified (PNI Modified).

The PNI Modified was determined using the formula:

$$\text{PNI Modified} = (\mathbf{I} - \mathbf{D}) / \mathbf{D},$$

where **I** is the desired (preferred) state and **D** is a current state (Wiratchai, 1999; Wongwanich, 2015). An increase in values will mean that more priority needs are necessary.

This study introduces the PNI (Prognostics and Evaluation) model to address the lack of empirical evidence in existing research regarding the priority of improvements in various aspects of human-machine collaboration. It is not used as a hypothesis testing tool, but solely to identify key optimization areas for human-machine collaboration governance in local universities, providing empirical evidence for the subsequent construction of efficiency improvement models.

### 3.3 Model Development and Validation

#### 3.3.1 Model Construction

Based on the theoretical framework, this paper constructs a conceptual model of the impact of HMC (Hardware Management Center) on AE (Action and Effect). HMC includes three dimensions: task allocation, decision support, and collaborative efficiency. AE includes three dimensions: time management, cost control, and quality assurance. This study examines the relationship between human-machine collaboration and administrative efficiency, focusing on identifying priority areas for improvement rather than testing causal hypotheses.

#### 3.3.2 Model Validation

Model validation is conducted in three steps: First, reliability analysis tests the internal consistency of the scale; Cronbach's  $\alpha$  for each dimension is higher than 0.70. Second, Pearson correlation analysis is used to test the association between HMC and AE. Finally, the PNI diagnostic results are combined to identify priority areas for improvement, providing empirical support for the model.

## 4. Results

### 4.1 Demographic Characteristics

**Table 3.** Demographic Characteristics of the Sample

Research variables	category	Frequency (n)	Percentage (%)	Valid percentage (%)
gender	male	162	57.9	57.9
	female	118	42.1	42.1
age	≤25 years old	22	7.9	7.9
	26-35 years old	126	45.0	45.0
	36-45 years old	84	30.0	30.0
	≥46 years old	48	17.1	17.1
Years of service	≤3 years	70	25.0	25.0
	4-8 years	98	35.0	35.0
	9-15 years	70	25.0	25.0
	≥16 years	42	15.0	15.0
administrative departments	Academic Affairs Department	56	20.0	20.0
	Human Resources Department	42	15.0	15.0
	Finance Department	28	10.0	10.0
	Student Affairs Department	70	25.0	25.0
	Logistics Department	42	15.0	15.0
	Information Center	42	15.0	15.0
Educational level	Undergraduate institutions	182	65.0	65.0
	vocational colleges	98	35.0	35.0
Student population	large-scale	140	50.0	50.0
	medium size	98	35.0	35.0
	small-scale	42	15.0	15.0

The sample demonstrated a balanced gender composition and was predominantly comprised of young and middle-aged respondents, with those aged between 26 and 45 accounting for approximately 75% of the total sample. Work

experience was distributed across all career stages, with mid-career respondents constituting 35.0% of the sample. Representatives from all major administrative departments were included, suggesting the absence of substantial sampling bias. Among the participating institutions, undergraduate colleges and universities accounted for 65.0% of the sample, a distribution reflective of institutional scale and broadly consistent with the general composition of higher education in Wenzhou.

#### 4.1 Correlation Analysis

Pearson product-moment correlation analysis was conducted to examine the relationship between human-machine collaboration (HMC) and administrative efficiency (AE). The results indicate a significant positive correlation between HMC and AE ( $r = 0.680$ ,  $p < 0.001$ ), suggesting a strong linear association between the two variables (see Table 4).

**Table 4.** Correlation Analysis of HMC and AE

Variable	Mean	SD	1	2
1. Human-machine collaboration	3.62	0.51	1.000	
2. Administrative efficiency	3.43	0.53	0.680**	1.000

Note: \* $p < 0.001$

#### 4.2 Multiple Linear Regression Analysis

To further examine the predictive effect of HMC on AE, multiple linear regression analysis was performed. The model was statistically significant ( $F = 239.11$ ,  $p < 0.001$ ), indicating a valid linear relationship between the variables.

The results show that HMC has a significant positive effect on AE ( $\beta = 0.680$ ,  $p < 0.001$ ). The model explains 45.9% of the variance in administrative efficiency (Adjusted  $R^2 = 0.459$ ), reflecting a moderate to high explanatory power.

**Table 5.** Regression Analysis of HMC on AE

Variable	B	SE	$\beta$	t	p
Constant	0.863	0.032	—	27.260	0.000
Human-machine collaboration	0.707	0.046	0.680	15.463	0.000
Model Fit Statistics	Value				
$R^2$	0.462				
Adjusted $R^2$	0.459				
F-value	239.11 ( $p < 0.001$ )				

These findings collectively demonstrate that human-machine collaboration constitutes a significant determinant of administrative efficiency in universities. The strong positive correlation ( $r = 0.680$ ) indicates that higher levels of collaboration between human actors and intelligent systems are systematically associated with improvements in administrative performance. Furthermore, the regression results confirm that HMC exerts a statistically significant predictive effect on AE, lending empirical support to the proposed theoretical relationship.

These findings further suggest that administrative efficiency can be meaningfully enhanced through the strengthening of human-machine collaboration mechanisms, encompassing integrated information systems, decision-support systems, and cross-departmental digital coordination. This provides empirical substantiation for the conceptual model advanced in this study and establishes an evidential foundation upon which the subsequent Priority Needs Index (PNI) analysis and governance model development are constructed.

#### 4.3 PNI Analysis Results

##### 4.3.1 PNI of HMC

The Priority Needs Index values indicate the extent to which individual items exhibit either a surplus or deficiency relative to their positional relevance, thereby identifying those areas warranting prioritized attention in administrative

management. Based on the rankings presented in Table 6, Items 2, 1, and 5 demonstrate comparatively higher priority needs, while the remaining items register low to moderate priority levels, rendering them appropriate candidates for inclusion in subsequent improvement planning.

**Table 6.** PNI Analysis Results of HMC

Question content	Current level (C)	Importance (I)	Designability (D)	PNI (IC)	PNI (ID)	Demand level
1. The system will automatically allocate an appropriate workload based on the complexity of the task.	3.85	4.50	4.30	0.144	0.105	2
2. The system can effectively identify and assign key parts of the task.	3.90	4.60	4.40	0.152	0.114	1
3. The system demonstrates high flexibility in task allocation.	3.80	4.40	4.20	0.136	0.095	6
4. The system's recommendations can significantly assist the decision-making process.	3.92	4.55	4.35	0.138	0.099	4
5. The system will update suggestions in real time to adapt to changing situations.	3.95	4.60	4.40	0.141	0.102	3
6. The system's recommendations are highly consistent with the judgments of human decision-makers.	3.88	4.50	4.30	0.138	0.098	5
7. Human-machine collaboration is more efficient than individual work.	3.88	4.45	4.25	0.128	0.087	8
8. The system reduces the cognitive burden on humans when performing tasks.	3.90	4.50	4.30	0.133	0.093	7
9. Human-machine collaboration improves the quality of task completion.	3.85	4.40	4.20	0.125	0.083	9

#### 4.3.2 PNI of AE

**Table 7.** PNI Analysis Results of AE

Question content	Current level (C)	Importance (I)	Designability (D)	PNI (IC)	PNI (ID)	Demand level
1. Administrative tasks can be completed within the planned timeframe.	3.76	4.50	4.30	0.164	0.126	1
2. The system can effectively optimize task time allocation.	3.80	4.45	4.25	0.146	0.106	4
3. No unnecessary time is wasted in the administrative process.	3.75	4.40	4.20	0.148	0.107	2
4. Administrative costs have been effectively controlled.	3.95	4.60	4.40	0.141	0.102	8
5. The system can identify and reduce unnecessary expenditures.	3.90	4.55	4.35	0.143	0.103	7
6. Maximize the utilization rate of administrative resources.	3.85	4.50	4.30	0.144	0.105	6
7. The quality of administrative services has continued to improve.	3.89	4.55	4.35	0.145	0.106	5
8. The system can monitor and improve service quality in real time.	3.92	4.60	4.40	0.148	0.109	3
9. The error rate in administrative processes has been significantly reduced.	3.88	4.50	4.30	0.138	0.098	9

Table 7 presents the Priority Needs Index (PNI) results for each item pertaining to Administrative Efficiency (AE). The PNI assesses improvement urgency by quantifying the deviation between the gap of importance and current performance level relative to the gap of importance and desired performance level. Higher PNI values indicate a greater discrepancy between perceived importance and actual conditions, alongside stronger feasibility for improvement. The results identify Items 1, 3, and 8 as high-priority areas, corresponding respectively to "administrative task time management," "administrative process time optimization," and "real-time service quality monitoring." These items are characterized by high perceived importance, low current performance levels, and strong design feasibility, collectively designating them as the primary priorities for enhancing administrative efficiency. The remaining items register comparatively lower priority levels and may be addressed sequentially following the optimization of these core areas, subject to the availability of institutional resources.

#### 4.4 Generation of the AEGIS-Wenzhou Human-Machine Collaboration Model for Improving Administrative Efficiency

Based on the preceding analyses and PNI diagnostic results, the present study integrates the empirical evidence to construct the "AEGIS-Wenzhou Model." Human-machine collaboration serves as the primary driving force of the model, which simultaneously addresses three interconnected areas of improvement: Intelligent Assignment and Classification of Tasks (IADC), Automated Workload Allocation (AWA), and Real-Time Resource Reallocation and Update (RRRU). These collaborative mechanisms correspond respectively to three performance indicators: Administrative Tasks Completed according to Plan (ATC), Reduction in Time Wasted (RTW), and Real-Time Monitoring of Quality (RMQ). Collectively, these components constitute a structured and ordered system linking collaborative mechanisms to performance outcomes (Agasisti et al., 2025).



**Figure 2.** AEGIS-Wenzhou Model

The Implementation Level of the "AEGIS-Wenzhou Model" is not a fixed structure; instead, it has developed into a prioritised forward-moving road according to changes in PNIs. In other words, the first optimises IADC for improved ATC; The second reinforces AWA for enhanced RTW; Finally, connect RRU to guarantee RMQ. Using a 3-stage approach to perform human-machine collaborative optimisation and enhance university administrative management efficiency.

## 5. Discussion

This study identifies the areas requiring most urgent attention in efforts to enhance university administrative efficiency through human-machine collaboration. Empirical findings confirm a significant association between HMC and administrative efficiency, with improvements in the latter systematically linked to advances in the former. Within the HMC dimension, the highest-ranked priority is "key task identification," followed by "complexity-based automatic allocation," and subsequently "real-time system context update" — reflecting that existing collaborative optimization is concentrated at the front-end stages of task definition and resource allocation, while post-operational system alert mechanisms remain comparatively underdeveloped.

The priority order within the AE dimension may be summarized as follows: completing work within allocated timeframes; reducing wasted time; and monitoring real-time service quality. Taken together, both priority sequences reveal a coherent structural correspondence: HMC addresses optimization at the level of structural inputs, whereas AE captures the resulting effects on time and quality outputs. This correspondence directly addresses the central research problem of the study — that human-machine collaboration improves administrative efficiency not through direct

intervention at the outcome level, but through the enhancement of initial system configuration and decision-making mechanisms.

The elevated priority assigned to dynamic updating capability reflects the distinctive organizational characteristics of university administration, which is marked by situational volatility and cross-departmental overlap. Although administrative tasks are broadly governed by institutional regulations, their execution is readily disrupted by unforeseen changes. In the absence of real-time corrective capabilities, deviations introduced at the front-end task allocation stage are liable to be compounded throughout subsequent processes (Li & Yeo, 2024; Ghose et al., 2025). Sociotechnical systems theory underscores the structural coupling of technology and organizational context (Ang et al., 2025). The present study extends this proposition by demonstrating that in highly institutionalized yet situationally volatile organizations such as universities, the dynamic adaptability of technology is a more robust explanatory variable for performance differences than the scale of technological investment; it is the embedded position and responsiveness of technology within organizational workflows that ultimately determines its governance value.

At the outcome level, both "improving task completion quality" and "reducing administrative process error rates" are ranked ninth. This ranking does not reflect a lack of importance, but rather indicates that quality assurance and error control are objectives belonging to a more advanced stage of collaborative development (Zheng et al., 2025), one that presupposes a stable front-end task structure and clearly delineated responsibility boundaries. When task identification and allocation mechanisms remain in the optimization phase, the institutionalization of outcome-level controls is difficult to fully establish. Activity Theory posits that tools restructure the logic of action within activity systems through their mediating function. The present findings corroborate this proposition: when technological tools first establish structural constraints at the process origin, their influence propagates along the action chain to affect quality and operational stability. The lower ranking of outcome indicators thus reflects the reality that the collaborative structure has not yet been fully institutionally embedded, rather than any inherent functional inadequacy.

The correspondence between HMC and AE priority rankings reveals a progressive improvement pathway extending from structural inputs toward execution outputs, directly addressing RQ2: the impact of human-machine collaboration is not linearly diffused, but follows a sequenced logic of dynamic adaptation priority (HMC-3), quality optimization (HMC-9), and error control extension (AE-9). This also explains why enhancing evaluation systems in isolation is insufficient to improve administrative efficiency; rather, it is the optimization of underlying processes that generates meaningful gains. The effectiveness of collaborative mechanisms is therefore determined not by the volume of technologies deployed, but by the degree to which those technologies are appropriately embedded within the organizational context.

In addressing RQ2, the findings indicate that the effect of HMC on administrative efficiency is structured and progressive in nature, rather than constituting a direct linear impact. Specifically, the highest-priority HMC items — task identification, complexity-based allocation, and adaptive system updating — are concentrated at the process-input level, whereas AE priorities converge on time efficiency and service quality at the process-output level.

Importantly, the findings suggest that HMC is significantly associated with, though not demonstrated to be a direct cause of, improvements in administrative efficiency. The correlation and regression results ( $r = 0.680$ ,  $p < 0.001$ ;  $\beta = 0.680$ ,  $p < 0.001$ ) indicate a strong predictive relationship; however, given the cross-sectional nature of the study design, causal inferences should be drawn with appropriate caution. The results are more appropriately interpreted as supporting a mechanism-based explanation, whereby HMC enhances efficiency through improved task structuring, decision-support processes, and adaptive system responses.

Theoretically, these findings are consistent with sociotechnical systems theory, which emphasizes the interdependence of technological capabilities and organizational structures. The present study extends this theoretical tradition by demonstrating that within highly institutionalized yet dynamic administrative environments — such as those characteristic of universities — the effectiveness of technology is contingent upon whether it has been adaptively integrated into established workflows.

Furthermore, the priority rankings reveal a distinct sequential logic: front-end structural optimization (task identification and allocation) constitutes the first order of intervention, followed by mid-process adaptability (dynamic updating), with outcome-level performance improvements (quality assurance and error reduction) emerging as the final stage. This progressive sequence explains why outcome indicators are ranked lower — not because they are of lesser importance, but because their realization is dependent upon the prior stabilization of process structures.

Collectively, these findings suggest that improving administrative efficiency requires a process-based and sequentially structured intervention approach, rather than isolated technological enhancements. The proposed AEGIS–Wenzhou

Model embodies this logic by integrating Deming's PDCA cycle (Plan–Do–Check–Act) (Deming, 1986) with the prioritized HMC improvement sequence, enabling iterative refinement and contextual adaptation at each stage. By translating the priority order into concrete improvement directions, the model's core contribution lies in its demonstration that technological performance is progressively realized through structural embedding and dynamic adaptation (Liang, 2024). The human-machine collaboration mechanism identified in this study thus indicates that local universities seeking efficiency gains must simultaneously advance front-end process optimization and institutional integration, proceeding in accordance with a clear priority sequence and progressive developmental logic.

## 6. Conclusion

In response to the prevailing challenges confronting administrative management efficiency in local universities, the present study systematically examined governance practices in universities across the Wenzhou region from the perspective of human-machine collaboration, and constructed the "AEGIS–Wenzhou Model." The findings reveal significant structural variation in the adoption and implementation of human-machine collaboration among universities in Wenzhou, indicating that an integrated governance model has yet to be established at the institutional level. Critically, the study demonstrates that improving administrative efficiency does not depend on a comprehensive intensification of collaboration across all dimensions, but rather hinges on the targeted optimization of front-end processes — particularly task identification and allocation. These front-end collaborative mechanisms exert amplifying effects throughout subsequent administrative processes, thereby providing an empirical basis for the application of human-machine collaboration in university governance.

From a theoretical standpoint, the study extends the application of Sociotechnical Systems Theory and Activity Theory to the domain of higher education governance, elucidating the practical pathways through which human-machine collaboration is embedded within organizational processes and translated into governance performance. It further enriches context-sensitive research perspectives by demonstrating that local universities must adopt a sequentially structured optimization approach that addresses existing deficiencies in a prioritized and progressive manner. At the practical level, the AEGIS–Wenzhou Model offers a concrete and operationalizable pathway for enhancing administrative efficiency within the constraints of limited institutional resources. At the policy level, the assessment frameworks for university digital governance should be reoriented toward evaluating collaborative effectiveness rather than technological investment alone. Educational administrative authorities are encouraged to strengthen the alignment between technology adoption and organizational processes, so as to facilitate the orderly and sustainable development of human-machine collaboration (Wang & Liang, 2024; Liang, 2024).

The present study is subject to certain limitations. The reliance on cross-sectional data precludes the observation of the dynamic evolution of governance effects over time. Furthermore, as the sample is concentrated within Wenzhou, the generalizability of the findings to broader regional or national contexts cannot be fully guaranteed. Future research would benefit from the incorporation of longitudinal data and comparative research designs, enabling systematic examination of governance practice variations across universities in different regions, and facilitating the ongoing refinement and expansion of the human-machine collaborative governance model.

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XL was responsible for conceptualization, investigation, formal analysis, and writing the original draft. SR contributed to methodology development, validation, supervision, and writing-review and editing. AW review and editing. All authors reviewed and approved the final manuscript.

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