



Data-Driven Evaluation of Leadership Competency Development for Elementary School Principals: A Systems Engineering Approach

*Nurtanio Agus Purwanto**, Lia Yuliana

Universitas Negeri Yogyakarta, Yogyakarta, Indonesia

Correspondence: E-mail: nurtanio@uny.ac.id

ABSTRACT

This study aims to evaluate the effectiveness of an elementary school principal's leadership competency development program using a systems engineering approach integrated with science and technology principles. Employing a mixed-method design, data were collected from supervisors, principals, and teachers through questionnaires and interviews. Quantitative findings showed leadership competencies were consistently rated as good. Qualitative analysis revealed systemic barriers, such as administrative burden, inconsistent feedback, and the absence of digital monitoring systems. These factors hinder adaptive learning because they reduce collaboration and data-driven decision-making. Integrating a systems engineering mindset with real-time digital supervision and peer mentoring is essential for iterative improvements. This approach impacts educational leadership by promoting structured yet flexible feedback loops, enhancing principal performance, and supporting scalable leadership innovation within diverse school ecosystems.

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1. INTRODUCTION

In the increasingly complex landscape of education systems, leadership has emerged as one of the most influential variables in determining the quality and effectiveness of school operations. Educational leadership is not only about maintaining organizational stability, but also about designing continuous, responsive, and context-sensitive improvement processes [1-5].

Globally, numerous studies have demonstrated that principals play a critical role in influencing student learning outcomes, teacher performance, organizational climate, and overall school innovation [7-9]. As the education system reforms and expands its mandate to achieve the Sustainable Development Goals (SDGs), the role of the principal is shifting to that of a change agent, someone who must operate strategically and adaptively in an increasingly data-intensive and performance-oriented environment.

In Indonesia, educational decentralization has transferred significant responsibilities to local governments, resulting in varied capacities for school management and quality assurance across regions. Consequently, school principals must navigate dynamic regulatory frameworks, limited resources, and diverse community expectations. To address these demands, leadership development programs must not only be comprehensive but also systematically evaluated to ensure effectiveness. These programs should be aligned with the principles of results-based management (RBM), systems engineering, and continuous performance monitoring. Unfortunately, many development models in practice remain overly instructional and top-down, lacking the adaptive mechanisms needed to generate real, scalable change.

The Indonesian Ministry of Education and Culture formally acknowledges the importance of principal leadership through Permendiknas No. 13/2007, which defines five key competencies: (i) personality, (ii) managerial, (iii) entrepreneurial, (iv) supervisory, and (v) social. While these dimensions offer a comprehensive blueprint for school leadership, their operationalization in the field remains uneven. Particularly in non-urban areas, principals often receive minimal exposure to targeted training or coaching that reflects these competencies measurably. Even where programs exist, they are frequently administrative and fail to integrate modern evaluation metrics or data visualization tools to track progress over time.

Furthermore, in many regencies, including Sleman in the Special Region of Yogyakarta, principal development programs tend to rely on instructive supervision. This model positions supervisors as primary actors who deliver knowledge and monitor compliance, rather than as facilitators of professional learning. Although this approach offers structure and clarity, it limits the potential for distributed leadership, peer learning, and context-specific innovation. In modern systems engineering, such rigidity is seen as a limitation, as adaptive systems require feedback loops, mutual accountability, and decentralized decision-making capabilities [10].

In line with global shifts toward evidence-based policymaking and performance-driven public sector reform, educational leadership development must also evolve. There is a growing consensus among scholars and practitioners that principal development should be guided by data-informed strategies, incorporating real-time monitoring, structured mentoring, and dynamic planning [11]. These components are essential for designing responsive and robust educational ecosystems. As such, the integration of *Results-Based Management (RBM)* offers a promising framework. RBM emphasizes the definition of clear

outcome indicators, the alignment of inputs and processes, and the establishment of mechanisms for continuous feedback and correction [12].

Sleman Regency provides a particularly useful case study for exploring the effectiveness of such a model. With a combination of urban, peri-urban, and rural characteristics, Sleman encompasses 17 sub-districts and over 400 elementary schools. This diversity presents both challenges and opportunities for leadership development. On the one hand, the heterogeneity of school contexts allows for a wide range of experiences and learning environments; on the other, it complicates the implementation of standardized development programs. The region's Education Office has initiated a development program that adopts an instructive model supported by supervisory visits, managerial coaching, and structured forums such as the *Kelompok Kerja Kepala Sekolah* (KKKS).

However, the implementation of such programs demands empirical assessment to determine whether they meet their intended objectives and contribute to sustainable leadership enhancement. While anecdotal evidence suggests some success in aligning principal performance with managerial goals, there is a notable lack of systematic evaluation that links program activities to outcomes. Without this linkage, it becomes difficult to justify resource allocation, optimize training content, or identify areas for intervention. The application of RBM principles offers a pathway to bridge this gap by treating leadership development as a structured system whose components can be measured, monitored, and improved [13].

From a scientific and engineering perspective, the study of educational leadership development can be conceptualized as a human-centered systems engineering problem [14, 15]. This involves understanding the interactions between various subsystems, individuals, policies, organizational routines, and societal demands, and aligning them toward shared performance goals. As in other engineering fields, the success of such systems depends not only on the initial design but also on feedback mechanisms, error detection, process optimization, and stakeholder engagement. Therefore, this study seeks to apply RBM as a practical framework to evaluate how effectively the leadership development system in Sleman functions under real-world constraints.

Importantly, the study recognizes the significance of enabling and inhibiting factors in shaping the effectiveness of development programs. These include institutional support, workload allocation, interpersonal dynamics, and the availability of performance indicators. In systems terminology, these factors function as inputs, constraints, or feedback moderators, influencing the system's ability to maintain equilibrium or respond to perturbations. As such, a key contribution of this study is its articulation of how such factors operate within the leadership development ecosystem and what structural or procedural adjustments might optimize system performance.

Beyond local relevance, the study's findings have implications for the broader ASEAN region, where education systems face similar challenges, from a shortage of principals to uneven supervision coverage and a lack of performance data. Studies from countries such as Malaysia, Vietnam, and the Philippines have begun integrating digital platforms, hybrid supervision models, and AI-based performance tracking into school leadership development. Indonesia, with its vast and diverse education system, has the potential to benefit from similar innovations if supported by context-based empirical evidence and policy advocacy.

2. METHODS

This research adopted a mixed-methods design framed within the systems engineering and data-driven evaluation paradigm [14]. The study conceptualizes the principal competency

development program as a complex socio-technical system, comprising interacting human, organizational, and policy subsystems [15]. This methodological framework is based on Results-Based Management (RBM), a management engineering approach that emphasizes evidence-based decision-making, a results orientation, and continuous feedback loops. Within this paradigm, the overall leadership development model is treated as a dynamic system with defined inputs (resources, training modules, personnel), processes (mentoring, supervision, knowledge transfer), outputs (measurable competencies, stakeholder satisfaction), and outcomes (improved leadership and school performance at the system level). This system's logic reflects engineering design thinking, where each phase is iteratively evaluated and optimized using data.

2.1. Participants

Detailed information regarding participants is shown in **Table 1**. Thirty-one participants, consisting of 4 school supervisors, 9 principals, and 18 teachers, were purposively selected as system actors with different functional roles. This multi-actor configuration was designed to capture the complexity of the system and the feedback pathways between hierarchical components and peers (supervisors as system controllers, principals as process agents, and teachers as operational end-users). The diversity in participant backgrounds ensured a robust data set, akin to *multi-source sensor inputs* in engineering studies, enabling detection of systemic issues and performance variations across subsystems (urban–rural, experience, school size).

2.2 Data Collection

To capture a comprehensive picture of the system's performance, this study employed both quantitative and qualitative data collection strategies, each reflecting principles found in engineering quality assurance. On the quantitative side, data were gathered using a carefully structured questionnaire designed to function as a performance measurement instrument. This tool was meticulously crafted to align with the core principles of engineering quality assurance, ensuring objectivity, replicability, and actionable insights. The questionnaire itself was anchored around five essential competency domains for elementary school principals: planning, leadership, curriculum, supervision, and administration. Each domain was translated into a series of measurable variables, operationalized through Likert-scale items that allowed for nuanced assessment of both strengths and areas for growth [16, 17]. This approach not only provided a numerical snapshot of competency development but also facilitated cross-case comparisons and system-wide benchmarking.

Complementing the quantitative data, qualitative insights were gathered through semi-structured interviews. These interviews functioned as a diagnostic subsystem, much like problem-solving in an engineering context, offering the opportunity to delve deeper into system bottlenecks, sources of inefficiency, and misalignments in existing workflows. At the same time, the interviews enabled the identification of emergent traits such as unexpected innovations, collaborative practices, or adaptive feedback mechanisms, which may not be easily captured through quantitative methods alone. By integrating these two data streams, the study was able to map not only what was happening in the system but also why certain patterns and challenges emerged [18, 19]. Ensuring the rigor and credibility of the data collection instruments was a primary concern. In parallel with the engineering verification process, validity testing was conducted to ensure that each questionnaire item accurately measured the intended domain and that the interview protocol yielded relevant and reliable

information. This systematic validation process enhanced the integrity and robustness of the research findings.

Finally, ethical considerations were treated with the same seriousness as compliance protocols in engineering projects. This research was conducted under the approval of the relevant ethics committee, and written informed consent was obtained from all participants. This commitment to ethical rigor not only protects the rights and well-being of those involved but also strengthens the integrity of the research process.

Table 1. Profile of study participants.

Participant Group	Number of Participants	Experience Range (Years)	Average Experience (Years)
School Supervisors	4	5–12	9.0
School Principals	9	7–14	10.0
Teachers	18	8–22	15.0
Total	31		

Note: From Sleman Regency: 4 school supervisors, 9 elementary school principals, and 18 teachers. Participants were selected to represent various sub-districts across urban and rural contexts, ensuring diversity in experience, school size, and leadership backgrounds. All participants had been directly involved in the competency development program over the previous two academic years. Supervisors had experience ranging from 5 to 12 years in leadership monitoring, while principals and teachers had an average professional experience of 10 and 15 years, respectively. Their perspectives were deemed essential for assessing the multi-layered aspects of program implementation.

2.3 Data Analysis

Quantitative analysis was conducted using descriptive and comparative statistics to evaluate system outputs, with mean scores and standard deviations used as indicators of system performance. Cross-group comparisons identified areas where the system (leadership development program) was functioning efficiently or revealed systemic gaps. Qualitative analysis followed a thematic coding process, followed by parallel engineering root cause analysis aimed at identifying enabling and inhibiting factors, communication breakdowns, and potential points of system failure or optimization. Inter-coder reliability checks served as a validation step to ensure the integrity and replicability of the system's diagnostics.

2.4 Integration: Data-Driven System Feedback

Findings from qualitative and quantitative data are integrated into a feedback-based evaluation cycle, which is the core of an engineering-inspired control system for developing core competencies. Quantitative results generated from structured surveys and performance metrics highlight which system components or competency domains are underperforming, serving as critical input for system monitoring and benchmarking [21]. Meanwhile, qualitative insights provide rich contextual understanding of the root causes behind these performance patterns, such as challenges in instructional leadership, barriers to collaboration, or context-specific administrative constraints.

By combining both types of data in a continuous feedback loop, the evaluation cycle supports the principle of continuous improvement, a concept fundamental not only to engineering and quality management but also to contemporary educational leadership. This integrative approach ensures that school superintendents and policymakers are equipped with actionable intelligence: quantitative data identifies what is happening, while qualitative data clarifies why. As a result, interventions can be more precisely designed, targeted, and adapted, resulting in more effective system redesign or process improvements.

This dynamic, evidence-based strategy aligns with global best practices in education systems engineering, enabling the principal development program in Sleman to remain adaptive and responsive to changing needs and emerging challenges [21]. Ultimately, this iterative cycle of data collection, analysis, feedback, and improvement helps foster a culture of learning and resilience at every level of the education ecosystem.

2.5 Integration: Data-Driven System Feedback

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2.6 Conceptual Model and Visualization

This study maps the main development model into a systems engineering diagram, where each subsystem and feedback loop is explicitly identified as depicted in **Figure 1**.

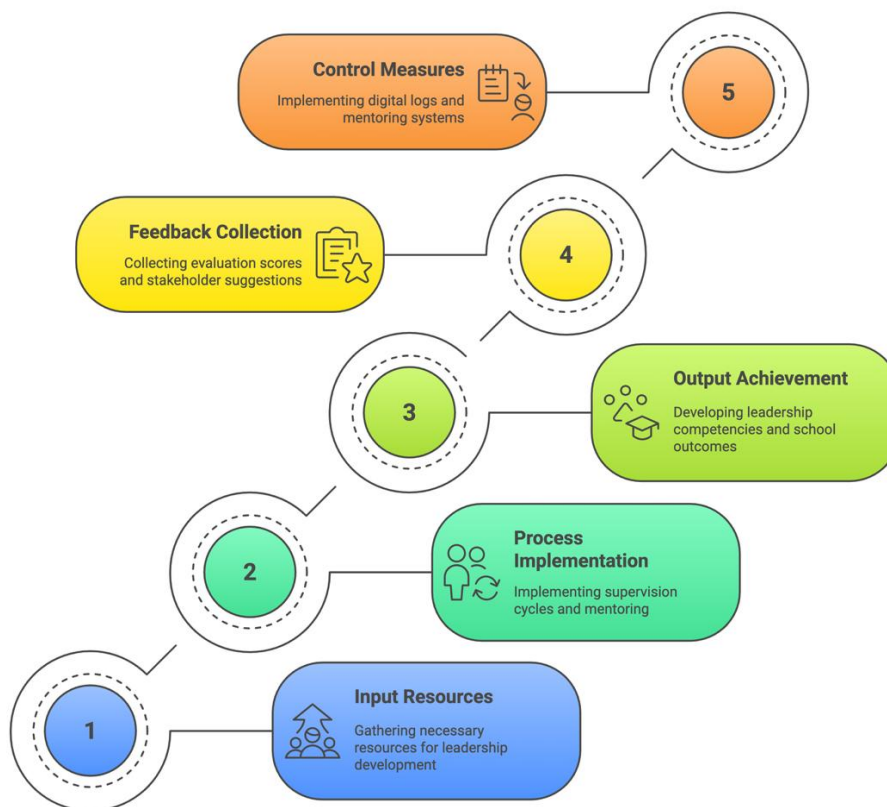


Figure 1. Achieving leadership competencies.

By adopting a systems engineering approach to educational program evaluation, this study seeks to ensure that each stage of the methodology used is transparent, structured, and replicable by other researchers. This approach not only allows for a systematic evaluation of the entire principal development program but also allows for continuous improvement based on empirical findings from the field. Through this data-driven evaluation process, the research findings are expected to be relevant not only to the Indonesian context but also to serve as a model that can be adapted for engineering similar educational interventions in the broader Southeast Asian region.

3. RESULTS AND DISCUSSION

3.1. System Architecture and Process Mapping of the Leadership Development Model

The primary school principal competency development model in Sleman Regency is best understood as a hierarchical socio-technical system. Within this framework, the school supervisor is positioned as the core controlling agent, orchestrating the flow of guidance, supervision, and managerial oversight. The principal acts as a key process node, situated at the intersection of policy directives and practical school management. Regular supervisory visits, scheduled with careful consideration of available resources, are conducted, considering that a single supervisor is responsible for 40 to 50 schools, thus serving as crucial checkpoints for monitoring, support, and compliance within this designed system.

A closer look at the operational workflow of this model reveals a structure that remains fundamentally instructional and top-down. Supervisors routinely provide coaching, conduct administrative checks, and provide formal managerial direction during their visits. While these efforts are important for maintaining standardization and accountability, they often reinforce a culture in which innovation is driven from the top, and principals are primarily viewed as implementers rather than active co-creators. To foster collegiality and encourage peer support, the system incorporates coordinating forums such as the Principals' Working Group (KKKS), a professional learning community for school leaders. These forums act as a crucial subsystem, designed to enable the exchange of ideas, collaborative problem-solving, and shared technical support. However, the effectiveness of these forums can fluctuate, greatly influenced by the quality of leadership within the group and the availability of resources for meaningful engagement.

Recognizing the need for greater agility and responsiveness within the system, the Sleman Education Office has introduced school clustering. This grouping of schools is based on geographic proximity and rotation of supervision themes, such as focused sessions on curriculum review or academic supervision practices. This approach aims to maximize limited supervision resources, distribute support more equitably, and provide principals with broader development experiences. Despite these adaptive measures, system diagnostics indicate that the workflow remains dominated by directives. Principals, while increasingly engaged in collaborative activities, remain positioned as recipients of top-down direction, rather than equal partners in shaping innovation.

One persistent limitation of this model is the lack of integrated digital documentation and systematic peer mentoring. The absence of a shared digital platform for recording supervision findings, action plans, and follow-up progress means that valuable feedback is often lost or tracked inconsistently, reducing the system's overall memory and capacity for cumulative learning. Similarly, opportunities for reciprocal peer mentoring, where principals learn directly from each other, remain underdeveloped, leaving much of the professional growth process dependent on supervisors' initiatives, rather than embedded in the principals' daily professional interactions. This highlights a key area for future development: building a more balanced and interactive system in which principals are empowered not only to receive guidance but also to actively contribute to and co-create ongoing school improvement efforts.

3.2. System Enablers: Supporting Factors for Effective Performance

Figure 2 is the illustration for understanding system resilience through levels of proactive support. In general, when viewed through a systems engineering lens, several supporting factors are crucial to ensuring the effective and sustainable operation of the principal competency development model in Sleman Regency. First and foremost is the coordination mechanism established among supervisors. Regular, structured meetings are not simply

administrative routines; they serve as crucial feedback loops, enabling the alignment of supervisors' in-person visit schedules, flexible adjustment of development priorities, and early identification and resolution of operational redundancies. This consistent coordination not only clarifies the roles and responsibilities of each supervisor but also strengthens the coherence of the overall system. This, in turn, results in more effective follow-up actions and a greater sense of collective purpose among those responsible for mentoring principals.

Equally important is the KKKS forum, which acts as a peer-driven subsystem within the broader model. This professional community serves as a dynamic hub for collaborative learning, allowing principals to share insights, discuss challenges, and provide technical and emotional support to one another. By encouraging distributed knowledge sharing and mutual support, these forums help the system adapt more smoothly to inevitable fluctuations and uncertainties, such as policy changes or local disruptions that can impact school operations. The adaptive capacity fostered within these peer groups contributes significantly to system resilience and continuous improvement.

Institutional support from the Sleman Education Office also plays a crucial role. This support takes the form of clear policy guidelines, structured skills-building programs, and dedicated resource allocation for principal development. This high-level involvement serves as an additional layer of system stability or redundancy, ensuring that, even when individual components experience challenges, the overall program remains resilient and operational. Institutional commitment provides the necessary framework for consistency and innovation across the school network.

Strong communication channels are another cornerstone of optimal system functioning. Open, consistent, and multidirectional communication practices create pathways for direct feedback, allowing principals, supervisors, and policymakers to share updates, clarify expectations, and address emerging issues quickly. These channels reduce the risk of misinterpretation or misalignment between school-level actions and broader system goals. As a result, problem-solving is accelerated, and all parties involved can move forward with greater confidence and shared understanding.

When these factors work together, they demonstrate a key lesson from systems engineering: technical solutions like better scheduling, digital tools, or procedural checklists are necessary, but not sufficient on their own. For a system to reach its full potential and remain resilient in the face of changing demands, these interventions must be balanced with strong relational and structural alignment. Ultimately, human collaboration, institutional support, and effective communication are as important as any technical fix. By addressing both the technical and social dimensions of the system, the Sleman model is better positioned to cultivate capable, innovative, and adaptive school leaders for the future.



Figure 2. Understanding system resilience through levels of proactive support.

3.3. System Bottlenecks: Inhibiting Factors and Points of Failure

Figure 3 shows the illustration of how inefficient supervision hinders school improvement. While the design of Sleman Regency's principal competency development model boasts several strengths, a closer look at system diagnostics reveals notable bottlenecks and constraints that continue to limit overall effectiveness. Excessive administrative burden is a persistent input constraint. Principals frequently report that the sheer number of administrative tasks, from mandatory reporting and documentation to compliance with ever-evolving regulations, disproportionately absorbs their time and energy. This administrative burden diverts attention and resources from more meaningful activities, such as reflective supervision and ongoing professional development. As a result, principals' capacity to engage deeply in the development process is often compromised, leading to missed opportunities for continued growth and innovation.

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Interpersonal tensions further hamper system performance. Differences in communication preferences and leadership styles can create subtle but significant barriers, sometimes leading to misunderstandings, disengagement, or even a reluctance to fully participate in mentoring relationships. When trust or rapport is lacking, principals tend to be reluctant to seek advice, share challenges openly, or take advantage of learning opportunities from peers. This process inefficiency means that the system's human resources are not being optimally utilized.

Another critical gap is the lack of quantitative performance indicators. Currently, the system does not use a consistent set of standard metrics to assess and compare the results of supervisory activities. Without such benchmarks, it is difficult to objectively measure the impact of interventions, identify areas for improvement, or implement targeted process optimizations. The absence of data-driven performance measurement ultimately limits the system's capacity for evidence-based decision-making and continuous quality improvement.

Supervisory limitations are also a serious constraint. Each supervisor is responsible for overseeing an average of 40–50 schools, making it impossible to provide regular and in-depth support to each principal. As a result, supervisory visits tend to be short and infrequent, reducing the frequency and quality of feedback. This weakens the system's overall adaptive capacity, as principals may not receive actionable feedback or direction for extended periods, slowing their response to emerging challenges.

Finally, feedback mechanisms remain largely informal and inconsistent. Most feedback provided during supervisory visits is delivered verbally, with little to no structured documentation or systematic follow-up. Without reliable records of observations, recommendations, and agreed-upon action plans, valuable insights are easily lost, and the link between feedback and actual improvement remains tenuous. This weakens accountability and reduces the effectiveness of the feedback-to-action cycle.

Overall, these challenges point to a clear need for innovation. Introducing digital monitoring tools and interactive data dashboards can help simplify documentation, enable real-time performance tracking, and support more consistent follow-up. At the same time, developing a joint evaluation protocol, where supervisors and principals engage in two-way

assessments, can foster a stronger culture of accountability and shared learning. By implementing these tools and approaches, the system can close critical performance gaps, accelerate the learning cycle, and better fulfill its mission of developing effective and adaptive school leaders.

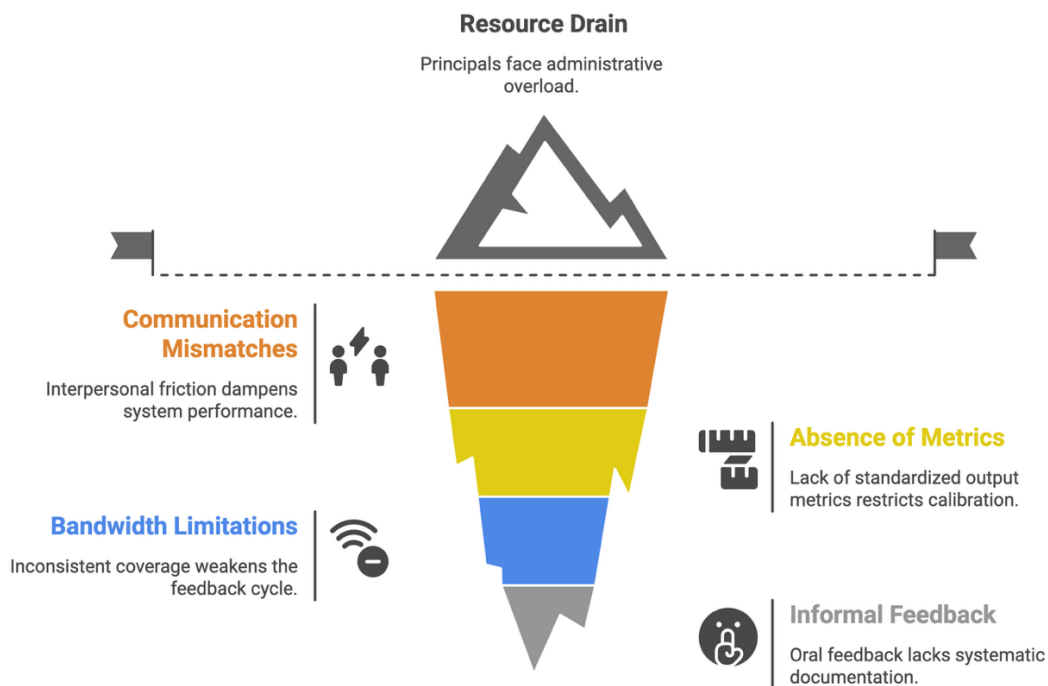


Figure 3. Inefficient supervision hinders school improvement.

3.4. Feedback, Control Loops, and Data-Driven Adjustments

Effective systems require robust control mechanisms and closed-loop feedback cycles. However, the current implementation relies on informal, transient feedback and lacks formalized protocols for tracking progress or verifying post-feedback changes. This absence undermines the system’s self-correction capacity and slows the optimization of leadership practices. Interview diagnostics reveal a perception gap: many principals view supervisory feedback as generic and lacking prioritization, while teachers sometimes do not see recommendations transmitted into actionable school-level changes. This suggests signal attenuation within the feedback loop, lowering the system's collective efficacy. Pilot initiatives such as digital supervision logs and peer mentoring summaries have been trialed to capture feedback data and enhance traceability, but full-scale institutionalization remains a work in progress. Benchmarking with advanced ASEAN education systems suggests that integrated digital review systems and reciprocal evaluation (supervisors evaluating each other and being evaluated) significantly increase accountability and continuous improvement.

3.5. Quantitative Findings

The findings are shown in **Table 2**. Analysis of system output metrics reveals a generally "good" level of performance across the four assessed competency domains. Notably, principals tend to self-rate higher than their supervisors or teachers, indicating a potential system calibration gap or self-perception bias among process agents. Academic supervision planning scored highest across all groups, reflecting the system's emphasis on structured processes. In contrast, slightly lower scores for execution and curriculum development signal

performance drag in translating plans into action and fostering curricular innovation. This points to the need for targeted process enhancement, capacity-building interventions, and more granular data collection to track micro-level system improvements.

Table 2. Average scores of principal competency areas.

Competency Area	Supervisors	Principals	Teachers
Managerial Competence	3.89	4.19	3.79
Academic Supervision Planning	4.13	4.44	3.89
Supervision Execution Curriculum Development	3.82	4.30	3.71
	3.83	4.11	3.72

3.5. In-Depth Analysis and Implications

Quantitative evaluations indicate that the principal competency development program in Sleman Regency currently consistently ranks in the "good" category. While this demonstrates fundamental effectiveness, the system has not yet reached optimal or "very good" conditions. This gap indicates opportunities for system-wide improvement, particularly considering the ambitious goals of educational transformation and organizational excellence.

From a systems engineering perspective, these results indicate a stable but not yet high-performing system. The instructional coaching model, in which the supervisor acts as the primary controlling agent, has been successful in establishing clear expectations and core competencies. However, this top-down approach risks hindering the system's adaptability by insufficiently activating feedback channels for innovation, reflection, and learning between principals [22]. In engineering terms, the system operates with a closed-loop controller that lacks adequate lateral (peer-to-peer) feedback, which is essential for dynamic optimization and adaptive learning [21].

Qualitative diagnostics support this view, revealing that feedback loops in the system are often one-way and poorly documented, limiting data retention and knowledge transfer. The lack of standardized evaluation tools for supervisors also means a lack of mutual accountability, which reduces the system's potential for self-correction and continuous improvement, a core principle of systems engineering [23].

The literature on educational leadership development and organizational change management confirms the critical role of structured mentorship, collaborative learning environments, and reflective practice in enhancing system performance. Effective educational systems, like high-reliability engineering systems, are characterized by robust internal communication, ongoing professional dialogue, and shared responsibility for outcomes. The lack of such mechanisms in the current model represents a form of organizational inertia that can stall further improvement. Experiences from Malaysia and Vietnam demonstrate that integrating mutual evaluation tools, adaptive leadership frameworks, and digital supervision platforms strengthens feedback loops and accelerates organizational learning. These enhancements also enable data-driven decision-making at all levels, supporting both transparency and accountability.

One of the strategic steps proposed in this research is a paradigm shift from a transactional development model to a more transformational and collegial one. This means that the principal development process is no longer solely oriented towards one-way instruction, but rather emphasizes collaboration through ongoing professional dialogue, joint workshops, and problem-solving forums involving various parties. This approach is believed to build collective

intelligence and encourage the emergence of adaptive leadership within the school environment. Furthermore, it is crucial to integrate standardized, digital-based performance measurement tools into the evaluation process for both principals and supervisors. By utilizing digital platforms and data dashboards, monitoring of performance indicators can be conducted more transparently, in real time, and easily analyzed. This simultaneously opens opportunities for more data-driven decision-making and increases overall system accountability. It is also crucial to strengthen networks among principals through peer mentoring mechanisms and collaborative learning communities. These efforts will accelerate the dissemination of best practices, encourage innovation, and foster a culture of reflection in school leadership. Such collaboration can also help principals face the increasingly complex challenges of the digital age.

On the other hand, challenges remain related to limited supervisor resources. Therefore, increasing the number of supervisors needs to be balanced with the use of digital supervision technology, such as e-mentoring platforms or asynchronous feedback tools. This way, the scope of coaching can be expanded without sacrificing the quality of the required interactions. The next recommendation is the importance of integrating principal competency data into the education quality assurance ecosystem at the regional level. This integration will enrich the database for policymaking, allowing capacity-building interventions to be more targeted, adaptive, and responsive to real needs on the ground. Finally, coaching programs need to implement a continuous and structured evaluation cycle, following the Plan-Do-Check-Act (PDCA) principle commonly used in engineering. This cycle ensures regular review, feedback gathering, and iterative program refinement, so that the quality of principal development can continuously improve in line with the dynamics of educational challenges.

3.6. Alignment with Sustainable Development Goals (SDGs)

The conceptual alignment of the leadership development system in Sleman Regency with selected Sustainable Development Goals (SDGs), particularly SDG 4 (Quality Education), SDG 16 (Peace, Justice and Strong Institutions), and SDG 17 (Partnerships for the Goals). The core functions of educational leadership (planning, supervision, curriculum innovation, and collaborative governance) are directly linked to the provision of inclusive and equitable quality education (SDG 4), while the system's emphasis on accountability, data transparency, and institutional feedback loops supports the creation of just, effective, and accountable institutions (SDG 16).

From a systems engineering perspective, the integration of data-driven evaluation mechanisms, such as digital supervision logs and peer mentoring structures, fosters inter-institutional collaboration (SDG 17) by encouraging shared responsibility and mutual learning among stakeholders. These mechanisms act as technical and social infrastructures that align local leadership practices with global development agendas. Moreover, the adoption of Results-Based Management (RBM) principles supports continuous improvement and evidence-based decision-making, which are essential for achieving long-term educational transformation.

However, system bottlenecks (such as limited access to digital tools, high administrative workloads, and insufficient feedback protocols) continue to hinder full alignment with SDG indicators, particularly in under-resourced areas. Addressing these constraints requires policy-level advocacy and the strategic integration of science and technology, such as open-source dashboards or AI-assisted supervision tools, to ensure that every school benefits from innovation regardless of geographic location.

Thus, embedding SDG frameworks into leadership development not only provides a global benchmark for local program assessment but also reinforces the ethical imperative to build adaptive, equitable, and future-ready education systems. Finally, this study adds new information regarding SDGs, as reported elsewhere (**Table 3**).

Table 3. Previous studies on SDGs.

No	Title	Reference
1	Low-carbon food consumption for solving climate change mitigation: Literature review with bibliometric and simple calculation application for cultivating sustainability consciousness in facing sustainable development goals (SDGs)	[24]
2	Towards sustainable wind energy: A systematic review of airfoil and blade technologies over the past 25 years for supporting sustainable development goals (SDGs)	[25]
3	Assessment of student awareness and application of eco-friendly curriculum and technologies in Indonesian higher education for supporting sustainable development goals (SDGs): A case study on environmental challenges	[26]
4	A study on sustainable eggshell-derived hydroxyapatite/CMC membranes: Enhancing flexibility and thermal stability for sustainable development goals (SDGs)	[27]
5	Integrating multi-stakeholder governance, engineering approaches, and bibliometric literature review insights for sustainable regional road maintenance: Contribution to sustainable development goals (SDGs) 9, 11, and 16	[28]
6	Computational engineering of malonate and tetrazole derivatives targeting SARS-CoV-2 main protease: Pharmacokinetics, docking, and molecular dynamics insights to support the sustainable development goals (SDGs), with a bibliometric analysis	[29]
7	Innovative nanofluid encapsulation in solar stills: Boosting water yield and efficiency under extreme climate, supporting sustainable development goals (SDGs)	[30]
8	Modernization of submersible pump designs for sustainable irrigation: A bibliometric and experimental contribution to sustainable development goals (SDGs)	[31]
9	Sustainable development goals (SDGs) in engineering education: Definitions, research trends, bibliometric insights, and strategic approaches	[32]
10	Sustainable packaging: Bioplastics as a low-carbon future step for the sustainable development goals (SDGs)	[33]
11	Production of wet organic waste ecoenzymes as an alternative solution for environmental conservation supporting sustainable development goals (SDGs): A techno-economic and bibliometric analysis.	[34]
12	Hazard identification, risk assessment, and determining control (HIRADC) for workplace safety in the manufacturing industry: A risk-control framework complete with bibliometric literature review analysis to support sustainable development goals (SDGs)	[35]
13	Techno-economic analysis of production ecobrick from plastic waste to support sustainable development goals (SDGs)	[36]
14	Techno-economic analysis of sawdust-based trash cans and their contribution to Indonesia's green tourism policy and the sustainable development goals (SDGs)	[37]
15	The influence of environmentally friendly packaging on consumer interest in implementing zero waste in the food industry to meet sustainable development goals (SDGs) needs	[38]

Table 3 (continue). Previous studies on SDGs.

No	Title	Reference
16	The relationship of vocational education skills in agribusiness processing agricultural products in achieving sustainable development goals (SDGs)	[39]
17	Sustainable development goals (SDGs) in science education: Definition, literature review, and bibliometric analysis	[40]
18	Physical adaptation of college students in high-altitude training: empirical findings and curriculum development insights to support Sustainable Development Goals (SDGs)	[41]
19	Enhancing job satisfaction through human resource information systems and communication: A commitment-based approach to achieve Sustainable Development Goals (SDGs) in education-oriented organizations	[42]

4. CONCLUSION

By viewing school leadership development as a complex adaptive system, these recommendations aim to create an environment that empowers principals as agents of change, not simply recipients of top-down directives. Embedding engineering logic, through data-driven monitoring, feedback optimization, and peer-driven innovation, will support the evolution of a resilient, high-performing educational leadership system that is responsive to future challenges.

5. ACKNOWLEDGMENT

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6. AUTHORS' NOTE

The authors declare no conflict of interest. All authors have agreed to the manuscript submission and affirm its originality.

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