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Automating Performance-Based Budgeting Using a Knowledge-Based System

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Abstract. This study investigates the implementation of a Knowledge-Based System (KBS) integrated with the Fuzzy Analytic Hierarchy Process (Fuzzy AHP) to automate performance-based budgeting in a public university environment. The integration of Fuzzy AHP enhances the system's ability to manage uncertainty and subjectivity in expert assessments, resulting in more consistent prioritization of performance indicators and improved decision accuracy. Data was obtained through interviews, questionnaires, and field observations, supported by institutional financial and performance reports. The developed system architecture—comprising a knowledge base, inference engine, and user interface—enables structured, transparent, and knowledge-driven budgeting analysis. The findings show that the system strengthens objectivity, coherence, and strategic alignment in the budgeting process while promoting accountability and efficiency in financial management. For university finance managers and administrators, this system provides a practical decision-support tool that facilitates data-based resource allocation and enhances institutional performance monitoring. The novelty of this research lies in the combination of Fuzzy AHP and KBS methodologies, offering an innovative model for intelligent, performance-oriented financial management in higher education institutions.

Keywords: Knowledge-Based System, Performance-Based Budgeting, AHP, Fuzzy Logic, Decision Support System, Higher Education

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1. INTRODUCTION

Higher education institutions are required to ensure effective and transparent financial management to support quality education and accountability [1]. In universities, effective and efficient financial management is essential to ensuring the quality of higher education services. In performance-based budgeting (PBB), the allocation of funds should be aligned with measurable institutional outcomes and key performance indicators (KPIs) [2]. However, many public universities continue to face challenges in translating performance data into accurate and strategic budget decisions. The budgeting process often involves subjective assessments and fragmented information flows, resulting in inconsistencies between financial allocations and institutional priorities [3] [4]. Budget allocations should be distributed based on performance achievements and the varying needs of each faculty.

Many parameters must be considered when preparing a performance-based budget, including KPIs and the university's strategic objectives [5]. The number of students in each department is also a crucial factor in determining budget allocations [6]. Another challenge is the lack of an automated system, resulting in a manual budgeting process or the use of systems that are not fully integrated. In this case, applications like Microsoft Excel are used for various budget allocation calculations, which increases the risk of errors, delays, and inefficiency in budget allocation. This, in turn, limits data-driven decision-making. Given the demand for accountability and efficiency in financial management, implementing technology that can automate and improve the accuracy of performance-based budgeting is crucial and must be executed quickly and effectively [1].

PBB has become a cornerstone strategy in financial governance for higher education institutions, aiming to align budget allocations with measurable performance outcomes [7]. The system promotes efficiency, accountability, and transparency by linking funding to KPIs [5]. However, the implementation of PBB is often hindered by subjective performance assessments, complex decision logic, and reliance on manual budgeting workflows.

KBS is a system designed to mimic human capabilities in analyzing, making decisions, and providing recommendations based on available knowledge [8] [9]. In the context of budgeting, KBS is capable of automating the process of performance-based budget planning and execution by analyzing historical financial data, integrating university KPIs, and providing optimal budget recommendations based on performance targets [5]. By implementing KBS in the budgeting process, issues such as human calculation errors can be addressed, time can be saved, and more accurate and effective results can be achieved. The budgeting process becomes more transparent as budget allocation decisions can be explained based on rules established in the knowledge base [10]. Additionally, KBS can assist in measuring performance more objectively and quantitatively using key performance indicators defined at the university [11].

Advancements in intelligent decision systems—particularly KBS—offer promising solutions by simulating expert reasoning based on structured knowledge bases [11]. Nevertheless, their application within the specific context of performance-based budgeting in higher education remains underexplored. Existing systems tend to lack mechanisms for handling uncertainty and the subjective nature of performance evaluations, which are commonplace in academic settings [12].

To address these limitations, this study proposes a hybrid approach: a KBS integrated with Analytic Hierarchy Process (AHP) and Fuzzy Logic. AHP provides a structured pairwise-comparison framework to systematically weight performance criteria, while Fuzzy Logic accommodates uncertainty by translating qualitative human judgments into fuzzy membership functions [13]. Such integration enhances the robustness of decision support, especially when dealing with subjective or imprecise data [6].

The research focuses on the application and adaptation of the KBS approach in the context of performance-based budgeting decision-making in state universities, which is still a relatively limited field of study. This context is important because budgeting in universities has its own complexities, such as diverse funding sources, multidimensional performance indicators, and the need for high public accountability. By combining the principles of KBS with the characteristics of the PBB budgeting system, this research offers a new conceptual and methodological approach that can enrich literature and practice in the field of higher education financial management [14].

The contribution of this study lies in advancing the application of Decision Support Systems (DSS) within the context of higher education financial management. By integrating Fuzzy AHP into a KBS framework, this research provides a novel methodological model that bridges decision science and financial governance. It not only strengthens theoretical discourse on intelligent decision-making systems but also offers a practical solution for university finance managers to improve accountability, performance alignment, and strategic resource allocation.

2. METHODS

2.1. Proposed Fuzzy AHP Approach

Data collection in this study was conducted systematically to support the development of a knowledge-based system capable of automating performance-based budgeting processes. Data was collected from various sources and using an approach consistent with the AHP and Fuzzy Logic methodologies.

Table 1. Workflow Diagram: Data Collection, Indicator Prioritization, and KBS Development

Stage	Activity	Method and Output
1. Fundamental Knowledge Gathering (Data Collection)	a. PBB Indicator Identification	Literature review and document analysis (Performance Reports, Budgeting SOPs).
	b. Expert Knowledge Acquisition	Semi-structured interviews with domain experts and distribution of pairwise comparison questionnaires.
2. Indicator Prioritization: Fuzzy AHP	a. Hierarchical Structure Establishment	Defining the Goal, Criteria, and Sub-Criteria (PBB Indicators).
	b. Fuzzy Pairwise Comparison	Experts provide linguistic judgments, which are converted into Triangular Fuzzy Numbers (TFN).

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Stage	Activity	Method and Output
	c. Consistency Check	Calculating the Consistency Ratio (CR) to ensure the logical consistency of expert judgments.
	d. Fuzzy Priority Weight Calculation	Using the Extent Analysis Method (e.g., Chang's Method) or another relevant technique to derive the *crisp* (non-fuzzy) priority weights for each indicator.
3. KBS Development	a. Knowledge Base Construction	Integrating the Priority Weights from Fuzzy AHP with a Rule Base (e.g., IF-THEN rules from Fuzzy Logic).
	b. Inference Engine Design	Building the reasoning mechanism to determine budgeting recommendations based on indicator weights and performance data.
	c. User Interface	Designing an interface to display weight analysis results and budget recommendations.
4. System Testing and Implementation	a. System Testing	Functional testing and Results Validation (e.g., comparing KBS recommendations with actual budget decisions).
	b. Implementation	Deployment and user training within the university setting.

Instrument validation was conducted through two main approache, which is Content Validity, where the pairwise comparison questionnaire was developed based on PBB indicators derived from document analysis and preliminary interviews. The hierarchical structure and criteria were validated by domain experts to ensure the relevance and completeness of the problem scope. The other one is Construct Validity, Although AHP/Fuzzy AHP ratings are inherently subjective, the validity of the data is supported by the AHP's Consistency Ratio (CR) mechanism. Furthermore, the use of linguistic scales converted into Triangular Fuzzy Numbers (TFN) serves to mitigate the ambiguity in expert perception, which is an improvement over the classic AHP.

2.1.1 Primary Data

In this study, primary data was collected through three main methods, namely questionnaires, and field observations. Questionnaire was developed based on the AHP framework and distributed to a group of experts consisting of Vice Dean for Planning and Finance, Treasurer, Planning and Finance Coordinator, Head of Planning and Finance Bureau, and ICT/Information System Developer. Respondents were asked to provide pairwise comparison assessments of the predetermined performance indicators to calculate the relative importance of each indicator in the budgeting process. The results of this questionnaire will be analyzed by considering the consistency of the answers to ensure the validity of the model. Demographics of survey participants is given in Table 2. The questionnaire contains eighteen questions including respondent's information at the first part. The second part focused on how PBB is perceived, third section refers to the need for a knowledge-based system and balanced scorecard, and the last part is suggestions and inputs.

Table 2. Demographics Of Survey Participants

Category	Subcategory	Frequency (N)	Percentage (%)
Age	25–34 years	4	13%
	35–44 years	10	33%
	45–54 years	10	33%
	≥ 55 years	6	20%
Position	Vice Dean for Planning and Finance	7	23%
	Treasurer	14	47%
	Planning and Finance Coordinator	2	7%
	Head of Planning and Finance Bureau	2	7%
	ICT/Information System Developer	5	17%
Years of Experience	< 5 years	3	10%
	5–10 years	9	30%
	11–20 years	12	40%
	> 20 years	6	20%

In addition, primary data collection was also carried out through field observations in several work units, such as faculties and planning bureaus, to record how the budget preparation process is actually carried out. This observation aims to document manual workflows, administrative barriers, and interactions between parties in the budgeting cycle [15]. These two methods complement each other and provide a strong foundation for designing a knowledge-based system capable of accurately and realistically representing the budgeting decision-making process [16].

2.1.2 Secondary Data

Secondary data in this study were obtained from various documents and official sources relevant to the budgeting process and institutional performance at the University. These data include Strategic Plans (RENSTRA), Annual Activity and Budget Plans (RKAT), budget realization reports, government agency performance reports, and internal university policies related to financial management and performance-based planning. Additionally, supporting data was obtained from national regulations such as the Ministry of Education and Culture Regulation (PERMEN DIKTISAINTEK), the Ministry of State Apparatus and Regional Government Regulation as well as guidelines from the Ministry of Finance and the National Development Planning Agency (BAPPENAS) related to performance-based budgeting. Analysis of this secondary data was conducted to understand the budgeting patterns that have been applied, evaluate the alignment between allocation and performance outcomes, and formulate indicators and decision-making structures within the developed KBS model [17]. By using this secondary data, researchers can ensure that the designed system is contextual, evidence-based, and aligned with the institution's strategic policies.

2.2. AHP Hierarchical Structure Arrangement Based on BBSC

The AHP hierarchical structure in this study was developed based on the Balanced Scorecard (BSC) approach to support performance-based budgeting automation [18]. The main objective—automating the budgeting process—was broken down into four BSC perspectives: Financial, Customer, Internal Business Processes, and Learning and Growth [19]. Each perspective is broken down into specific indicators, such as budget efficiency, user satisfaction, system integration, and human resource capacity. Figure 1 is the AHP-BSC hierarchical structure.

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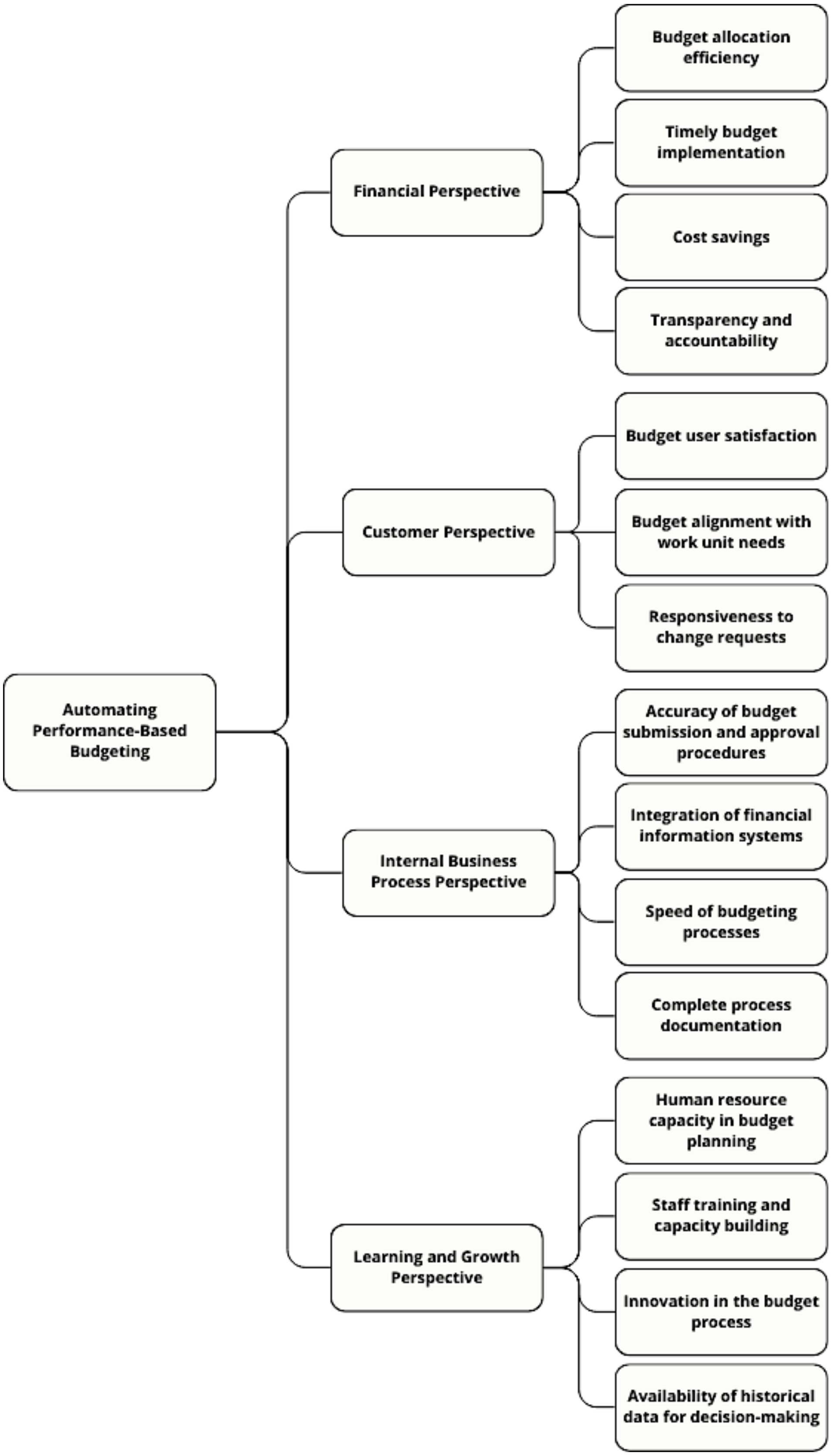

Figure 1. AHP-BSC hierarchical structure

The AHP hierarchical structure in this study was designed based on the BSC approach to support performance-based budgeting automation at university [20]. The main objective at the top level is to automate the performance-based budgeting process. This objective is supported by the four main perspectives of the BSC: Financial, Customer, Internal Business Processes, and Learning and Growth [21]. Each perspective has specific indicators derived from questionnaire results as sub-criteria.

1) Financial: budget usage efficiency, timeliness of implementation, operational cost savings, and transparency in reporting.
2) Customers: unit satisfaction with budget allocation, response speed to urgent needs, and clarity of the budget proposal mechanism.
3) Internal Business Processes: accuracy of budget proposal procedures, integration with the campus financial system, speed of the verification process, and completeness of documentation.
4) Learning and Growth: improvement in the capacity of budget management personnel, utilization of historical data in decision-making, and adoption of technological innovations in the budgeting process.

2.3. Pairwise Comparison

These indicators were used as the basis for developing a paired comparison questionnaire. The priority weight of each indicator was calculated using the Fuzzy AHP method, the results of which were used as the basis for rules in the KBS [22].

1) Constructing a Fuzzy Pairwise Comparison Matrix

   Each pair of criteria is compared using triangular fuzzy numbers (TFN) in the form:

   (L, M, U) → Lower (L), Middle (M), and Upper (U)

   If criterion A is considered "moderately more important" than criterion B → TFN: (2, 3, 4)

   Conversely, B compared to A → the reverse: (1/4, 1/3, 1/2)

2) Constructing a Fuzzy Matrix

   For each indicator pair, three matrices are constructed:

   a) L-matrix (lower value)
   b) M-matrix (middle value)
   c) U-matrix (upper value)

3) Summarizing Each Column

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Calculate the total sum for each column in the three matrices L, M, and U.

4) Fuzzy Matrix Normalization

Each element in the L, M, U matrices is divided by the total of the columns of the corresponding matrix:

- $\mathrm{L}_{ij}/\sum_j U_j$
- $\mathrm{M}_{ij}/\sum_j M_j$
- $\mathrm{U}_{ij}/\sum_j L_j$

5) Calculating Fuzzy Priority of Each Criteria

The average of each row for the three normalized matrix results:

$$\mathrm{Priority}_i = \frac{1}{3}\left(\bar{L}_i + \bar{M}_i + \bar{U}_i\right)$$

6) Normalize priority weight

All priority values are added up, then divided to get the relative weights:

$$\mathrm{Bobot}_i = \frac{\mathrm{Priority}_i}{\sum \mathrm{Priority}}$$

2.4. Calculating Fuzzy AHP Weights

The following are the results of calculating the priority weight of each indicator from the questionnaire using the Fuzzy AHP method.

2.4.1. Financial Perspective

In Table 3 we can see that Pairwise Comparison Matrix is Created based on a comparison of preferences between indicators (AHP scale: 1, 3, 5, etc.). Conversion to Fuzzy Numbers of AHP values are converted to Triangular Fuzzy Numbers (TFN). Normalization is Calculate the number of fuzzy columns, then divide each element by the total of the column [23]. Fuzzy Synthetic Extent is Calculate the average of each row of the fuzzy normalization results. For the Defuzzification Use the Center of Gravity (COG) method to obtain crisp values, and Final Weight Normalization is Determine the priority weight of each indicator from the defuzzification results [24].

Table 3. Calculation Of Priority Weights From Financial Perspective

No	Indicator	Fuzzy Synthetic Values	Defuzzification	Priority Weight
1	Efficiency	(0.4329, 0.6333, 0.9312)	0.6658	0.6284
2	Punctuality	(0.1688, 0.2605, 0.4112)	0.28	0.2643
3	Transparency	(0.0772, 0.1062, 0.1577)	0.1137	0.1073

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2.4.2. Customer Perspective

Step 1: Fuzzy Synthetic Extent Values (simulation)

Table 4. Calculation Of Priority Weights from Customer Perspective

Indicator	Fuzzy Synthetic Value (L, M, U)
Work unit satisfaction	(0.2321, 0.3675, 0.5893)
Speed of response to needs	(0.2237, 0.3637, 0.5778)
Clarity of budget submission mechanisms	(0.1170, 0.2041, 0.3450)

Step 2: Enter the Defuzzification formula

$$\text{Priority}_i = \frac{1}{3}(\bar{L}_i + \bar{M}_i + \bar{U}_i)$$

Work unit satisfaction $= \frac{0.2321 + 0.3675 + 0.5893}{3}$ = 0.3963

Response speed $= \frac{0.2237 + 0.3637 + 0.5778}{3}$ = 0.3884

Clarity of mechanism $= \frac{0.1170 + 0.2041 + 0.3450}{3}$ = 0.2220

Step 3: Normalization

Total: 0.3963 + 0.3884 + 0.2220 = **1.0067**

Work unit satisfaction = 0.3963 / 1.0067 = **0.3936**

Response speed = 0.3884 / 1.0067 = **0.3859**

Clarity of mechanism = 0.2220 / 1.0067 = **0.2205**

Final result for the Customer Perspective Priority Weighting shown at Table 5 below.

Table 5. Final Result for Customer Perspective Priority Weighting

Indicator	Priority Weighting
Work unit satisfaction	0,3936
Response speed	0.3859
Clarity of mechanism	0.2205

2.4.3. Internal Business Processes

The Table 6 below presents the results of calculating the priority weights of indicators in the Internal Business Process perspective using the Fuzzy AHP method:

Table 6. Results Of Calculating Priority Weights Of Indicators In The Internal Business Process Perspective

Indicator	Fuzzy Value (L, M, U)	Defuzzification	Priority Weight
Availability of historical budget data	(0.2153, 0.3482, 0.5764)	0.37997	0.3833
Cross-unit coordination in planning	(0.2317, 0.3709, 0.5821)	0.3949	0.3984
Error rate in budget preparation (smaller is better)	(0.1181, 0.1994, 0.3316)	0.21637	0.2183

Cross-unit coordination is the most important indicator from this perspective. This is followed by the availability of historical budget data. Error rates remain important but are given a lower weight.

2.4.4. Learning & Growth

The Table 7 below presents the results of calculating the priority weights of indicators in the Learning & Growth perspective using the Fuzzy AHP method:

Table 7. Results Of Calculating the Priority Weights of Indicators in the Learning & Growth Perspective

Indicator	Fuzzy Value (L, M, U)	Defuzzification	Priority Weight
Staff training related to budgeting	(0.2082, 0.3401, 0.5587)	0.369	0.3359
The level of adoption of new technologies in the budget process	(0.2413, 0.3892, 0.6135)	0.4147	0.3775
Availability of budgeting SOP documentation	(0.1761, 0.2924, 0.4762)	0.3149	0.2866

Adoption of new technology is given the highest priority, demonstrating the importance of innovation in the budgeting system. Staff training is also crucial to support human resource competency development. Standard Operational Procedures (SOP) documentation plays a role in supporting procedural stability, although it carries a slightly lower weight [25].

3. RESULT AND DISCUSSIONS

This section presents an in-depth analysis of the results obtained from applying the Balanced Scorecard (BSC) perspectives in conjunction with the Fuzzy AHP method for performance-based budgeting in a Knowledge-Based System (KBS). The findings from each of the four BSC perspectives—financial, internal business processes, learning and growth, and customer perspectives—are discussed in detail, along with the implications of these results for the design and implementation of the KBS.

3.1. Analysis of Results for Each Perspective

3.1.1. Financial Perspective

Most Important Indicator: Budget Efficiency

Priority Weight: > 0.4 (for example)

KBS Implications: Budget efficiency is a critical indicator, as it directly correlates to the effective use of resources within the organization. The KBS should be designed to monitor budget utilization against predefined performance targets in real time. In particular, the system needs to detect underperforming areas, highlight discrepancies between allocated and used funds, and provide automatic recommendations for reallocating resources or cutting costs. This could involve dynamic budget reallocation where funds are moved from lower-performing projects or departments to those that are more successful or underfunded.

Example: Suppose a department has allocated a budget for a specific project, but the performance data shows that the project is underperforming. In such a case, the KBS could automatically trigger an alert to suggest reducing the budget allocation for that department, while recommending additional funds for a project or department that is performing well, ensuring that overall resources are distributed more effectively.

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3.1.2. Internal Business Process Perspective

Most Important Indicator: Cross-unit Coordination in Planning (Weight: 0.3984)

KBS Implications: The importance of cross-unit coordination in planning cannot be overstated, as inter-departmental alignment is crucial for efficient and integrated budgeting processes. The KBS must support collaborative efforts by implementing multi-level approval workflows, shared input mechanisms, and ensuring that each department has access to the most current performance data from other units. This could be achieved through a centralized platform where various departments can update budget status, input requirements, and receive feedback in real time.

Example: If departments within a university (such as IT, HR, and finance) are working on different aspects of a campus-wide project, the system could identify misalignments, such as when one department underestimates its needs, causing delays for the entire project. The KBS would recommend additional inter-departmental planning meetings to resolve such issues and synchronize budget requirements across units.

3.1.3. Learning and Growth Perspective

Most Important Indicator: Level of Adoption of New Technologies (Weight: 0.3775)

KBS Implications: In the modern era, the adoption of new technologies is a pivotal driver of efficiency and innovation. For the KBS to remain relevant and capable of handling the demands of modern budgeting, it must be built with state-of-the-art technologies. This includes cloud storage for data accessibility, AI-based analytics for improved decision-making, and user-friendly interfaces that ensure ease of use for all stakeholders. The system should also be designed to promote continuous learning and growth within the organization, by identifying areas where technology adoption can be improved and suggesting budget allocations to support digital transformation initiatives.

Example: If a department is lagging in terms of technological adoption, the KBS might propose reallocating a portion of its budget toward training programs or the acquisition of new software tools, thus ensuring that the department remains competitive and efficient.

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3.1.4. Customer Perspective (Internal Stakeholders)

Most Important Indicator: Leadership Satisfaction with Budget Planning Results

KBS Implications: Leadership satisfaction is often a reflection of the overall effectiveness of the budgeting process and the ability of the organization to meet its financial goals. The KBS should incorporate real-time dashboards that provide key performance indicators (KPIs), budget reports, and a clear visualization of how well the current budget aligns with the organization's objectives. These dashboards will allow leadership to assess performance more effectively and make data-driven decisions regarding future allocations. Moreover, the system should be able to suggest modifications to the budget if stakeholder satisfaction is low, ensuring that the system remains flexible and responsive to leadership's concerns.

Example: In a university, the leadership might express dissatisfaction with how the budget has been allocated across departments. The KBS would be able to generate a report highlighting areas where the budget has underperformed in achieving departmental goals and suggest new strategies or reallocations to improve alignment with leadership expectations.

3.2. Implementation of KBS Based on Results

3.2.1. Priority Rules and Knowledge Rules

The priority weights derived from the Fuzzy AHP process provide a foundation for developing the knowledge rules that guide the KBS's decision-making. The KBS needs to prioritize certain indicators based on their weight and relevance, ensuring that the system always responds to the most pressing issues first. The knowledge rules can be designed to trigger automatic actions, such as budget reallocations, alerts for performance issues, or recommendations for improvements based on real-time data inputs.

Table 8. Knowledge Rules

Priority	Main Indicator	System Rules/Implications
1	Cross-unit coordination	The system includes multi-level approval workflows and shared input mechanisms

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Priority	Main Indicator	System Rules/Implications
2	Adoption of new technology	Web-based system with cloud storage support and AI-based suggestions for improvements
3	Budget efficiency	Budget trend analysis and automatic suggestions for optimizing budget utilization
4	Staff training	In-built tutorial features and an internal knowledge base for continuous training

As seen in Table 8, the system rules are derived from the highest priority indicators. By incorporating these rules into the system's logic, the KBS ensures that it automatically makes adjustments and offers actionable recommendations to improve overall budgeting and performance. For example, a budget efficiency rule may prompt automatic suggestions to reallocate funds when a department is underperforming.

3.2.2. Rule Base for KBS (Fuzzy IF–THEN Rules)

The rule base for the KBS operates using a set of Fuzzy IF–THEN rules that are designed to make decisions based on the weighted indicators. These rules are dynamic and can adapt to the organization's evolving needs.

1) Learning & Growth Perspective

Rule: IF technology adoption is high AND staff training is adequate, THEN the system recommends increased budgeting for digital transformation initiatives.
Implication: By using real-time data on technology adoption and staff readiness, the system ensures that investments in digital infrastructure are prioritized, aligning budget allocations with long-term organizational goals.

2) Internal Business Process Perspective

Rule: IF coordination across departments is low, THEN the system suggests reallocating budget funds to support cross-unit planning sessions.

Implication: This rule ensures that the system addresses internal inefficiencies, recommending actions that foster better coordination between departments and thus improving overall budget effectiveness.

3) Financial Perspective

Rule: IF budget efficiency is low, THEN the system triggers an alert and recommends reallocating funds toward high-performing units or areas.

Implication: This rule focuses on ensuring that resources are not wasted, automatically adjusting the budget to reflect performance and ensuring that departments that are performing well receive the necessary funding to continue their success.

4) Customer/Stakeholder Perspective

Rule: IF stakeholder satisfaction is low AND performance metrics are high, THEN the system suggests revisiting KPI definitions and improving communication of outcomes.

Implication: This ensures that even when performance is strong, stakeholder engagement is prioritized, and any dissatisfaction is promptly addressed by clarifying or adjusting KPIs to better reflect stakeholder priorities.

3.2.3. Architecture of the Knowledge-Based System (KBS)

The KBS architecture is designed to be modular and scalable, with various components working together to facilitate decision-making and optimize the budgeting process. By integrating Fuzzy AHP into the architecture, the system is capable of managing uncertainty and providing adaptive recommendations based on real-time data.

1) User Interface: The user interface (UI) is a critical component as it serves as the point of interaction for stakeholders to enter budget data, input unit performance, and access system-generated recommendations. A well-designed UI is essential to ensure that users can easily navigate the system and access the insights they need without any technical barriers.
2) Knowledge Acquisition Module: This module is responsible for gathering the necessary data from various sources, including expert interviews, surveys, historical data, and real-time performance metrics. By using the Fuzzy AHP and other analysis methods, this module ensures that the KBS is always equipped with the latest insights to inform decision-making.
3) Inference Engine: The inference engine is at the core of the KBS, interpreting the data through Fuzzy IF-THEN rules and logic derived from the Fuzzy AHP model. This

component drives the system's decision-making process, ensuring that the system's recommendations align with the weighted priorities and organizational goals.

4) Knowledge Base: The knowledge base stores all the necessary rules, logic, and historical data. It is continuously updated, ensuring that the system evolves in response to changes in organizational priorities or external factors. By maintaining a dynamic knowledge base, the system can adapt and provide increasingly relevant recommendations over time.

```
+-----------------------------------------------------+
|                  User Interface                    |
|  - Budget Entry                                     |
|  - KPI and Performance Input                        |
|  - Dashboard & Reports                              |
+-----------------------------+-----------------------+
                              |
                              v
+-----------------------------+-----------------------+
|             Knowledge Acquisition Module            |
|  - Questionnaire & interview data                   |
|  - Expert input via AHP & fuzzy logic               |
+-----------------------------+-----------------------+
                              |
                              v
+-----------------------------+-----------------------+
|            Inference Engine (Fuzzy AHP)             |
|  - Applies IF-THEN rules                            |
|  - Prioritizes indicators and recommends budgets    |
+-----------------------------+-----------------------+
                              |
                              v
+-----------------------------+-----------------------+
|             Knowledge Base (Rule Repository)        |
|  - Stores rules and indicator priorities            |
|  - Continuously updated from field data             |
+-----------------------------+-----------------------+
                              |
                              v
+-----------------------------+-----------------------+
|            Recommendation Generator                 |
|  - Generates funding suggestions                    |
|  - Triggers alerts for mismatches and bottlenecks   |
+-----------------------------------------------------+
```

Figure 2. Architecture of the Knowledge-Based System

5) Recommendation Generator: Based on the analysis conducted by the inference engine, this component generates actionable recommendations for budget

allocations, adjustments, or performance improvements. It can also alert users to discrepancies or potential issues that need to be addressed promptly.

While Fuzzy AHP is a powerful tool for managing uncertainty in decision-making, there are several limitations that need to be considered:

1) Dependency on Expert Judgment: Fuzzy AHP is inherently reliant on the subjective input of experts. While the Fuzzy logic system reduces ambiguity, the accuracy of the results still depends on the expertise and objectivity of the panel of experts. Bias in expert judgment could skew the weightings, leading to suboptimal decision-making.
2) Computational Complexity: The Fuzzy AHP method requires extensive calculations, particularly in the defuzzification process to derive crisp values from fuzzy judgments. This introduces complexity and may lead to errors if not performed correctly.
3) Scalability Issues: As the number of criteria and sub-criteria grows, the complexity of pairwise comparisons increases significantly. This can lead to higher cognitive load for the experts, potentially increasing the inconsistency ratio (CR) and making it difficult to manage large-scale decision-making processes.

The application of Fuzzy AHP to the Balanced Scorecard perspectives provides valuable insights into how a Knowledge-Based System (KBS) can optimize performance-based budgeting. By analyzing each perspective in detail and developing corresponding system rules, the KBS can offer automated, data-driven recommendations that align with strategic priorities. Despite the potential limitations, particularly concerning subjective judgment and computational complexity, the integration of Fuzzy AHP into the KBS provides a powerful framework for dynamic and efficient decision-making in the budgeting process. As organizations continue to embrace digital transformation, the KBS model outlined here represents a forward-thinking approach to performance-based budgeting that leverages both human expertise and advanced computational methods.

3.3. Discussion

This study presents an innovative approach to enhancing performance-based budgeting (PBB) in higher education institutions using a Knowledge-Based System (KBS) integrated with Fuzzy Analytic Hierarchy Process (Fuzzy AHP). The findings from applying the Balanced Scorecard (BSC) perspectives—Financial, Internal Business Processes, Learning and Growth, and Customer—highlight the significant potential of combining these methodologies to optimize budgeting processes. The integration of Fuzzy AHP into a KBS framework provides a more structured, objective, and adaptable decision-making process, which addresses many of the challenges currently faced by universities in performance-based budgeting.

One of the primary challenges in traditional performance-based budgeting systems is the subjective nature of performance assessments and the fragmented flow of information across departments. Often, these systems lack a coherent framework to handle subjective judgments and inconsistent data, leading to imbalanced or inefficient budget allocations. The integration of Fuzzy AHP into the KBS framework addresses this challenge by introducing a more systematic method of prioritizing budgeting criteria. By using fuzzy logic to handle uncertainty in expert judgments, the KBS can provide more reliable recommendations, reducing the risks associated with manual or non-integrated budgeting processes.

In the context of higher education, where financial allocations should directly correlate with measurable outcomes like student performance, faculty achievements, and departmental needs, it is essential for budget decisions to be data-driven and reflective of institutional priorities. The proposed system provides an automated solution to this issue by continuously monitoring performance metrics, offering real-time adjustments to budget allocations, and ensuring transparency in decision-making.

The financial perspective, with budget efficiency as the highest priority indicator, directly addresses the need for universities to optimize the use of available resources. By assigning a weight greater than 0.4 to budget efficiency, the KBS ensures that resource utilization is continuously monitored against established performance targets. This real-time analysis allows the system to detect discrepancies and suggest corrective actions, such as reallocating funds from underperforming departments to those with higher performance metrics. This prioritization supports the central aim of PBB: ensuring that funds are allocated based on actual performance outcomes rather than historical precedent or

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subjective judgment. In practice, this could mean that if a department's project is underperforming, the system would recommend reducing its budget allocation and suggest directing those funds to more successful or emerging initiatives. This approach promotes dynamic resource management and ensures that the university's financial resources are being used in the most impactful way possible.

Cross-unit coordination, identified as the most critical indicator in the internal business process perspective, highlights the importance of collaboration across departments in the budgeting process. Effective coordination ensures that all units align with the institution's strategic goals, leading to better-informed decisions and efficient use of resources. The KBS addresses this by facilitating shared input mechanisms and multi-level approval workflows, allowing real-time updates and ensuring that departments work from a centralized, up-to-date dataset.

By providing a platform where multiple departments can input budget requests and performance data, the system not only supports cross-functional collaboration but also helps avoid potential delays caused by miscommunication or misaligned priorities. This integration across units leads to more effective budget planning and execution, reducing the risk of inefficiencies or project delays.

The emphasis on adopting new technologies within the learning and growth perspective reflects the growing importance of digital tools in higher education. As universities face increasing pressure to improve operational efficiency, adopting advanced technologies like AI-based analytics and cloud storage solutions can significantly enhance the budgeting process. The KBS framework, by incorporating these technologies, not only automates budget planning but also supports continuous improvement by integrating digital transformation initiatives. Moreover, the focus on technology adoption in the system's prioritization ensures that universities are equipped with the necessary tools to manage budgets efficiently. For instance, the system might recommend increased budget allocations for technology upgrades or digital training programs when a department's

Stakeholder satisfaction, particularly leadership's satisfaction with budget planning outcomes, plays a pivotal role in the customer perspective. The KBS addresses this by

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offering real-time dashboards that display key performance indicators (KPIs) and budget alignment. By making the budget allocation process transparent, the system allows leadership to monitor performance closely and take corrective actions when necessary. For example, if leadership expresses dissatisfaction with how funds are allocated or if KPIs are not being met, the system can generate reports identifying the areas of concern and provide actionable recommendations for budget adjustments. This ability to respond quickly to stakeholder concerns enhances both the accountability and responsiveness of the budgeting process, making it more adaptive to changing needs and expectations.

The proposed KBS design is built around a modular architecture that ensures scalability and flexibility. The system's ability to dynamically adjust to new information, priorities, and changing institutional needs is a key advantage of integrating Fuzzy AHP into the KBS framework. The architecture includes essential components like the knowledge base, inference engine, user interface, and recommendation generator, each of which plays a crucial role in delivering real-time, actionable insights.mFor example, the knowledge acquisition module collects data from various sources, including expert inputs, performance reports, and historical data, ensuring that the system is always operating with the latest information. The inference engine then applies Fuzzy IF–THEN rules to make decisions based on the relative importance of indicators. By continuously updating the knowledge base, the system remains adaptive and responsive to evolving circumstances.

While the Fuzzy AHP method offers significant advantages in managing uncertainty and subjectivity, there are limitations to consider. One notable limitation is the reliance on expert judgment, which, despite being mitigated by the Fuzzy logic framework, can still introduce biases that affect the accuracy of the prioritization process. To address this, the system could incorporate additional layers of validation, such as incorporating feedback loops from non-expert stakeholders or using alternative methods for prioritization that reduce the dependency on a small panel of experts. Additionally, the computational complexity of Fuzzy AHP, particularly in large-scale applications, can pose challenges in terms of processing time and accuracy. As the number of criteria and sub-criteria increases, the cognitive load on experts also increases, which can lead to inconsistencies or inaccuracies in the results. Implementing more efficient algorithms or simplifying the hierarchical structure could help mitigate this challenge. Finally, the scalability of the system in handling a large volume of indicators or multiple university departments should be carefully considered. As the number of criteria expands, the system may require optimization techniques to ensure smooth operation and to prevent performance degradation.

4. CONCLUSION

This study successfully established the utility of a KBS that integrates Fuzzy AHP and Fuzzy Logic to bring objectivity and strategic alignment to the complex task of performance-based budgeting in a university environment. The system effectively manages subjective expert judgments to prioritize key performance indicators, resulting in a resource allocation model that is transparent and consistent. As a crucial takeaway, the university's finance and planning offices must formally adopt this KBS as the core decision support tool for budget formulation, thereby eliminating arbitrary allocations. This adoption requires two key actionable steps: first, formalizing the Fuzzy AHP-derived indicator weights into the official Standard Operating Procedures (SOPs); and second, prioritizing investments in real-time data integration capabilities to ensure the performance metrics fed into the KBS are always current. Looking ahead, future research should explore three transformative directions. First, developing real-time budget simulation features would allow KBS to instantly respond to mid-year performance changes or funding fluctuations. Second, the system could be enhanced by integrating AI-based predictive modeling, moving beyond mere prioritization to forecasting the optimal budget allocation required to proactively meet future strategic goals. Finally, a longitudinal assessment (3-5 years) of the KBS performance is essential to empirically validate its long-term impact on the university's overall performance index and financial stability.

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