Fuzzy logic modelling of a performance evaluation system for academic programmes in Nigeria higher education

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Abstract

Over the past few decades, computer applications have extended beyond the traditional areas to non-traditional ones. Notably, real life applications often present vague, ambiguous and imprecise data. Previous investigations have shown that most current efforts to deploy ICT tools for schools management in Nigeria have resulted in multiplicity of ad-hoc incompatible information systems consisting of fragmented mixtures of single function systems that neither share data nor communicate effectively. Also, data acquired from numerous academic processes have varying degrees of imprecision, incompleteness, ambiguity, vagueness and subjectivity. Analysing the data to generate various reports for effective school administration and quality assurance presents challenges not easy to resolve with conventional information processing systems built on normal relational databases. Based on the premise that enough literature exists on systems integration standards and best practices, this study proposes a model for building a decision support system for monitoring and evaluating the performance of academic programmes in Nigerian Schools using fuzzy logic. This is achieved by using the approach proposed by Daniel Fasel to introduce fuzzy concepts into the derived multi-dimensional data schema and adding a meta table structure for classification, without affecting the core of the crisp data. This will eliminate the possibility of parallel data structures for different sub-systems and allow the use of both sharp and fuzzy queries simultaneously. Specific implementation issues are examined with a case study of the University Programmes Accreditation Status Monitoring System in Nigeria.
Keywords: fuzzy relational databases, data integration, integrated fuzzy data repository, membership function, fuzzy classification, quality assurance.

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1 Introduction

One of the greatest challenges facing man today is how to effectively manage and generate useful, timely and accurate information from the huge volume of data acquired from multifarious business activities of life. Every organization has its own level of information system, however simple it may be. This often ranges from simple manually prepared records and reports used to control and plan the business, to electro-mechanical equipment like calculators in some fairly complex environments. However, more complex organizations require a higher level of both equipment and procedural sophistication, which can only be achieved by the use of computers.

Computer-based information systems can be seen as management's solutions to organizational problems and challenges posed by the environment, using available and suitable technology. The education sector in Nigeria is yet to fully benefit from computer-based information systems in educational administration. Although technologies exist for data integration, economic and other environmental factors account largely for failure of Information Systems (IS) projects in Nigeria. This results in independent efforts of various departments within the same organization to deploy Information Technology (IT) solutions.

Based on the preliminary investigations in this work, two key problems are identified in most tertiary institutions in Nigeria to which solution is sought.

- There exists elements of "Chaotic Information Systems" in most institutions, this arises from the presence of ad-hoc incompatible information systems comprising of fragmented mixtures of single function systems that were built to meet certain operational requirements of the user departments and therefore neither share data nor communicate effectively with other sub-systems within the organization.
- Data encountered in academic processes occur in both numeric and non-numeric forms, sometimes domain specific terms are used to represent entities. Inconsistencies, vagueness, subjectivity and sometimes missing elements exist in the sort of data encountered in academic processes. In practice, these information systems mostly use relational databases to store these data collections. Using the relational model poses the restriction of having sharp precise data and therefore a dichotomous querying process not well suited for decision making (Werro [1]). Real life decision making processes most often involve the use of domain specific terms for documenting decisions. Similarly, qualitative interpretation of facts and dimensions are required which are not supported by conventional relational database systems. Administrators and supervisory bodies are therefore unable to look up qualitative information they require across all areas of the institution from a central repository to enhance their decision making capabilities.

As noted by Fasel and Shahzad [2], real life decision making processes are often verbal processes and domain specific terms are used for documenting decisions. Facts are mostly quantitative in nature. Qualitative interpretation of facts and dimension attributes is not supported by classical relational databases. In practice, information systems mostly use relational databases to store data collections (Werro [1]). The introduction of a fuzzy classification approach (Fasel and Shahzad [2], Werro [1]) which combines relational databases with fuzzy logic promises a laudable solution to qualitative analysis of data. This approach reduces the complexity of the data by classifying similar elements together and at the same time extracts additional available information by having fuzzy classes (Werro [1]).

As a result of current issues in globalization in education, quality assurance in education has drawn concerns from governments, industry and other stakeholders in international education. We are of the view that except where conscious effort is made to develop environment specific technologies to deploy IT tools in school administration, manual procedures for pursuing quality assurance programmes in Nigeria may not yield desirable results.

Consequently, the goal of this work is to propose a model, using fuzzy classification architecture, for building a decision support component of an Academic Information Management System that can be used to evaluate the performance of academic programmes. Performance in this context is a quality assurance index. The proposed model aims to establish an architectural framework for resolving the chaotic information systems problem in higher educational institutions in Nigeria and propose a methodology for integrating Fuzzy concepts into the dimensions structure of the Integrated Data Repository without affecting the core of the crisp database, thus allowing both crisp and fuzzy measures as well as quantitative and qualitative attributes to be used for analysis and decision making. The proposed model is intended to allow users to query the database with both standard SQL commands as well as to formulate classification queries using domain specific terms. Thereafter, we establish the technical feasibility and viability of this model with a case study of Quality Assurance in Higher Education using the University Programmes Accreditation in Nigeria.

1.1 Basic assumptions

This work assumes the existence of a system integration platform. The entity aggregation component of the proposed model assumes the existence of integration and data aggregation procedures. Adequate research and publications are available. Standards and best practices have been established in this aspect (TrowBridge *et al.* [3], Microsoft [4], Hohpe and Woolf [5], Alur *et al.* [6]). This work will not attempt to compare programmes accreditation procedures of other regulatory bodies or of other nationalities and will not attempt to compare and justify the superiority of this fuzzy classification approach over other existing fuzzy integration approaches. Also, the study of the effect of the use of this approach on decision making though desirable is not covered in this work.

1.2 Quality assurance in higher education

In Nigeria academic programmes accreditation is a means of evaluating standards and quality in Higher Education (HE). Quality Assurance is the systematic review of educational programmes to ensure that acceptable standards of education, scholarship and infrastructure are being maintained (UNESCO [7]).

Quality means different things to different people (Mishra [8]). A lot of people consider quality as a relative term that has many dimensions that form a fuzzy entity referred to as quality through social consensus rather than defining it. The various available definitions have therefore been classified into five main groups (Mishra [8]):

- Transcendent definitions. These definitions are subjective and personal. They are eternal but go beyond measurement and logical description. They are related to concepts such as beauty and love.
- Product-based definitions. Quality is seen as a measurable variable. The basis for measurement is objective attributes of the product.
- User-based definitions. Quality is a means for customer satisfaction. This makes these definitions individual and partly subjective.
- Manufacturing-based definitions. Quality is seen as conformance to requirements and specifications.
- Value-based definitions. These definitions define quality in relation to cost. Quality is seen as providing good value for costs.

When it we consider as absolute, it is given and considered as the highest possible standard (Mishra [8]). Examples are the picture of “Mona Lisa” by Da Vinci, the Egyptian Pyramids and the Taj Mahal, which are works of high standards and quality. In product terms, they are attached with “high brand” values, status and positional advantages. Educational institutions such as Oxford, Cambridge and Stanford in the West have the absolute quality standard, although in the case of education it might still be perceptual. Quality as being relative suggests that the quality of a product or service can be described in relative terms. Quality here can be measured in terms of certain specifications [8]. Quality as a process suggests that in order to achieve quality of a product or service, it must undergo certain processes and conform to the procedural requirements. Thus quality is the outcome of systems and procedures laid down for the purpose. Quality as a culture recognises the importance of organizational view of quality as a process of transformation where each entity is concerned and acknowledges the importance of quality. In educational institutions, we are particularly concerned with the latter, though all other ideas of quality too have their respective places (Mishra [8]).

From the above, we can adduce that the meaning of quality is contextual, ranging from “standard” to “excellence”. These two concepts are deeply rooted in their respective values and operationalized in individuals, institutions as well as national practice. Standards can be defined in terms of “minimum threshold” by which performance is judged. In Nigeria for instance, we refer to Minimum

Acceptable Standards (MAS) set by the supervisory agency for the various categories of higher institutions.

In this context, quality is assessment in terms of a set of norm-referenced standards such as the NAAC & Commonwealth of Learning Criteria (Mishra [8]), the European Association for Quality Assurance in Higher Education (EAQAHA [9]), the UNESCO Guidelines for Quality Provision in Cross-border Higher Education (UNESCO [7]), the Nigerian Universities Commission (NUC) Minimum Academic Standards (MAS) and the NUC Benchmarks MAS (Suleiman [10]). These are built around what is considered as minimum standards. In higher education, the objective is to achieve the standards and move towards excellence.

2 Summary of some existing related approaches

Notable efforts have been made in the past that are related to this work. Medina *et al.* [11] proposed the Generalized Fuzzy Relational Database (GEFRED) Model which is based on the definition called the Generalized Fuzzy Domain (D) and Generalized Fuzzy Relation (R) that includes the classic domain and classic relations respectively. This model is generally an eclectic synthesis of some other models and has the advantage that it consists of a general abstraction that allows for the use of various approaches.

Galindo *et al.* [12] developed a server for Fuzzy SQL (FSQL) based on the GEFRED model. This was extended to produce the extended Free FSQL server (Galindo [13]). Those efforts, besides the shortcoming of producing parallel data structures, also use predefined Fuzzy Labels.

There are multiple levels at which system integration is done (TrowBridge *et al.* [3]) including data integration, Functional integration, Presentation integration, Portal integration and Process integration. They provided guidance to system integrations in the form of best patterns and practices (Hohpe and Woolf [5]), a catalog common integration pattern with an emphasis on system integration via asynchronous messaging using different commercial products (Alur *et al.* [6]) and prototypes of the role of DB2® information integration technologies and architectures in IBM®`s patterns for e-business using a type of customer insight business scenario. This is aimed at providing guidance to IT professionals, architects and system integration professionals with best patterns and practices with specifics on the role of DB2® information integrator technologies.

Balasubramanian *et al.* [14] outlines methodology for function integration of system using Model Driven Engineering (MDE) which involves the systematic use of models as essential artefacts throughout the software lifecycle. They described the technologies that help to simplify the functional integration of systems built using component middle ware. This type of integration operates at the logical business layer, typically using distributed objects/components, exposing service-oriented architectures, or messaging middleware and is responsible for delivering services to clients with the desired quality of service (QoS). This integration technology using Model Driven Engineering focused on functional integration of systems. No particular effort was made at extending this to system integration at the logical data layer.

All these efforts do not directly provide tools for integration but instead provide pattern-based guidance to apply existing tools to achieve more effective integration.

This work assumes that an integrated system based entity aggregation pattern (Trowbridge *et al.* [3]) exists in the institution. This integration pattern outlines procedures that can be used to achieve an Integrated Data Repository (IDR) for an Educational Institution. This repository is extended to derive a dimensional data schema to which we can integrate fuzzy concepts.

In conclusion we propose that the performance evaluation model presented in this work is generic enough to cover all specific solutions discussed above. That an Integrated Data Repository (IDR) for an educational institution would resolve the problems of incompatible ad-hoc information systems by picturing them as operational subsystems and integrating data from them into a unified data repository. That the integration of fuzzy concepts by introducing Meta table structures for classification (Werro[1], Fasel and Shahzad [2]) would make the IDR intelligent with improved querying and information generation capability. We propose an extension to this approach by introducing time dimension in order to have data at different states at different points in time thereby introducing chronological versioning and historization.

3 The proposed graphical model

We now present a model to address three problems identified during the preliminary study.

This solution calls for a model with two basic components:

- **The Integration Component Layer**
  This layer is introduced to hold copies of data extracted from operational source systems. These may be text files or data from relational tables. Here the data from the diverse sources are scrubbed, conformed and standardized into dimension tables. There are no user queries at this layer.

- **The Decision Support Component Layer**
  Two processes take place here, the determination of membership degrees of the attributes in the resulting dimensional tables using trapezoidal function and classification of the attributes using a fuzzy classification algorithm. External query and reporting tools interact with this component.

The proposed graphical model is presented in Figure 1.

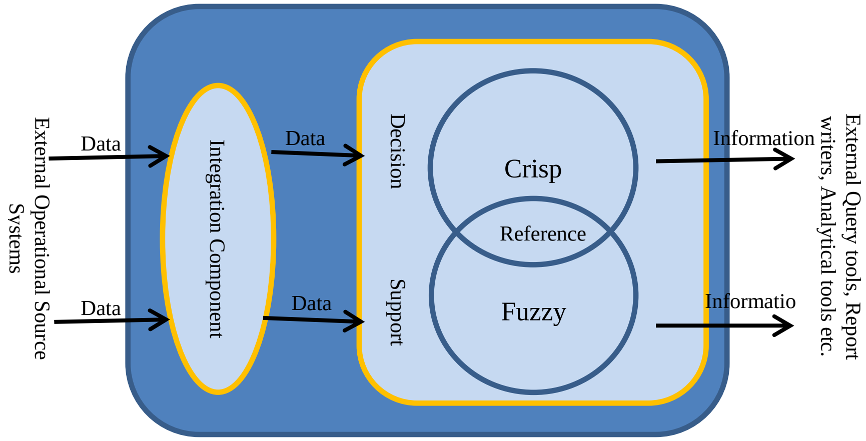

Figure 1: Proposed model of Fuzzy Integrated Academic Information Management System (FIAIMS).

Considering also the specific issues the model is to address, such as the performance of various academic programmes over a period of time using defined performance indicator criteria, we find that the structure of the database in the repository assumes a star schema structure as illustrated in Figure 2.

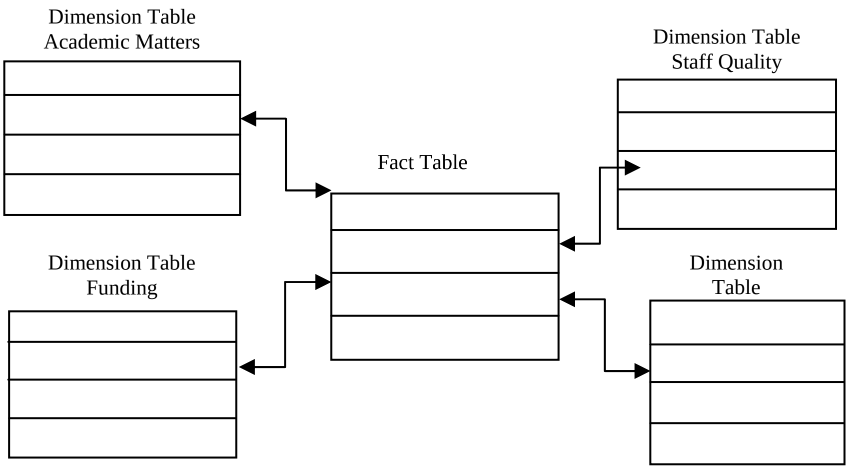

Figure 2: Star Schema of the IDR.

Imposing time invariability into this schema gives the structure away as a multi-dimensional database (Cube) as shown in Figure 3.

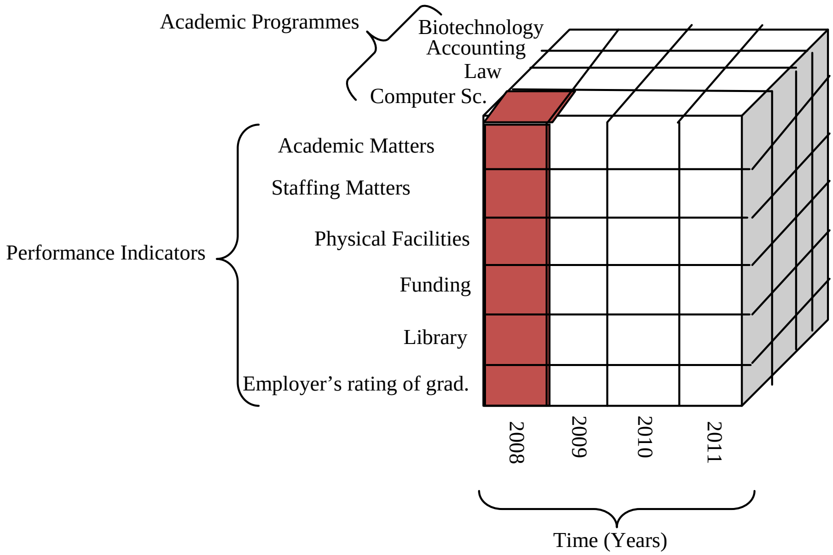

Figure 3: Multidimensional representation of the IDR.

3.1 Application and implementation perspective

To illustrate the viability of the proposed model we consider a university programme accreditation monitoring system. This system evaluates the performance level of academic programmes in the university, to determine the level of compliance with the Minimum Acceptable Standards (MAS) set by the supervisory body, like NUC. Evaluation criteria are set to measure performance under six main performance indicators, such as academic matters, staffing, physical facilities, funding, library, and employees rating of graduates.

3.1.1 Accreditation instruments/documents

Nigerian Universities Commission Programme Evaluation Form (NUC/PEF) document is an evaluation form to be completed by each Accreditation Panel Member. This document indicates

- The university offering programme/sub-discipline/discipline for which accreditation is sought.
- Title of programme
- Date of visit (From … To …)

The document contains notes on how the NUC/PEF is to be completed. The NUC/PEF has eight components as follows: a) Academic Matters, b) Staffing, c) Physical facilities, d) Financing, e) Library resources, f) Signature of panel member and Vice Chancellor, g) Panel recommendation for NUC.

3.1.2 Assessment

Evaluation is carried out by assessing six main performance indicators specified by the NUC accreditation regulations highlighted above.

At the end of the accreditation visit, the executive committee at NUC reviews the reports submitted by the accreditation panel to take a decision on the accreditation status of the programme under consideration. An evaluated programme may earn any of 3 (three) possible accreditation status:

- Full Accreditation: a minimum of 70% aggregate score + 70% in each of the four core areas of academic matters, staffing, physical facilities and library. This accreditation is valid for 6 (six) years with mid-term review.
- Interim Accreditation: aggregate score of not less than 60% or programme with a total score above 70% but which scores less than 70% in any of the indicated 4 (four) core areas. This accreditation is valid for 2 (two) years.
- Denied Accreditation: failed to satisfy MAS with less than 60% aggregate score. Admission of new entrants into this programme ceases until deficiencies are remedied.

For the purpose of this prototype system, we have used a Computer Science department for illustration, assessed over a four year period.

Example 1

The university administrators may want to know the overall rating of Computer Science programme across all performance indicators for 2008. This is a dice operation over a sub cube visualising the overall assessment score grouped by programme but executed on the dimension of time (year = 2008). Using the aggregate function and GROUP BY operator in sql (Gray *et al.* [16]), the result set in table 1 can be achieved.

Table 1: Sql query result for example 1.

Programme	Year	Perf. Indicator	Performance Rating (%)
Computer Science	2008	ALL	62.02

Example 2

The interest may be in the overall performance of Computer Science across all performance indicators over the 4 (four) years under review. This is a symmetric aggregation called cross-tabulation (cross-tab). It is a two-dimensional aggregation which is equivalent to the relational aggregation using the ALL values. Both generalise to N-dimensional cross-tab. Using the aggregate function, GROUP BY and CUBE operator in sql (Gray *et al.* [16]), the result set in table 2 can be achieved.

3.1.3 Integration of fuzzy concepts

The above illustration has classified the programmes into accreditation status categories using classical approach. With this no programme can be classified into more than one category. However it is important to note that academic programmes do in actual fact belong to each of the accreditation categories to certain degrees. For instance, Computer Science achieved full accreditation to a certain degree and interim accreditation to a certain degree also. This situation cannot be visualised using this classical approach.

We follow the steps outlined below to integrate fuzzy concepts into the dimension tables.

Table 2: Table of aggregated assessment scores for the Computer Science query result for example 2.

COMP. SCIENCE Performance Indicator	2008 Perf. Rating (%)	2009 Perf. Rating (%)	2010 Perf. Rating (%)	2011 Perf. Rating (%)	TOTAL %
acad matters (23)	82.607	73.913	65.217	69.565	72.826
staffing matters (32)	59.375	65.625	71.875	84.375	70.313
Phy Facilities (25)	56	68	80	84	72
Funding (5)	20	40	70	60	47.5
Library (12)	58.333	66.667	75	75	68.75
Empl. Rating (3)	66.667	66.667	66.667	83.33	70.833
TOTAL RATING					70

3.1.4 Fuzzy classification process

Figure 4 shows the meta table structure of the proposed model.

We illustrate the Fuzzy classification procedures as follows:

Step 1: Determine the target attributes *Tx*. In this case the performance ratings.

Step 2: Determine the class membership attributes (CMA) of the target attributes.

Step3: Specify the Fuzzy Classification for instance, full, interim or denied accreditation status.

Step 4: Calculate the membership degree of each Tx, using the function (Zadeh [15])

$$\mu_{CMA}(Tx) \in [0,1]$$

Step 5: Specify the Fuzzy Membership Table (FMT), which gives the degree to which a value is related to a membership class.

This approach will enable sharp and fuzzy classification of academic programmes performance rating. In the first instance, we classify the overall performance of a programme of study according to the criteria:

Performance Score $\geq$ 70	Full Accreditation
60 $\leq$ Performance Score < 70	Interim Accreditation
Performance Score < 60	Denied Accreditation

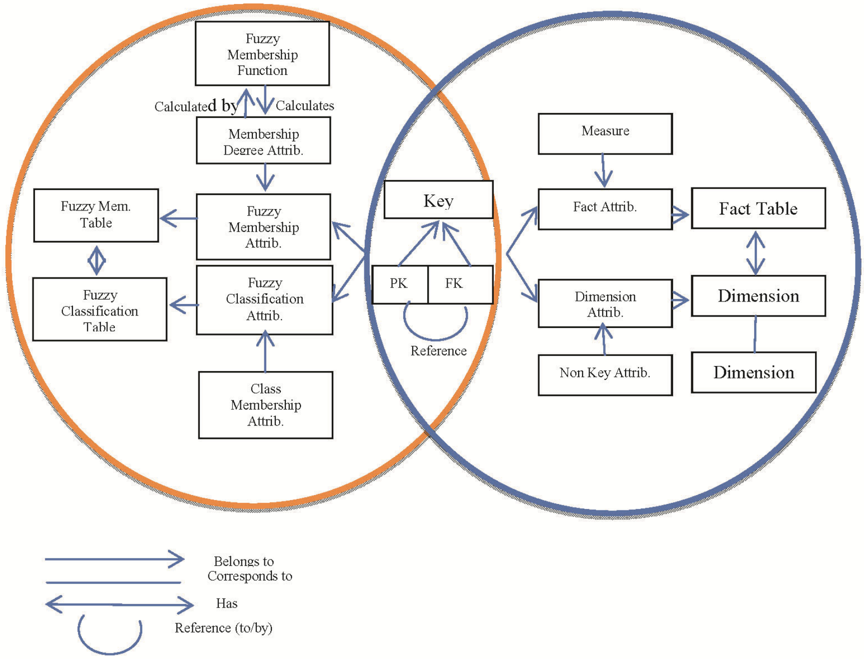

Figure 4: Proposed fuzzy integrated data repository meta model.

We define the programme performance rating attribute in the dimension programme of the study table as the target attribute in the first task of the modelling process. In the second step of the process a set of linguistic terms is defined as (full_accreditation, interim_accreditation, denied_accreditation). We use an adaptive fuzzy concept and define the membership functions as follows:

μ_{denied_accr}(perf_score) = {if perf_Score<40, MD_perf_Group=1
if perf_Score>=60, MD_perf_Group=0
else if MD_perf_Group=(60-perf_Score/60-40)}
$\mu_{interim\_accr}$(perf_Score)={if amScore>=60 AND <70, MD_perf_Group=1
if perf_Score<40, MD_perf_Group=0
if perf_Score>=80, MD_perf_Group=0
else if 40<= perf-Score <= 60,
MD_perf_Group=(perf_Score-40/60-40)
Else if 60<=perf_Score<=80,
MD_perf_Group=(perf_Score-60/80-60)}
μ_{full_accr}(perf_Score)={if perf_Score>=80, MD_perf_Group=1
if perf_Score<60, MD_perf_group=0
else if MD_perf_Group=(perf_Score-60/maxScore-60)}

For the cumulative 4-year assessment in example 2, we derive the fuzzy membership table as in table 3.

Table 3: Membership degree attribute table for aggregated assessment scores for Computer Science query result for example 2.

Perf. Indicator	Perf. Rating	CMA Full_Accredit.	CMA Interim Accredit.	CMA Denied Accredit.
Academic Matters	72.826	0.6413	0.3587	0.00
Staffing	70.313	0.5157	0.4844	0.00
Physical Facilities	72.00	0.600	0.400	0.00
Library	68.75	0.4375	0.5625	0.00
Funding	47.5	0.000	0.375	0.625
Employer |Rating	70.833	0.5417	0.4584	0.00
OVERALL RATING	70.00	0.500	0.500	0.00

4 Discussion

From table 3, we can visualize that a performance indicator belongs to a fuzzy class only to a certain degree. We can visualize that the department is not completely underfunded though not fully funded. With sharp classification, funding belongs completely to denied accreditation. There is no reflection of the meager funding since the indicator can only be classified into one class. However, with the fuzzy classification we can see that it belongs to the interim class to a degree of 0.375 and belongs to the denied class to a degree of 0.625. The same visualization holds for all other indicators and the aggregate rating.

5 Conclusion

This study examined the key issues such as the problem of ad-hoc incompatible information systems comprising of fragmented mixtures of single function systems that neither share data nor communicate effectively. Issues concerning inconsistencies, vagueness, subjectivity and sometimes missing elements in the sort of data encountered in academic processes in our environment have not been handled in this work. Real time implementation issues have not been considered.

Following established systems engineering hierarchy procedures and established design science approaches, a graphical model of the decision support system has been proposed. This model basically comprises a data aggregation component and a decision support component. One of the major goals of this model is to have data stored on a timely basis. A time dimension is therefore necessary in order to have data in different states at different points in time (Fasel and Shahzad [2]). However, the meta table structure in Fasel and Shahzad's work has not foreseen any chronological versioning or historization of fuzzy concepts. This work therefore extends Fasel and Shahzad's approach to include the ability to see how data was classified at different points in time in the past.

The case study example with quality assurance in higher education using accreditation procedures is seen as a good example since the process seeks to examine performance over a specified period in the past using certain performance indicators. This creates a multidimensional or star schema data structure.

Thereafter we adopted the Fuzzy Classification approach (Werro [1]), which combines fuzzy logic with relational databases, and that of Fasel and Shahzad [2], who propose the integration of fuzzy concepts at the Meta table layer of a data warehouse. Both approaches provide for report generation and analysis using both sharp and fuzzy queries simultaneously on the database. This approach does not require any transformation nor migration of the business data since all the fuzzy classification definitions are stored separately in met tables. Thus, there are no disturbances to the organization's business processes.

These approaches reduce the complexity of the data by classifying similar elements together as well as having fuzzy classification which is achieved by extending the relational database schema.

The advantage of this approach over other existing fuzzy approaches lies in the fact that fuzzy membership degrees do not have to be normalized to use fuzzy dimensional tables; it becomes possible to use fuzzy and sharp dimensions simultaneously. The use of this approach is expected to yield more accurate classification of values, allow analysis of quantitative and qualitative data attributes as well as enable the use of both crisp and fuzzy measures for analysis and decision making. It is hoped that a decision support system for performance evaluation built with this model would yield more predictable results in quality assurance in higher education in Nigeria.

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