Selection of Outsourcing Relationship for a Maintenance System Using Fuzzy Axiomatic Design Principles and Fuzzy VIKOR

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Abstract. *Maintenance outsourcing potentially saves cost, improves efficiency and enhances the company's competitive advantage. Yet in the instant food industry, the practice is difficult to implement with high failures of outsourcing relationships. To fill this research gap, this paper proposed a fuzzy axiomatic design (FAD) method coupled with fuzzy VIKOR (Vlse Kriterijumska Optimizacija I Kompromisno Resenje) to track uncertainty and imprecision to select external service providers in outsourcing relationships. The VIKOR method is coupled to the FAD method at the introduction of fuzzy triangular members based on the selection pillar indices of cost, equipment, vendor, production and human aspects. Four relationships are defined, namely support, alignment, reliance and alliance while the selection indices were measured against them. By weights, the model evaluated the relationships as consisting of support (20.25%), alignment (25.15%), reliance (25.19%) and alliance (29.41%). The VIKOR indices for the relationships are support (0.0141), alignment (0.0431), reliance (1.000) and alliance (0.9849). The conclusion was that alliance outsourcing was the least desired outsourcing relationship for the system.*

Received by	4 February 2021
Revised by	22 May 2021
Accepted by	15 July 2021

Keywords: Fuzzy axiomatic design principles, fuzzy VIKOR, maintenance vendor, manufacturing system, fuzzy logic

1. Introduction

To several world-class organisations, installing an effective maintenance outsourcing relationship is a route to achieving higher value creation to customers, attaining improved maintenance cost, enhanced efficiency and improved competitive advantage [1]-[8]. However, Bhimani et al. [3] cautioned that while the service quality monitoring of the organization that outsources increases, it has reduced control over the outsourced job execution, which is a bottleneck to progress. Corrections that may save tremendous costs in outsourcing mistakes could not be achieved. Prominent outsourcing studies in maintenance engineering have been documented in several cases [9], automakers [10], universities [11] and facilities management services [12]. In the instant food industry, which produces convenience food needing minimal preparation, it is extremely difficult to implement outsourcing relationship as high failure rates are experienced [13]. Yet new products are developed day after day, which complicates the outsourcing issue in the industry [13].

At present, the conventional logic technologies are ineffective in outsourcing relationships as the degree of truth describing such relationships is imprecise and uncertain ranging between 0 and 1. Relying on conventional logic implies wrong and ineffective manufacturing decisions [14]. To fill this research gap, this paper proposed a fuzzy axiomatic design (FAD) method coupled with fuzzy VIKOR (Vlse Kriterijumska Optimizacija I Kompromisno Resenje) to track uncertainty and imprecision to select external service provides in outsourcing relationships. The VIKOR method is coupled to the FAD method at the introduction of fuzzy triangular members based on the selection pillar indices of cost, equipment, vendor, production and human aspects. Four relationships are defined, namely support, alignment, reliance and alliance while the selection indices were measured against them. Uncertainty and imprecision monitoring has been considered in the maintenance outsourcing relationship for the instant food industry as a necessary activity for effective outsourcing practices [13].

Fuzzy axiomatic design (FAD) is a decision-making methodology based on multicriteria principles (MCDM) that specifically analyze the maintenance outsourcing problem based on conflicting criteria. In addition, FAD takes advantage of quality management benefits by extracting and managing the design and functional requirement of the maintenance outsourcing problem using the matrix analysis conventions. FAD is innovative and captures the necessary elements to satisfy customer needs and requirement and easy to apply. The fuzzy VIKOR method works on the principle of aggregation of the merits of the fuzzy system which shows the distance of an option to the ideal solution. It combines the fuzzification elements with the VIKOR method championed by the researcher, Opricovic, and establishes itself as an outranking approach that compromises by principle to establish a ranking list, solution and weights of parameters of interest. It is equally innovative. In installing the fuzzy concept, the parameters of all the membership functions were tuned to obtain the best results on the awareness that this depends on the application and data available on the instant food industry. Thus, the novelty of this study is to evaluate the outsourcing relationship in the instant food industry and to establish appropriate selection indices and relationship definitions which yields meaningful result for select practices of the external service providers.

To enhance the output of the maintenance system in the instant food industry in Nigeria, the industry needs to outsource maintenance services with the highest level of outsourcing relationships and efficiency. The system of outsourcing ought to be enhanced such that fewer financial losses are incurred at all times. For example, if at the planning stage errors have been committed and unknowingly delivered to the maintenance outsourcing service provider, at the detection of errors, the organization outsourcing should have a control on the system, to correct the errors and stop the process at any stage. Furthermore, though a growing application of maintenance outsourcing is spelt out by many investigators maintenance outsourcing relationships are not closely monitored and followed by the instant food industry because of the lack of knowledge regarding this issue. There is no knowledge on how to treat the imprecision and uncertainty when establishing an outsourcing relationship in maintenance in the instant food industry. Consequently, it is compelling to promote studies on maintenance outsourcing relationship in the Nigerian instant food industry to reap the benefits of outsourcing efficiently and in a healthy outsourcing environment.

To briefly review the literature, the following information is helpful. Tai [15] presented a model for a constantly decaying system for an optimal inspection-maintenance policy to be defined. Of interest is the capability of the model to handle a situation where maintenance service, for instance, outsourced activities, could be deferred. The mentioned factors under study are availability, inspection period, inter-inspection time and degradation. While the study promotes outsourcing activities, what is yet to be covered in the examination of factors affecting the outsourcing relationships. Furthermore, an interesting discussion is found by Haoues et al. [16] on capacity planning regarding outsourcing while reliability maintenance constraints are imposed on the system. The wide range of factors considered are random failures, corrective maintenance, preventive maintenance and total cost and these factors were considered in a supply chain categorized as single-manufacturer and multiple-subcontractors. Despite the added knowledge of this work to the maintenance outsourcing literature, it is not very useful to determine the specific factors associated with fuzziness regarding maintenance outsourcing practices in the instant food industry.

Yet in another study, Tsao et al. [17] analyzed the parameters to represent a maintenance outsourcing system to include the following: maintenance cost subsidization contract, uptime reward contract, bonus contract and uptime target, failure rate and maintenance capability. The key result of the research is that uptime target and bonus, as well as uptime reward contracts, attains channel organization given particular situations. Though the area of research application shares a boundary with the current study being in maintenance outsourcing, the parameters defined for the instant food industry's case study are different.

To further understand the maintenance outsourcing literature, consider Ali-Marttila et al. [18]. The chosen factors to represent the system analyzed are safety at work, service providers’ reputation, environmental safety, reliability and operators knowledge. The principal result is that multiple elements are associated with the value of maintenance services but the services are not quantified in several situations. Despite obtaining substantial findings in the search, there is still a gap of outsourcing relationship regarding imprecision and uncertainty in an instant food industry not treated in the study. Furthermore, the study by Valjakka and Valkokari [19] is associated with the present study. The researchers established an integrated service-controlled logic and inter-organizational association theories to expand knowledge on service resource combination existing among service providers, manufacturing plants and other network members. The chief findings of the research were oriented around how the resources of the plant and service providers could be combined into a networked value-creation procedure. Notwithstanding the contribution, a direct insight on how to evaluate maintenance outsourcing relationship in an instant food industry was not stated. In Chaabane et al. [20], the mentioned factors are reliability, time, budget, amount of sources, cost rate, maintenance level, its age and failure rate. Weighed against the present study, it is not clear how to approach outsourcing relationship from the study, particularly in the instant food industry.

Besides, several studies have considered other quantitative aspects of the outsourcing problem including learning influence on maintenance outsourcing [21], data management in maintenance outsourcing [22], outsourcing of maintenance activities for medical device [23] and association of maintenance outsourcing and remote control [24]. To establish the influence on learning in maintenance outsourcing, Tarakci et al. [21] considered the following factors: preventive maintenance frequency, preventive maintenance intervals, payment to contractors, the number of failures, contract period, total expected repair cost, failure pattern and manufacturing profits. Weighed against the current study, there is no insight provided on how to tackle the maintenance outsourcing relationship problem and the case of the instant food industry is missing. Furthermore, Murthy et al. [22] established a case for the management of maintenance outsourcing data with the maintenance service contracts factors being considered in their study. It was argued that information flow is needed for effective data management in outsourcing. Besides, Cruz and Rincon [23] reviewed the literature on the outsourcing of medical devices for maintenance. The principal conclusion is that the aspect of outsourcing of medical devices in hospitals is at its childhood phase and requires additional studies. The study, unfortunately, does not provide any lead on how to solve the outsourcing relationship problem associated with uncertainty and imprecision. Furthermore, Persona et al. [24] analyzed how remote control is associated with maintenance outsourcing. They concluded that the structure proposed is useful to group various e-maintenance systems and gain insight into how the various components relate within the network. It was also stated that the structure could be used to establish the diverse variables that could affect the establishment of the systems.

In summary, the following observations were obtained from the brief literature review conducted in this work. First, maintenance outsourcing has been considered using different quantitative principles such as data management, learning curves, and remote control association with maintenance outsourcing. Second, the application range of maintenance outsourcing is expanding, having been established in the medical device aspect, automakers, facility maintenance services. Third, compared to other aspects of maintenance such as scheduling, maintenance outsourcing is at its childhood. Fourth, understanding the area of maintenance outsourcing in the instant food industry where uncertainty and imprecision are considered has been excluded in the literature. Based on these outcomes, the fuzzy axiomatic design and the fuzzy VIKOR have been selected as the investigation tools and the instant food industry was chosen as the case study while the maintenance outsourcing relationship idea has been chosen for exploration. Thus, the objective of this paper is to propose a multicriteria framework for selecting the outsourcing relationship for a maintenance system using the fuzzy axiomatic design and fuzzy VIKOR. The framework was tested by using the instant food industry with decision makers' inputs.

The remaining sections of this study are organised as follows: In section 2, the proposed conceptual framework is presented. The application of the conceptual framework is contained in section 3. The conclusions of this study are presented in section 4.

2. Methodology

The proposed conceptual framework is designed for a maintenance system in which planned maintenance is practice (Fig. 1). This type of maintenance is selected because they are more effective than breakdown maintenance [25, 26]. Four outsourcing relationships are considered in this study [27, 28]. These relationships are support (R_1), alignment (R_2), reliance (R_3) and alliance relationships (R_4). While Fig. 1 shows the maintenance outsourcing selection framework, Table 1 is a list of criteria for selecting the outsourcing relationships. However, detailed explanation of the entire sub-criteria is given as follows:

Opportunity cost (x_{11})

This refers to the value a maintenance department loses when embarking on an outsourcing activity that consists of choosing at least an outsourcing organization. This cost index helps the instant food industry to establish whether to outsource maintenance services evaluates the economic advantage of engaging outsourcing service by weighing it with the option of not outsourcing maintenance service at all. Consequently, in the current manufacturing scenario increasing pressure for efficiency opportunity pressure for the efficiency of increasing cost becomes an important decision for the maintenance department of the instant food industry.

Transaction cost (x_{12})

A transaction cost refers to the cost incurred by the maintenance department in pursuing outsourcing service from the third party. They are essential since they are principal determinants of net returns in an outsourcing endeavour depending on the size, capacity the nature of equipment or activity being outsourced, maintenance managers strive to choose outsourcing service provides whose transaction cost are comparatively low. Consequently, with the present state of the economy in manufacturing paints, where cost reduction is a critical issue, the transaction cost is a necessary cost index to consider when deciding on maintenance outsourcing decisions in the instant food industry.

Overhead cost (x_{13})

This refers to the day to day running cost of the maintenance department but excludes the direct cost involved in actualizing maintenance services. The breakdown usually involves the administrative overhead that involves costs associated with managing the maintenance department of the instant food industry by tracking maintenance overhead, the instant foo industry could reduce its tax burden as overhead costs are tax-deductible. Consequently, in the cost-cutting drive of manufacturing plants in recent days, overhead cost becomes an important cost index when planning for outsourcing relationship decisions.

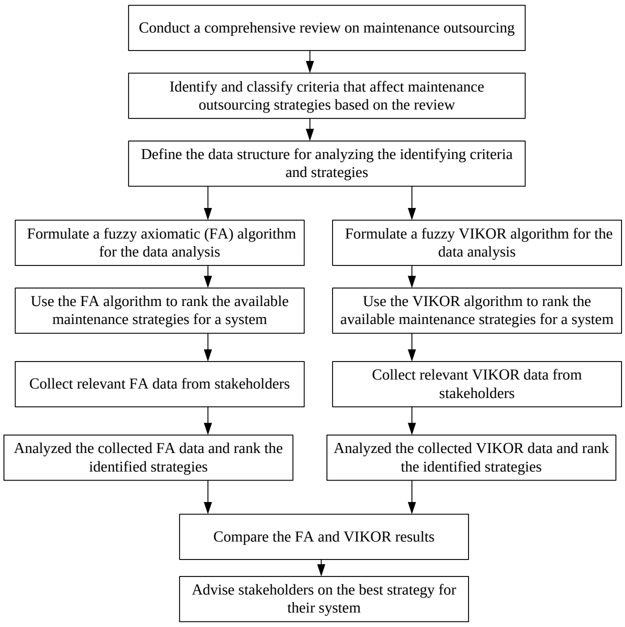

Fig. 1 A conceptual framework for maintenance outsourcing relationship selection

Criterion	Sub-criterion
Cost indices (C_1)	Opportunity cost (x_{11}) Transaction cost (x_{12}) Overhead cost (x_{13}) Cooperation cost (x_{14}) Spare parts inventory cost (x_{15}) Staff cost (x_{16})
Equipment indices (C_2)	Equipment availability (x_{21}) Equipment reliability (x_{22}) Equipment effectiveness (x_{23}) Equipment efficiency(x_{24}) Mean time before failure (x_{25})
Vendor indices(C_3)	Information threats (x_{31}) Dependence on the vendor (x_{32}) Loss of control (x_{33}) Vendor selection (x_{34}) Growth of maintenance capacity (x_{35})
Production indices (C_4)	Product quality (x_{41}) Scrap and rework (x_{42}) Production rate (x_{43}) Production time (x_{44}) Delivery promptness (x_{45})
Human indices (C_5)	Staff expertise (x_{51}) Staff retention (x_{52}) Safety compliance (x_{53}) Performance sustainability(x_{54}) Morale improvement(x_{55})

Table 1 Criteria for selecting outsourcing relationships

Cooperation cost (x_{14})

This refers to realistic fees, express and costs incurred by the outsourcing service provider (apart from inquiry cost) to react to enquires by manufacturing agencies concerning regulatory issues such as effluent disposal services. The principal advantage of this is that interruption in the operation of the instant food industry is avoided as prompt responses to requests are made on behalf of the outsourcing organization. Consequently, in the present manufacturing dispensation where idles time and production stoppages are avoided, building the cooperation cost index in planning for outsourcing relationship in maintenance is a necessity.

Spare parts inventory cost (x_{15})

A spare part sometimes is given different names such as replacement part, service part or repair part is used to interchange a failed unit. However, these parts are stored and obtained from stones when needed. The process of keeping these parts involves express in labour, space and maintenance of stock such as cleaning while planning for outsourcing relationship in the instant food industry, the spare parts inventory cost is an essential cost index to account for. By monitoring the cost, efforts are made to reduce inventory levels for a low cost.

Staff cost (x_{16})

This refers to the wages and benefits derived by the maintenance staff in the instant food industry it may also include health insurance cost in the current dispensation of cost-cutting drive the factor, staff cost becomes a necessary cost index to consider while taking maintenance outsourcing relationship decisions.

Equipment availability (x_{21})

Equipment availability refers to a measure of the percentage of time that the instant food equipment can be used for production. It specifies the actual time that the food equipment runs and is available for production. In the present era of drive for improved operational efficiency, high availability achievement for the instant food industry is a necessity. This will provide the industry with an adequate production run time to produce profit for the organization. Consequently, while planning for outsourcing relationships in the maintenance department of the instant food industry, the equipment availability index is an essential item to consider.

Equipment reliability (x_{22})

This measures the time that the instant food equipment will correctly function, evaluating the possibility of remaining functional at a point in time. In practice efforts made to improve the reliability of the food equipment have been made to train plant workers, use quality lubricants to reduce breakdown and install redundant equipment. Consequently, a piece of equipment that is reliable helps to achieve the goals of maintenance in providing equipment to production at the desired level of performance. Consequently, when planning for maintenance outsourcing, the planner should incorporate equipment reliability as a factor to consider for a complete analysis of essential parameters into the framework.

Equipment effectiveness (x_{23})

This measure indicates how well the instant food operation is utilized regarding the inputs such as time, equipment hours and materials and comparing the utilization of these inputs to their full potentials. Thus, while planning for outsourcing relationship in the maintenance section of the instant food industry, the incorporation of the equipment effectiveness criterion is a necessity.

Equipment efficiency (x_{24})

The maintenance department of the instant food industry may be described as efficient if it inputs minimum efforts to obtain the expected results. Besides efforts, the resources used should be minimized while the waste produced should also be minimum. By explaining the efficiency of the equipment, it means how well the equipment performs its designed tasks. Consequently, while planning for outsourcing relationship in the maintenance department, the incorporation of the equipment efficiency metric in the framework for analysis is a necessity.

Mean time between failure (x_{25})

Since a production system is a non-disposable unit it must fail and be repaired severally. However, it is desired to have a long time difference between when a failure occurs and another one emerges. This reflects the competence of the maintenance crew in restoring the equipment to a functional state and also whether the equipment is old or not. If a piece of old equipment is maintaining, irrespective of how competent the crew is it will still break down too frequently. While planning for the maintenance function of the instant food industry regarding outsourcing relationship, the incorporation of meantime before failure is an essential step to achieve a robust framework.

Information threats (x_{31})

A threat is a probable negative action taken by a third party who is the outsourcing service provider, which results in an undesirable impact on the instant food industry. Information, including trade secrets, is vital to the survival of modern manufacturing systems. It is expected that product information should be kept secret by the outsourcing service organisation as a key ingredient of the outsourcing agreement. Consequently, in developing maintenance outsourcing plans for the instant food industry, the inclusion of clauses on information threat regarding non-divulgence of product information and trade secret is a requirement.

Dependence on the vendor (x_{32})

Business transactions with a third party on outsourcing maintenance services are based on trust. It is expected that the vendor act on behalf of the outsourcing organisation in good faith. Hence, in the plan regarding the maintenance outsourcing relationship, the inclusion of the clause bearing dependence on the outsourcing service provider is an essential issue.

Loss of control (x_{33})

The control of outsourcing activities by the service provider during implementation assures the high possibility of attaining excellent results. However, if control is lost, there is no guarantee of achieving the set goals. Consequently, in planning for maintenance outsourcing activities in the instant food industry, the incorporation of the loss of control clause is an essential requirement.

Vendor selection (x_{34})

This sub-criterion implies that the method should be sensitive to the selection of vendor. Thus, in a maintenance outsourcing relationship, it is essential to incorporate vendor selection in the development of the framework.

Growth of maintenance capacity (x_{35})

Over the years that the instant food industry is installed, it is expected that there is positive growth in the activities of the plant. This expansion may be a result of the penetration of the product in the market. Thus, in planning for maintenance outsourcing relationship it is important to incorporate the index of growth of maintenance capacity into the framework.

Production quality (x_{41})

Instant food quality, which refers to the total features of the food (i.e. appearance, taste, aroma, shape, colour) that bears on its ability to accomplish the given needs is an essential issue to consider when planning for outsourcing relationship in maintenance within the instant food industry.

Scrap and rework (x_{42})

The instant food industry produces good quality products but accompanied by scraps and reworks due to machine malfunctioning, errors in humans and system imposed constraints. However, ignoring these elements in planning for maintenance outsourcing is enormous. Thus, the inclusion of scraps and reworks as human indices for maintenance outsourcing relationship planning is compelling for an adequate representation of the outsourcing system.

Production rate (x_{43})

In the instant food industry, there is installed capacity of machines but the operating capacity of the system may differ from installed capacity since various system constraints account for this. The operating capacity however determines the production rate. But in the planning of maintenance outsourcing relationship for the instant food plant, there is a necessity to include the production rate for a complete overview of the system.

Production time (x_{44})

In production, the tune to transform the inputs to outputs is essential to determine the expected output per shift and the projected profit for the organisation. As machine failure drastically reduce output, the production time guides the maintenance engineer to suggest which equipment in the instant food plant should be given immediate attention in outsourcing activities. Thus, in planning for maintenance outsourcing relationship, the incorporation of production rate as an index of production is a necessity.

Delivery promptness (x_{45})

Products delivered to the customers must be promptly delivered. However, omitting this index in the planning for maintenance outsourcing is a serious issue. Thus, when planning for outsourcing activities in the instant food industry, delivery promptness is a necessary inclusion criterion.

Staff expertise (x_{51})

Consequently, as the modern manufacturing systems emphasize expertise and multiskilling in practice, the inclusion of the staff expertise index in outsourcing relationship in maintenance for the instant food industry is a necessity.

Staff retention (x_{52})

When maintenance services are outsourced in the instant food industry to a third party, the maintenance staff are affected in many ways. There are staff that would feel being relieved of the heavy burden of repairs and maintenance. Other staff may feel that the primary source of training and career development through repairs and maintenance has been taken away by the third party. In either case, the decision to continue or stop working for the company by the employee is influenced. This is staff retention in the instant food industry. Furthermore, though learn practices are implemented companywide, yet manufacturers are skillful staff. Thus, in planning for maintenance outsourcing in the food industry, the inclusion of the staff retention index is a necessity toward continued maintenance efficiency of the plant.

Safety compliance (x_{53})

A careless effort of an employee can ruin the instant food industry in a fire accident. But a culture of safety compliance can be built in the employee overtime such that protective equipment is work at the right time. Also, the machine guards are not displaced to endanger the employees for any reason. Thus, in planning for an outsourcing decision for the instant food industry, the inclusion of the safety compliance index is a necessity.

Performance sustainability (x_{54})

In modern manufacturing systems, the regular maintenance of high performance by considering all factors, including the environment, is a certain route to forging ahead of the competition. Thus, in planning for outsourcing decisions in the instant food industry the inclusion of performance sustainability is essential.

Morale improvement (x_{55})

The morale of workers may be high or low depending on their viewpoint in outsourcing decisions within the instant food industry. To those who feel that maintenance services should not be outsourced the morale may be low if a decision by the organization is made otherwise. The case is the reverse for those who feel otherwise. The case is the reverse for those who feel otherwise. In either case, it is essential to consider how to enhance morale as an index for inclusion when attempting to plan for maintenance outsourcing in the instant food industry.

2.1 Fuzzy Axiomatic Design Principles

Axiomatic design **(**AD) principle is a methodology developed by Suh [29] for the selection of the most suitable approach, tool, method or relationship for accomplishing a task or system. AD principle is based on two axioms (Independence and information axioms). The first principle is used to determine the independence of an approach, tool, method or relationship with respect to functional requirements of a task or system (independence axiom). The second principle is used to determine the information content of an approach, tool, method or relationship (information axiom).

During the application of AD principles, three types of design are considered. These designs are decoupled, uncoupled and coupled designs (Fig.s 2(a)-(c)). A decoupled design ensures that the independence of functional requirements is maintained and it generates the best solution [30]. After the independence of a design has been established, the most suitable design is selected based on the value of their information content. The approach, tool, method or relationship with the highest information content is considered as the most suitable approach, tool, method or relationship for accomplishing a task.

The evaluation of information content for a most suitable approach, tool, method or relationship is based on the intersection of system and design ranges [29, 31].

$$\begin{bmatrix} X & X & X \\ X & X & X \\ X & X & X \end{bmatrix} \quad \begin{bmatrix} X & 0 & 0 \\ 0 & X & 0 \\ 0 & 0 & X \end{bmatrix} \quad \begin{bmatrix} X & X & X \\ 0 & X & X \\ 0 & 0 & X \end{bmatrix}$$

(a) (b) (c)

Fig. 2 Three types of design: (a) coupled, (b) uncoupled and (c) decoupled

The intersection of the system and design range gives what is known as a common range (Fig. 3). The value of information content of a most suitable approach, tool, method or relationship is expressed as (1). FAD methodology is a modified AD principle that is designed for the selection of the most suitable approach, tool, method or relationship for accomplishing a task or system in a fuzzy environment [31]-[33]. Since the importance of criteria is not the same, the current paper considered weighted information content during the analysis of the maintenance outsourcing relationships as (2).

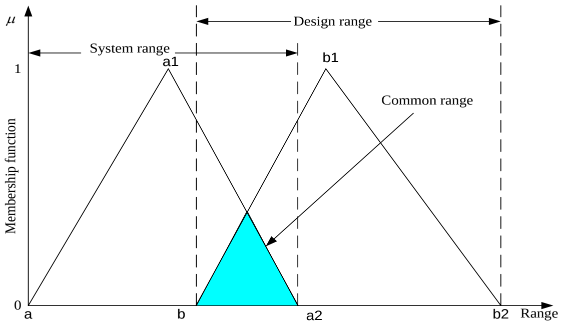

Fig. 3 Common, design and system ranges for a fuzzy functional requirement

$$I_c = \log_2\left(\frac{SR}{CR}\right) \quad (1)$$

$$I_i = w_i I_c \quad (2)$$

; where I_c represents information content, *SR* represents system range and *CR* represents a common range.

From Fig. 3, the common area between SR and DR is expressed is expressed as (3), while system areas is expressed as (4) [32]-[33].

$$CR = \frac{(a_2 - b)^2}{2(a_2 - a_1 + b_1 - b)} \quad (3)$$

$$SR = \sqrt{s(s-a)(s-a_1)(s-a_2)} \quad (4)$$

$$s = \frac{a + a_1 + a_2}{2} \quad (5)$$

; where *s* represents the perimeter of a triangle.

To apply FAD principles for maintenance outsourcing relationship selection, five-scale linguistic terms are considered for the system range (Table 2 and Fig. 4).

Linguistic term	Notation	Fuzzy number
Very low	VL	1,1,3
Low	V	1,3,5
Moderate	M	3,5,7
High	H	5,7,9
Very high	VH	7,9,9

Table 2 Membership functions for system range

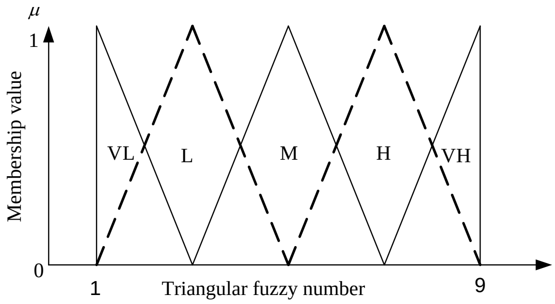

Fig. 4 The system range membership functions

During the literature survey conducted in this paper to find out the appropriate membership functions that should be the bedrock of the fuzzy set theory analysis, it was noted that the fuzziness in a fuzzy set is established by its membership function. It was also noted that the shapes, assumed for membership functions are important for this study as they influence the fuzzy inference system. Furthermore, the literature reviewed reveals the various membership function as many as five are used for solving problems, namely the sigmoid membership, Gaussian membership, trapezoidal membership, bell-shaped membership and triangular membership function. The trapezoidal membership function is often described by four parameters, namely the lower, upper, lower-support and upper support limits. The Gaussian membership function exhibits an upper value of 1, while its mean and standard deviation are evaluated for each input value. The bell membership function has a symmetrical bell shape and three main parameters that define it, namely the bells width, a positive integer and the parameter locating the centre of the curve. The sigmoid membership function exhibits two parameters that control its slope at the crossover point. The triangular membership function has three specifications, including the lower and upper limits as well as the value in-between.

However, the triangular membership function is chosen to analyse the problem in this paper because the calculations involving it are relatively easy compared with the authentic operations of other membership functions like the Gaussian, Bell sigmoid and trapezoidal. The ease of usage of the triangular membership function lies in that it requires only a small amount of data to expense its membership function. Besides, the modal values, which describe the modification of parameters, are easy for the triangular membership function than the other four alternatives mentioned above. Notice that the modal values are the foundation of measure values of the input/output description of a system. Furthermore, turning is an important concept when describing the membership functions for a problem. However, the parameters cannot be tuned. Instead, appropriate partitioning of the universal set is required. In most case, scholars use five partitions.

Consequently, under the application of FAD principles, the use of more than one decision-maker is required [32, 33]. The aggregated value of decision-makers responses to a particular question is expressed as (6).

$$x_{ij} = \frac{1}{k}\left(x_{ij}^1 + x_{ij}^2 + \ldots + x_{ij}^k\right) \quad (6)$$

In order to obtain the crisp values of the sub-criteria weights, Girubha and Vinodh [34] approach of crisp weights determination was adopted. A graded mean integration representation approach that was proposed by Chen and Hsiel [35] is used in obtaining the crisp weights for the various criteria as (7).

$$w_{ij} = \frac{a + 4a_1 + a_2}{6} \quad (7)$$

;where w_{ij} represents the weight of sub-criterion *j* belonging to criterion *i*.

2.2 Vlse Kriterijumska Optimizacija I Kompromisno Resenje (VIKOR)

VIKOR approach is a multi-criteria decision-making tool. It employs a procedure which determines the closeness of criteria towards the desired values of each criterion. The procedure of VIKOR involves five stages. These stages are presented as follows [36, 37]:

Stage 1: Determination of the best and worst selection sub-criterion, the best outsourcing relationship sub-criterion is the best value outsourcing relationship sub-criterion among the outsourcing relationship as (8). The worst outsourcing relationship sub-criterion is the minimum value outsourcing relationship sub-criterion among the outsourcing relationship as (9).

$$f_j^* = \max\left(f_{rj}\right) \quad (8)$$

$$f_j^- = \min\left(f_{rj}\right) \quad (9)$$

;where f_{rj} is of sub-criterion *j* obtained from outsourcing relationship *r*; f_j^* is maximum f_j^- is minimum value for criterion *j*, and value for sub-criterion *j*.

Stage 2: Estimation of regret measure ($\bar{R}$) and utility (*S*) for each relationship. The value of $\bar{R}$ value is expressed as (10). *S* value is expressed as (11).

$$\bar{R}_r = \max_j\left(\frac{w_j\left(f_j^* - f_{rj}\right)}{f_j^* - f_j^-}\right) \quad (10)$$

$$S_r = \sum_{j=1}^{n} \frac{w_j\left(f_j^* - f_{rj}\right)}{f_j^* - f_j^-} \quad (11)$$

From Table 3, it is indicated that the domain of weight of sub-criteria varies between O and 1. However, the weighted information contents of the sub-criteria (cost index, vendor index and production index) are shown to be greater than 1. The reason is that since the weighted information content is a function of a criterion's weight an alternative rating, it can be greater than 1.

Linguistic variables	Notation	Fuzzy number
Unimportant	U	0.00, 0.15, 0.30
Fairly unimportant	F	0.15, 0.30, 0.45
Important	I	0.30, 0.45, 0.60
Moderately important	M	0.45, 0.60, 0.75
Highly important	H	0.60, 0.75, 0.90
Extremely important	E	0.75, 0.90, 1.00

Table 3 Linguistic variables for weight of sub-criteria

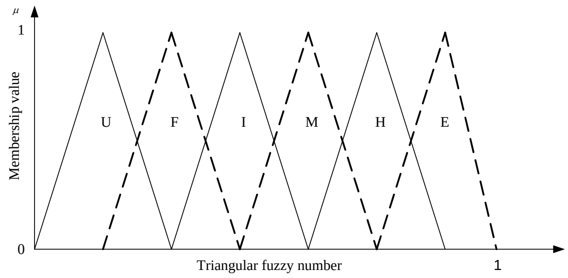

Fig. 5 Membership functions for the criteria weights

Stage 3: Calculation of VIKOR index (*Q*) for the maintenance outsourcing relationship, the value of *Q* index for a maintenance outsourcing relationship is based on regret and utility values as well as weight (*v*). The *Q* index for an outsourcing relationship is expressed as (12).

$$Q_s = \frac{v\left(S_r - S_r^-\right)}{S_r^* - S_r^-} + \frac{(1-v)\left(\bar{R}_r - \bar{R}_r^-\right)}{\bar{R}_r^* - \bar{R}_r^-} \quad (12)$$

; where $\bar{R}_r^-$ and $\bar{R}_r^*$ represents min($\bar{R}_r$) and max($\bar{R}_r$), S_s^* and S_r^- represents max(S_r) and min (S_r).

Stage 4: Ranking and selection of the maintenance outsourcing relationship using the values obtained from (10)-(11). The most maintenance outsourcing relationship is the maintenance system with the lowest value for *S*, *R* and *Q*.

Stage 5: Determination of compromise solution using the VIKOR indices that are obtained from (12), the condition for compromise solution generation for the maintenance outsourcing relationship problem is given as follows:

CC1: Acceptable advantage

$$Q\left(a''\right) - Q\left(a'\right) \geq \frac{1}{T-1} \quad (13)$$

; where a'' represents the second-ranked maintenance outsourcing relationship based on VIKOR indices.

CC2: Acceptable stability

The most suitable maintenance outsourcing relationship must also be the most suitable maintenance outsourcing relationship based on either utility or/and regret measure.

When a violation of any of the above conditions occurs, a compromise solution is generated as follows:

i. Alternative a' and a'' when the acceptable stability is violated.

ii. Alternative $a', a'' \ldots a^m$ when the acceptable advantage is violated. Alternative a^m is determined based on (12).

$$Q(a^m) - Q(a') \geq \frac{1}{T-1} \quad (14)$$

3. Model Application

The source of data used in this article is a Nigerian instant food industry located in south-western Nigeria. The plant has equipment for the production of instant food that is complex to manage. In some instances, the expertise of the in-house maintenance staff is insufficient to repair the failed equipment and the repair services are outsourced to sister companies. However, some situations arise that the skills required for the repairs are not readily available and foreign experts and equipment manufacturers' assistance are required. The expert's opinions were sought from five experts within the plant. The information that is used for the implementation of the proposed framework is obtained using a structured questionnaire that captures the required information. Five decision-makers were considered during the implementation of the proposed framework. The responses of the decision-maker were first obtained in linguistic forms (Table 4 and Table 5).

Based on the information in Tables 4 and 6, the aggregated triangular fuzzy numbers for various outsourcing relationships were determined (Table 6). In order to compute the common areas for the various relationships, the design ranges for the various sub-criteria were specified (Table 7).

Sub-criterion	Support relationship (R_1)					Alignment relationship (R_2)				
	D_1	D_2	D_3	D_4	D_5	D_1	D_2	D_3	D_4	D_5
x_{11}	H	VH	VH	H	H	M	H	M	H	M
x_{12}	H	VH	M	H	M	L	H	M	M	M
x_{13}	H	VH	L	M	M	L	VH	M	L	M
x_{14}	M	M	L	M	M	H	M	M	M	M
x_{15}	H	VH	M	M	M	M	M	M	L	M
x_{16}	H	VH	H	M	M	M	H	M	M	H
x_{21}	H	H	VH	VH	H	H	H	M	VH	H
x_{22}	H	H	VH1	VH	H	H	H	M	VH	H
x_{23}	H	M	H	VH	H	H	M	M	VH	H
x_{24}	M	H	H	VH	H	H	H	M	VH	H
x_{25}	L	L	M	H	M	L	H	M	VH	M
x_{31}	H	L	L	VL	M	L	L	M	VL	M
x_{32}	VL	H	M	VL	M	H	H	M	VL	M
x_{33}	H	L	M	VL	M	L	H	M	VL	M
x_{34}	VH	H	M	M	H	H	H	M	L	M
x_{35}	H	M	M	H	M	H	H	M	VH	H
x_{41}	L	VH	VH	VH	H	VH	M	M	VH	H
x_{42}	H	M	M	VL	M	VL	H	M	VL	M
x_{43}	H	H	H	VH	H	H	H	M	VH	H
x_{44}	H	H	H	M	H	H	H	M	H	H
x_{45}	H	H	VH	H	H	VH	L	M	H	M
x_{51}	H	H	H	VH	H	H	H	M	VH	H
x_{52}	H	M	M	H	H	H	H	M	H	H
x_{53}	H	H	H	VH	H	H	VH	M	VH	H
x_{54}	H	H	H	VH	H	H	H	M	VH	H
x_{55}	H	L	M	H	H	H	H	M	H	H

Table 4 System range in linguistic terms for alignment and support relationships

Sub-criterion	Reliance relationship (R_3)					Alliance relationship (R_4)				
	D_1	D_2	D_3	D_4	D_5	D_1	D_2	D_3	D_4	D_5
x_{11}	L	H	H	H	M	L	H	H	H	M
x_{12}	L	M	H	M	M	L	H	H	H	M
x_{13}	M	H	M	M	M	H	H	M	L	M
x_{14}	L	H	M	M	L	H	M	M	M	M
x_{15}	M	VH	H	VL	M	M	H	H	L	M
x_{16}	M	H	L	VL	M	M	H	H	M	M
x_{21}	H	H	L	VH	H	H	H	VH	VH	H
x_{22}	H	VH	H	VH	H	H	H	VH	VH	H
x_{23}	H	VH	H	VH	H	H	M	VH	VH	H
x_{24}	H	H	M	VH	H	H	H	H	VH	H
x_{25}	L	H	VH	H	M	L	L	H	VH	M
x_{31}	L	L	VH	VL	M	L	H	H	L	M
x_{32}	H	H	H	L	M	H	H	M	L	M
x_{33}	L	M	H	VL	M	L	H	M	L	M
x_{34}	H	H	H	L	M	H	M	M	L	M
x_{35}	H	H	H	H	M	L	H	M	VH	M
x_{41}	VH	H	H	VH	H	H	H	H	VH	H
x_{42}	L	M	H	VL	M	H	M	H	VL	H
x_{43}	H	H	M	H	H	H	H	H	H	H
x_{44}	H	VH	VH	H	H	H	H	VH	H	H
x_{45}	H	H	VH	VH	M	H	H	VH	VH	H
x_{51}	H	H	M	VH	H	H	H	VH	VH	H
x_{52}	H	H	M	H	H	H	H	H	VH	H
x_{53}	VH	VH	M	VH	H	H	M	H	VH	H
x_{54}	H	H	H	VH	H	H	H	H	VH	H
x_{55}	H	H	H	VH	H	H	H	H	H	H

Table 5 System range in linguistic terms for reliance and alliance relationships

Sub-criterion	R_1	R_2	R_3	R_4
x_{11}	5.80, 7.80, 9.00	5.96, 7.96, 9.00	5.75, 7.75, 9.00	5.50,7.50, 9.00
x_{12}	4.60, 6.60, 8.20	4.52, 6.52, 8.04	4.02, 6.02, 7.85	4.23, 6.23, 8.02
x_{13}	3.80, 5.80, 7.40	3.56, 5.56, 7.08	2.87, 4.87, 6.70	3.25, 5.25, 7.04
x_{14}	2.00, 3.60, 5.20	1.80, 3.32, 4.84	2.16, 3.98, 5.81	2.39, 4.18, 5.97
x_{15}	4.20, 6.20, 7.80	4.04, 6.04, 7.56	3.45, 5.45, 7.27	3.54, 5.54, 7.33
x_{16}	4.60, 6.60, 8.20	4.52, 6.52, 8.04	4.02, 6.02, 7.85	3.83, 5.83, 7.62
x_{21}	5.80, 7.80, 9.00	5.96, 7.96, 9.00	6.15, 8.15, 9.00	5.98, 7.98, 9.00
x_{22}	5.80, 7.80, 9.00	5.96, 7.96, 9.00	6.15, 8.15, 9.00	5.98, 7.98,9.00
x_{23}	5.00, 7.00, 8.60	5.00, 7.00, 8.52	5.40, 7.40, 8.82	5.48, 7.48, 8.79
x_{24}	5.00, 7.00, 8.60	5.40, 7.40, 8.92	5.48, 7.48, 8.90	5.58, 7.58, 8.88
x_{25}	2.60, 4.60, 6.60	2.92, 4.92, 6.92	3.30, 5.30, 7.30	3.36, 5.36, 7.36
x_{31}	2.20, 3.80, 5.80	1.64, 3.16, 5.16	1.77, 3.19, 5.19	1.92, 3.23, 5.23
x_{32}	3.80, 5.40, 7.00	3.16, 4.68, 6.60	2.79, 4.22, 6.12	2.75, 4.06, 5.94
x_{33}	2.60, 4.20, 6.20	2.12, 3.64, 5.64	2.34, 3.77, 5.77	2.21, 3.52, 5.52
x_{34}	4.60, 6.60, 8.20	4.12, 6.12, 8.04	3.94, 5.94, 7.85	4.13, 6.13, 8.02
x_{35}	3.80, 5.80, 7.80	3.56, 5.56, 7.56	3.67, 5.67, 7.67	3.81, 5.81, 7.81
x_{41}	5.40, 7.40, 8.20	6.28, 8.28, 8.84	6.14, 8.14, 8.81	5.96, 7.96, 8.77
x_{42}	3.00, 4.60, 6.60	2.60, 4.12, 6.12	2.52, 3.94, 5.94	2.42, 3.73, 5.73
x_{43}	5.40, 7.40, 9.00	5.48, 7.48, 9.00	5.58, 7.58, 9.00	5.69, 7.69, 9.00
x_{44}	4.60, 6.60, 8.60	4.52, 6.52, 8.52	4.42, 6.42, 8.42	4.31, 6.31, 8.31
x_{45}	5.40, 7.40, 9.00	5.48, 7.48, 9.00	5.58, 7.58, 9.00	5.29, 7.29, 9.00
x_{51}	5.40, 7.40, 9.00	5.48, 7.48, 9.00	5.58, 7.58, 9.00	5.69, 7.69, 9.00
x_{52}	4.20, 6.20, 8.20	4.04, 6.04, 8.04	4.25, 6.25, 8.25	4.50, 6.50, 8.50
x_{53}	5.40, 7.40, 9.00	5.48, 7.48, 9.00	5.58, 7.58, 9.00	5.69, 7.69, 9.00
x_{54}	5.40, 7.40, 9.00	5.48, 7.48, 9.00	5.58, 7.58, 9.00	5.69, 7.69, 9.00
x_{55}	3.80, 5.80, 7.80	3.56, 5.56, 7.56	4.07, 6.07, 8.07	4.29, 6.29, 8.29

Table 6 Aggregated system range in term of triangular fuzzy number

Sub-criterion	Fuzzy numbers	Sub-criterion	Fuzzy numbers
x_{11}	3, 5, 7	x_{33}	1, 3, 5
x_{12}	1, 3, 5	x_{34}	3, 5, 7
x_{13}	1, 3, 5	x_{35}	7, 9, 9
x_{14}	1, 3, 5	x_{41}	7, 9, 9
x_{15}	1, 3, 5	x_{42}	1, 3, 5
x_{16}	1, 3, 5	x_{43}	7, 9, 9
x_{21}	7, 9, 9	x_{44}	7, 9, 9
x_{22}	7, 9, 9	x_{45}	7, 9, 9
x_{23}	7, 9, 9	x_{51}	7, 9, 9
x_{24}	7, 9, 9	x_{52}	7, 9, 9
x_{25}	3, 5, 7	x_{53}	7, 9, 9
x_{31}	1, 3, 5	x_{54}	7, 9, 9
x_{32}	3, 5, 7	x_{55}	7, 9, 9

Table 7 Design requirements for the sub-criteria

In order to generate the information content for the sub-criteria, the common areas of the relationships were determined from the information in Table 6 and Table 7. The system areas were determined using the aggregated fuzzy numbers as indicated in Table 6. Each of the relationship sub-criterion information (Table 8) was consequently computed by using (1).

To generate the total weighted information content for the sub-criteria, the decision-makers were asked to evaluate the weights of the sub-criteria using linguistic expressions (Table 9). Since most studies that considered weights usually specified that the total sum of weights must be equal to unity [9, 36], the actual crisp weights are normalised (Table 10).

	System area				Common range				Information content			
	R_1	R_2	R_3	R_4	R_1	R_2	R_3	R_4	R_1	R_2	R_3	R_4
x_{11}	22.37	10.55	10.55	10.55	1.28	0.85	0.85	0.85	4.13	3.63	3.63	3.63
x_{12}	15.17	6.50	6.50	10.55	0.50	0.33	0.33	0.12	4.92	4.28	4.28	6.46
x_{13}	10.89	7.11	8.48	8.48	0.50	0.23	0.21	0.21	4.45	4.96	5.31	5.31
x_{14}	2.57	8.48	4.52	8.48	0.36	0.48	0.48	0.21	2.85	4.14	3.24	5.31
x_{15}	12.97	4.52	10.17	8.48	0.72	0.12	0.14	0.21	4.17	5.24	6.20	5.31
x_{16}	15.17	10.55	4.18	10.55	0.18	0.48	0.51	0.12	6.40	4.46	3.02	6.46
x_{21}	22.37	17.50	15.17	22.37	4.00	2.69	2.69	1.60	2.48	2.70	2.50	3.81
x_{22}	22.37	17.50	22.37	22.37	4.00	1.42	1.60	1.60	2.48	3.62	3.81	3.81
x_{23}	17.50	15.17	22.37	19.82	4.84	1.42	1.60	2.03	1.85	3.41	3.81	3.29
x_{24}	17.50	17.50	17.50	19.97	4.00	2.22	2.22	1.80	2.13	2.98	2.98	3.47
x_{25}	4.52	10.89	12.97	8.94	1.28	0.70	0.70	1.16	1.82	3.96	4.21	2.95
x_{31}	2.14	2.14	4.95	6.50	1.09	0.51	0.55	0.33	0.98	2.06	3.16	4.28
x_{32}	10.17	7.91	10.55	8.48	1.80	0.91	0.85	1.08	2.50	3.11	3.63	2.97
x_{33}	4.18	4.18	4.18	4.52	0.80	0.51	0.51	0.48	2.39	3.02	3.02	3.24
x_{34}	15.17	8.48	10.55	6.50	1.62	0.85	0.85	1.33	3.23	3.31	3.63	2.28
x_{35}	10.55	17.50	15.00	10.89	4.00	2.69	2.42	3.76	1.40	2.70	2.63	1.54
x_{41}	19.54	17.42	22.37	19.97	4.00	1.60	1.60	1.80	2.29	3.44	3.81	3.47
x_{42}	6.03	10.17	4.18	9.87	0.20	0.55	0.51	0.13	4.91	4.20	3.02	6.26
x_{43}	19.97	17.50	15.00	17.41	4.00	2.69	2.42	2.00	2.32	2.70	2.63	3.12
x_{44}	15.00	15.00	13.17	19.97	4.84	2.65	3.78	1.80	1.63	2.50	1.80	3.47
x_{45}	19.97	10.89	19.82	22.37	6.76	1.80	2.03	1.60	1.56	2.60	3.29	3.81
x_{51}	19.97	17.50	17.50	22.37	4.00	2.22	2.22	1.60	2.32	2.98	2.98	3.81
x_{52}	12.72	15.00	15.00	19.97	4.84	2.42	2.42	1.80	1.39	2.63	2.63	3.47
x_{53}	19.97	19.82	22.03	17.50	3.24	1.60	1.83	2.22	2.62	3.63	3.59	2.98
x_{54}	19.97	17.50	19.97	19.97	4.00	1.80	1.80	1.80	2.32	3.28	3.47	3.47
x_{55}	10.55	15.00	19.97	17.41	4.84	1.62	1.80	2.00	1.12	3.21	3.47	3.12

Table 8 System area, common range and information content of the sub-criteria

Sub-criterion	D_1	D_2	D_3	D_4	D_5	Sub-criterion	D_1	D_2	D_3	D_4	D_5
x_{11}	M	I	F	H	M	x_{33}	E	I	M	E	I
x_{12}	H	H	F	H	M	x_{34}	H	H	M	H	H
x_{13}	H	H	F	U	M	x_{35}	H	I	M	H	I
x_{14}	H	E	F	U	M	x_{41}	E	I	I	E	E
x_{15}	E	M	F	H	M	x_{42}	H	H	I	E	I
x_{16}	H	H	E	U	M	x_{43}	E	F	M	E	M
x_{21}	E	H	E	U	H	x_{44}	E	I	M	H	H
x_{22}	E	H	E	U	M	x_{45}	E	H	M	E	H
x_{23}	E	H	E	H	H	x_{51}	E	H	M	E	H
x_{24}	E	H	E	H	H	x_{52}	H	M	H	H	E
x_{25}	H	H	I	M	M	x_{53}	E	E	H	E	E
x_{31}	H	I	I	E	M	x_{54}	E	E	M	E	M
x_{32}	M	H	I	M	I	x_{55}	H	E	M	H	M

Table 9 Linguistic variables for the sub-criteria weights

	Actual	Normalised		Actual	Normalised		Actual	Normalised		Actual	Normalised		Actual	Normalised
x_{11}	0.53	0.07	x_{21}	2.66	0.22	x_{31}	1.95	0.26	x_{41}	3.37	0.29	x_{51}	2.77	0.18
x_{12}	0.94	0.13	x_{22}	2.29	0.19	x_{32}	0.90	0.12	x_{42}	2.32	0.20	x_{52}	2.77	0.18
x_{13}	0.79	0.11	x_{23}	3.15	0.26	x_{33}	1.95	0.26	x_{43}	1.95	0.17	x_{53}	3.67	0.24
x_{14}	1.84	0.25	x_{24}	3.15	0.26	x_{34}	1.73	0.23	x_{44}	1.31	0.11	x_{54}	3.45	0.23
x_{15}	0.90	0.12	x_{25}	0.94	0.08	x_{35}	0.90	0.12	x_{45}	2.77	0.24	x_{55}	2.40	0.16
x_{16}	2.29	0.31												

Table 10 Actual and normalised values for the sub-criteria weights

By considering the weights of the various sub-criteria in Table 10 and the information contents in Table 9, the weighted information content of the sub-criteria of each maintenance outsourcing relationship was determined (Table 11). The results obtained were used to determine the total weighted information contents of the maintenance outsourcing relationships (Fig. 6). The results obtained showed that apart from cost criterion, the use of other criteria as a basis of selection of maintenance outsourcing relationship showed that the best maintenance outsourcing relationship for the case study is supported outsourcing relationship (Fig. 6).

	R_1	R_2	R_3	R_4
Cost index (C_1)				
x_{11}	0.30	0.26	0.26	0.26
x_{12}	0.63	0.55	0.55	0.83
x_{13}	0.48	0.54	0.58	0.58
x_{14}	0.72	1.05	0.82	1.34
x_{15}	0.52	0.65	0.77	0.66
x_{16}	2.01	1.40	0.95	2.03
Equipment index (C_2)				
x_{21}	0.54	0.59	0.55	0.83
x_{22}	0.47	0.68	0.71	0.71
x_{23}	0.48	0.88	0.98	0.85
x_{24}	0.55	0.77	0.77	0.90
x_{25}	0.14	0.30	0.32	0.23
Vendor index (C_3)				
	R_1	R_2	R_3	R_4
x_{31}	0.26	0.54	0.83	1.12
x_{32}	0.30	0.38	0.44	0.36
x_{33}	0.63	0.79	0.79	0.85
x_{34}	0.75	0.77	0.84	0.53
x_{35}	0.17	0.33	0.32	0.19
Production index (C_4)				
x_{41}	0.66	0.99	1.09	1.00
x_{42}	0.97	0.83	0.60	1.24
x_{43}	0.39	0.45	0.44	0.52
x_{44}	0.18	0.28	0.20	0.39
x_{45}	0.37	0.61	0.78	0.90
Human index (C_5)				
	R_1	R_2	R_3	R_4
x_{51}	0.43	0.55	0.55	0.70
x_{52}	0.26	0.48	0.48	0.64
x_{53}	0.64	0.89	0.88	0.73
x_{54}	0.53	0.75	0.79	0.79
x_{55}	0.18	0.51	0.55	0.50

Table 11 Weighted information contents the sub-criteria

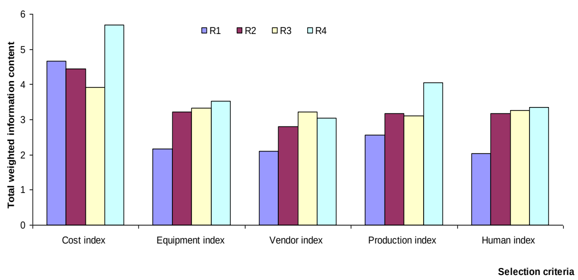

Fig. 6 Pair-wise comparison of total weighted information content for maintenance outsourcing relationships

Based on the FAD principle results, grand total weighted information content results showed that the most suitable maintenance outsourcing relationship for the case study is a supportive outsourcing relationship (Fig. 7). The ranking obtained using the grand total weighted information contents are consistent with those of the equipment and human indices (Fig. 6).

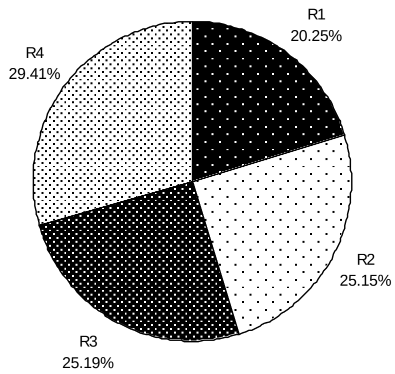

Fig. 7 Grand total weighted information content for maintenance outsourcing relationships

Based on the information in Table 6, the fuzzy triangular numbers were determined (Table 12) and used to obtain the normalised crisp values for the sub-criteria (Table 13). The normalisation process starts by considering a criterion is considered as either benefit- or non-benefit based. The fuzzy numbers are normalised before been converted into crisp values.

	R_1	R_2	R_3	R_4
x_{11}	0.42, 0.49, 0.66	0.49, 0.66, 1.00	0.49, 0.66, 1.00	0.49, 0.66, 1.00
x_{12}	0.37, 0.45, 0.65	0.43, 0.60, 1.00	0.43, 0.60, 1.00	0.38, 0.52, 0.79
x_{13}	0.41, 0.52, 0.79	0.45, 0.60, 1.00	0.41, 0.56, 0.88	0.41, 0.56, 0.88
x_{14}	0.38, 0.56, 1.00	0.27, 0.37, 0.59	0.30, 0.43, 0.77	0.27, 0.37, 0.59
x_{15}	0.33, 0.42, 0.62	0.39, 0.57, 1.00	0.37, 0.48, 0.68	0.35, 0.48, 0.76
x_{16}	0.32, 0.39, 0.57	0.33, 0.45, 0.68	0.42, 0.62, 1.00	0.33, 0.45, 0.68
x_{21}	0.64, 0.87, 1.00	0.56, 0.78, 0.96	0.51, 0.73, 0.91	0.64, 0.87, 1.00
x_{22}	0.64, 0.87, 1.00	0.56, 0.78, 0.96	0.64, 0.87, 1.00	0.64, 0.87, 1.00
x_{23}	0.56, 0.78, 0.96	0.51, 0.73, 0.91	0.64, 0.87, 1.00	0.60, 0.82, 0.96
x_{24}	0.56, 0.78, 0.96	0.56, 0.78, 0.96	0.56, 0.78, 0.96	0.60, 0.82, 1.00
x_{25}	0.30, 0.43, 0.77	0.27, 0.34, 0.53	0.26, 0.32, 0.48	0.29,0.37, 0.59
x_{31}	0.38, 0.58, 1.00	0.38, 0.52, 0.85	0.31, 0.44, 0.85	0.31, 0.44, 0.73
x_{32}	0.49, 0.63, 0.89	0.49, 0.68, 1.00	0.44, 0.59, 0.89	0.46, 0.63, 1.00
x_{33}	0.42, 0.62, 1.00	0.42, 0.62, 1.00	0.42, 0.62, 1.00	0.39, 0.57, 1.00
x_{34}	0.56, 0.80, 1.00	0.41, 0.66, 0.90	0.46, 0.71, 0.95	0.37, 0.61, 0.85
x_{35}	0.44, 0.67, 0.91	0.58, 0.81, 1.00	0.53, 0.77, 1.00	0.44, 0.67, 0.86
x_{41}	0.60, 0.82, 0.91	0.56, 0.78, 0.91	0.64, 0.87, 1.00	0.60, 0.82, 1.00
x_{42}	0.39, 0.57, 0.87	0.42, 0.62, 1.00	0.42, 0.48, 0.68	0.35, 0.48, 0.68
x_{43}	0.60, 0.82, 1.00	0.56, 0.78, 0.96	0.51, 0.73, 0.96	0.56, 0.78, 1.00
x_{44}	0.51, 0.73, 0.96	0.51, 0.73, 0.96	0.49, 0.67, 0.80	0.60, 0.82, 1.00
x_{45}	0.60, 0.82, 1.00	0.42, 0.64, 0.82	0.60, 0.82, 0.96	0.64, 0.87, 1.00
x_{51}	0.60, 0.82, 1.00	0.56, 0.78, 0.96	0.56, 0.78, 0.96	0.64, 0.87, 1.00
x_{52}	0.47, 0.69, 0.91	0.51, 0.73, 0.96	0.51, 0.73, 0.96	0.60, 0.82, 1.00
x_{53}	0.60, 0.82, 1.00	0.60, 0.82, 0.96	0.64, 0.87, 0.96	0.56, 0.78, 0.96
x_{54}	0.60, 0.82, 1.00	0.56, 0.78, 0.96	0.60, 0.82, 1.00	0.60, 0.82, 1.00
x_{55}	0.42, 0.64, 0.87	0.51, 0.73, 0.96	0.60, 0.82, 1.00	0.56, 0.78, 1.00

Table 12 Fuzzy triangular numbers for the sub-criteria

From VIKOR literature, when v = 0.5, it means that decision-makers have come to a consensus [37]. The current study considered when v = 0.5 in generating the various VIKOR indices for the criteria (Table 14 and Table 15).

	R_1	R_2	R_3	R_4	f_{ij}^{+}	f_{ij}^{-}		R_1	R_2	R_3	R_4	f_{ij}^{+}	f_{ij}^{-}
x_{11}	0.50	0.68	0.68	0.68	0.68	0.50	x_{33}	0.65	0.65	0.65	0.61	0.65	0.61
x_{12}	0.47	0.64	0.64	0.54	0.64	0.47	x_{34}	0.80	0.66	0.71	0.61	0.80	0.61
x_{13}	0.54	0.64	0.58	0.58	0.64	0.54	x_{35}	0.67	0.81	0.77	0.67	0.81	0.67
x_{14}	0.60	0.39	0.47	0.39	0.60	0.39	x_{41}	0.80	0.76	0.85	0.81	0.85	0.76
x_{15}	0.44	0.61	0.50	0.51	0.61	0.44	x_{42}	0.59	0.65	0.50	0.49	0.65	0.49
x_{16}	0.41	0.47	0.65	0.47	0.65	0.41	x_{43}	0.81	0.77	0.73	0.78	0.81	0.73
x_{21}	0.85	0.77	0.73	0.85	0.85	0.73	x_{44}	0.73	0.73	0.66	0.81	0.81	0.66
x_{22}	0.85	0.77	0.85	0.85	0.85	0.77	x_{45}	0.81	0.64	0.81	0.85	0.85	0.64
x_{23}	0.77	0.73	0.85	0.81	0.85	0.73	x_{51}	0.81	0.77	0.77	0.85	0.85	0.77
x_{24}	0.77	0.77	0.77	0.81	0.81	0.77	x_{52}	0.69	0.73	0.73	0.81	0.81	0.69
x_{25}	0.47	0.36	0.34	0.39	0.47	0.34	x_{53}	0.81	0.81	0.84	0.77	0.84	0.77
x_{31}	0.62	0.55	0.49	0.47	0.62	0.47	x_{54}	0.81	0.77	0.81	0.81	0.81	0.77
x_{32}	0.65	0.70	0.61	0.66	0.70	0.61	x_{55}	0.64	0.73	0.81	0.78	0.81	0.64

Table 13 Normalised crisp values, best and worst values of the system requirements

		R_1	R_2	R_3	R_4			R_1	R_2	R_3	R_4			R_1	R_2	R_3	R_4
	C_1	0.74	0.48	1.87	3.53		C_1	0.13	0.25	0.66	1.00		C_1	0.04	0.07	0.53	1.00
	C_2	0.43	0.92	3.00	0.93		C_2	0.26	0.26	1.00	0.58		C_2	0.00	0.01	0.79	0.72
S	C_3	0.18	0.28	2.63	4.43	*R*	C_3	0.11	0.17	1.00	1.00	*Q*	C_3	0.00	0.04	0.79	1.00
	C_4	0.35	0.68	3.13	1.87		C_4	0.17	0.29	1.00	1.00		C_4	0.00	0.13	1.00	0.77
	C_5	0.52	0.72	1.65	1.22		C_5	0.18	0.23	1.00	1.00		C_5	0.00	0.12	1.00	0.81

Table 14 Calculation of utility, regret measure and VIKOR index for the criteria

The ranking of the maintenance outsourcing relationships using cost and vendor selection indices were the same. These two indices ranked support maintenance outsourcing relationship as the most suitable for the maintenance system. This result is consistent with that of the other selection indices (i.e., human, equipment and production). However, the least suitable maintenance outsourcing relationship using human, equipment and production indices is different from that of cost and vendor selection indices. The ranking order using cost and vendor selection indices are the same as the ranking order using the grand total weighted information content as shown in Fig. 7.

$$C_1, C_3(Q): R_1 \to R_2 \to R_3 \to R_4$$
$$C_2, C_4, C_5(Q): R_1 \to R_2 \to R_4 \to R_3$$

In terms of multi-criteria performance indices, the ranking results obtained were the same as those of the human, equipment and production indices (Table 15). However, there is consistency in the ranking of the most suitable maintenance outsourcing relationship from the multi-criteria and criterion perspectives (Tables 14 and 15) (see also [38, 39]).

	R_1	R_2	R_3	R_4
S	0.0000	0.0861	1.0000	0.9699
R	0.0282	0.0000	1.0000	1.0000
Q (v=0.5)	0.0141	0.0431	1.0000	0.9849

Table 15 Calculation of utility, regret measure and VIKOR index

$$Q: R_1 \to R_2 \to R_4 \to R_3$$

5. Conclusions

The principal aim of this study was to build up a deeper insight on maintenance outsourcing in the instant food industry by examining the parametric relationship from the lens of imprecision and uncertainly, using combined fuzzy axiomatic design and fuzzy VIKOR methods in the instant food industry. Although maintenance researchers appreciate the potential value of outsourcing service in tangible product-oriented organizations, previous attempts have focused on human factors. However, this work builds on previous knowledge by developing a framework that establishes relationship from the customer respective of design and functional requirements of the parameters of the maintenance system in a matrix form, which is an advanced novel argument about outsourcing parameters in relationships. It can be deduced that the proposed framework worked effectively and potentially improved vendor-employer relationships and the performance of a maintenance system.

Four relationships are defined, namely support, alignment, reliance and alliance while the selection indices were measured against them. By weights, the model evaluated the relationships as consisting of support (20.25%), alignment (25.15%), reliance (25.19%) and alliance (29.41%). The VIKOR indices for the relationships are support (0.0141), alignment (0.0431), reliance (1.000) and alliance (0.9849). The conclusion was that alliance outsourcing was the least desired outsourcing relationship for the system. The first contribution of the current paper is the classification of criteria which can be used in the analysis of maintenance outsourcing relationships analysis. Another contribution of this study is the ranking of maintenance outsourcing relationships using FAD principle and fuzzy VIKOR method. In the present article, the fuzzy axiomatic design and fuzzy VIKOR are combined. Based on this, only five decision makers were used to make conclusions. While this study did not have access to the top management but middle managers, future studies should overcome this barrier by obtaining information from top management. These top managers may include the general manager, maintenance manager and then the middle level managers. This will improve the quality of results obtained from the work. Furthermore, the questionnaires could cover more details about the dynamics of the organization and the instant food industry in Nigeria. Another possible interesting extension of the study is the comparison of the result and that of another developing country.

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