PROFITABILITY ANALYSIS WITH THE FUZZY LOGIC: A HOSPITAL EXAMPLE

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Abstract

Implementation of the fuzzy logic is a modern approach for cost-volume-profit analysis and decision-making process under risk and uncertainty (Yuan, 2009). The implementation of the fuzzy logic approach especially makes sense for profit or loss estimations in developing countries, where uncertainties and risks are often observed (Roztocki & Weistroffer, 2005). This study aimed to estimate the profit or loss of indirect Coombs blood test, which is among the 100 blood tests run by the laboratory department of a healthcare organization located in Istanbul, Turkey, that started operations in 2018. Another purpose of the research was to compare the profit or loss estimated by fuzzy logic with the actual values. Research questions of the study were: 1) Can fuzzy logic be used in the health sector's profitability estimates? 2) What is the estimated success rate of fuzzy logic in the case of uncertainty and complexity? 3) If the fuzzy logic can be used in the health sector's profit forecasts, how close are the estimated profit sums achieved by the fuzzy logic to the actual profit sums? Based on the findings of the study, profit estimated by the fuzzy logic is in a close range to actual values with a low error rate.

Keywords: Accounting, Finance, Fuzzy Logic, Profitability, Health Sector, Estimation

Authors' individual contribution: Conceptualization — T.A.; Methodology — T.A.; Software — T.A.; Writing — Original Draft — T.A.; Investigation — C.K. and E.Y.; Writing — Review & Editing — C.K.; Project Administration — E.Y.; Supervision — E.Y.

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1. INTRODUCTION

Accounting is a science and information system related to recording, classifying, summarizing, reporting, analyzing, and interpreting monetary transactions and events. Business stakeholders, which are spread over a wide range, benefit from the data offered by accounting. While accounting was only a recording tool when it first appeared, especially analysis and interpretation functions come to the fore today. At the same time, accounting science is integrated with technology in modern times. Topics, such as accounting software, e-ledger, e-invoice and e-declaration applications, integrated reporting, accounting and reporting of intellectual capital, cloud accounting, artificial intelligence in accounting, accounting of cryptocurrencies, accounting and machine learning, the relationship between accounting and the IoT (Internet of Things) are frequently discussed (Kizil, Selvi Hanişoğlu, & Aslan, 2019).

The health sector is one of the important components of any given country's economy in the world. This situation is likewise in Turkey and the importance of the health sector in Turkey is increasing. The intensive state sovereignty was in question from the first years of the republic until the 1980s in the context of ownership in the health sector in Turkey. However, since the 1980s, the private sector started to undertake the burden of the health sector besides the state. Referring to the current situation in the health sector, it has already grown steadily in Turkey and it is observed that the number of institutions and hospital inpatient bed capacity steadily increase. At the same time, total health spending in Turkey is increasing as the years pass. However, the number of physicians per person, the number of employed nurses, the number of nurses per physician, the number of graduate nurses, and the nurses who have been trained abroad are still not at the demanded and desired levels compared to OECD (The Organization for Economic Co-operation and Development) level (Kalanlar, 2018).

Fuzzy logic is considered a modern computer logic revolution that helps computers, based on logical applications similar to human behavior. The use of fuzzy logic in manufacturing processes and industries has brought many advantages. Time and money savings, more efficient production, high accuracy in cost and profit estimates are just a few of them. Fuzzy logic is developed for uncertain situations frequently encountered in daily life, unlike classical logic. At the same time, fuzzy logic adopts multi logic by rejecting binary logic because it argues that classical Aristotelian logic is inadequate today (Kiyak & Kahvecioğlu, 2003).

This study has the objective to predict the profit or loss of indirect Coombs blood test, which is among the 100 blood tests run by the laboratory department of a healthcare organization that initiated operations in 2018. Another objective of the research is to compare the profit or loss predicted by fuzzy logic with the actual values. The MATLAB software is used to realize the mentioned objectives. The research concentrated and focused on the indirect Coombs blood test because it is the most frequently run test in the laboratory department of the healthcare organization.

The research is relevant and significant because fuzzy logic is an up-to-date technique for cost-volume-profit analysis and decision-making process under risk and uncertainty. Also, the application of the fuzzy logic technique provides effective results for the profit or loss predictions in developing countries and economies. It should be noted that uncertainties and risks are more common in emerging countries compared to developed ones.

Specific research questions are subject to this study. They can be listed as:

RQ1: Can fuzzy logic be used in the health sector's profitability estimates?

RQ2: What is the estimated success rate of fuzzy logic in the case of uncertainty and complexity?

RQ3: If the fuzzy logic can be used in the health sector's profit forecasts, how close are the estimated profit sums achieved by the fuzzy logic to the actual profit sums?

Thus, this study has the intention to answer the following research questions. In order to address the research questions, it was attempted to predict the profit or loss of indirect Coombs blood test, which is among the 100 blood tests run by the laboratory department of a healthcare organization located in Istanbul, Turkey, that initiated operations in 2018. The MATLAB software was used for profitability analysis of the mentioned healthcare organization by taking advantage of the fuzzy logic technique and the predicted values of fuzzy logic were then compared with the actual values. The date coverage of the study is from 2018 to 2019. January–February of 2021 is the period of investigation when it was conducted.

The study has three research hypotheses:

H1: Fuzzy logic can be used in the health sector's profitability estimates.

H2: The estimated success rate of fuzzy logic in the case of uncertainty and complexity is high with at least 95%.

H3: Estimated profit sums achieved by the fuzzy logic are close to the actual profit sums with an error margin that is less than 5%.

The mentioned three hypotheses are tested with the estimated profits and calculations of fuzzy logic.

It is believed that the study contributes to the literature in a variety of ways. First of all, the number of studies running profitability analysis with the fuzzy logic approach is limited in Turkey. Moreover, its application in the healthcare industry is much more restricted. The fuzzy logic approach is also a modern and up-to-date technique, which brings several benefits, such as time and money savings, more efficient production, and high accuracy in cost and profit estimates. The research also contributes to literature, because its results and findings point out that estimated profit values achieved by the fuzzy logic are very close to actual values.

The first part of this study is the introduction. In the introduction section, important terminology, such as accounting, health sector, and fuzzy logic are discussed and the content, as well as the general plan of the research, are presented. The second section of this study is devoted to the literature review. In this section, the relevant resources are reviewed in detail, and the studies that focus on the relationship of fuzzy logic with the health sector, accounting, finance, and auditing areas are emphasized following the perspective of the research. In the third section of the study, cost and profit concepts are mentioned. In the fourth section of research, information on the fuzzy logic theory is provided. The fifth section of the study is concerned with the research methodology, which carries out blood test profitability estimation. In this section, the profit or loss status of the indirect Coombs blood test, which is one of the 100 blood tests carried out in the laboratory department of a health institution, is estimated with the fuzzy logic method and compared with the real values. The success of the prediction of the fuzzy logic method under uncertainty is tested, and that helps the health institution to predict the monetary results of its operations. The application is realized by using the MATLAB package program. The name of the health institution that allows obtaining application data is kept anonymous and confidential.

But, the mentioned health institution is located in Istanbul, Turkey, and it began operations in 2018. The sixth section of the study includes results and discussion, which presents the findings of the research. Finally, the conclusion section finalizes the research, provides a general overview of outcomes, and includes recommendations for future studies.

2. LITERATURE REVIEW

In research that applies the fuzzy logic method to the energy sector, the need for energy was emphasized with the rapid development of technology today. Within the scope of research, the financial performance of eight energy companies listed on Borsa Istanbul (Istanbul Stock Market) was analyzed by intuitive fuzzy logic and a multi-criteria decision-making method. In the research, real data of eight energy companies in question for the period of 2013–2017 were used. The performances of the energy sector companies were compared (Karcioğlu, Yalçin, & Gültekin, 2020).

In a study where fuzzy logic is applied in the health sector, firstly the complex structure of the services provided by the specified sector was mentioned. Emphasis was placed on determining the cost of health care. In particular, it was mentioned how the inaccurate estimation of the costs of services provided by the hospitals may negatively affect the efficient distribution of resources and the efficiency as a whole. Therefore, the importance of accurately estimating the cost of all services provided by hospitals was described. In the research, dental prosthesis unit service costs of an oral and dental health hospital were calculated and presented by integrating the time-based activity-based cost system and the fuzzy logic method (Türk & Ertaş, 2018).

Another study highlighted that all businesses need accurate and reliable profit analysis in today's intensely competitive environment. In this study, the profitability analysis of an enterprise was carried out using computer-aided programs with the help of fuzzy logic under uncertain conditions, and then the results were compared with real values. In this research, the profit-loss situation of fasting blood glucose test, which is one of the 50 blood tests carried out in a laboratory department of one health institution that started its activities in 2017, was analyzed using fuzzy logic and then compared with real values. The MATLAB package program was utilized; three inputs and one output were included in the application model. Within the scope of the research, Mamdani fuzzy logic inference model (system) was preferred and the mean of maximum (MOM) was chosen as the clarification method. Values estimated by fuzzy logic were consistent with the actual results (Aslan & Kizil, 2018).

In another research that uses a fuzzy logic method in the risk assessment process within the scope of internal controls, the importance of the concept of internal controls was initially mentioned. The advantages of fuzzy logic under uncertainty were explained. At the same time, it was emphasized that fuzzy logic is used in risk valuation in a wide range of fields from engineering to finance. In the study, the effectiveness of using a fuzzy logic method in risk assessment activities within the scope of internal controls was investigated. In this study, a literature review was first presented. Then, the traditional method and fuzzy logic method were compared on a sample. The Mamdani fuzzy logic method (system) was used in the research (Umarusman & Seldüz, 2018).

There is also a study in which the fuzzy logic method was proposed regarding the risk assessment activities of the public internal auditors. In this study, fuzzy logic was shown as a way out for the audit profession, because the risk contains uncertainty and provides objective results suitable for human behavior. In this research, traditional methods and fuzzy logic methods were compared on an application based on explanations in the Risk Assessment Guide in Public Internal Audit published by the Ministry of Finance — Internal Audit Coordination Board (Seldüz & Umarusman, 2018).

In a study on fuzzy logic, it was emphasized that all businesses should generate profit in order to survive and they should plan their pave to the targeted profit. It was explained that this is only possible with target costing. At the same time, the key role of fuzzy logic in estimation within the target costing process in an uncertain environment and thus achieving the targeted profit was mentioned (Aslan, Baral, & Mucedidi, 2017).

In a study that uses fuzzy logic to measure the quality of electronic accounting (e-accounting) principles, it was mentioned that IFAC (International Federation of Accountants) offers the principles of electronic accounting (e-accounting) to make accounting information more reliable. The study focused on the differences between traditional accounting and electronic accounting (e-accounting). At the same time, the role of fuzzy logic tools in measuring the quality of electronic accounting (e-accounting) principles in Iraq was emphasized (Thabit & Abbas, 2017).

Concerning a study that measures and compares the financial risk levels of airline companies with the fuzzy logic method, it was mentioned that the demand for civil aviation which gained importance globally, has increased in the world and the sector has progressed in recent years. Besides, the competitive structure of the civil aviation industry was also stated. The mentioned competitive structure forces airline companies to form alliances and build partnerships. Competition in the field of civil aviation has increased even more, especially with the inclusion of airline companies that have adopted the low-cost strategy since the 1990s. At the same time, the requirement to meet the minimum requirements for flight safety has also increased the costs of airline firms. Therefore, this research underlined that it is much more difficult to manage financial risks for airline companies today. In this study, financial risk levels measured over the financial ratios of Star Alliance, Oneworld, and SkyTeam, which are accepted as the three most famous global airline alliances, and the low-cost airlines, were compared with the fuzzy logic method (Tunahan, Esen, & Takil, 2016).

In a study that applied the fuzzy logic method to a dairy business, it was stated that classical logic did not provide objective results. Also, it was argued that fuzzy logic was producing faster and more flexible solutions. Accordingly, a fuzzy logic linear programming model was developed using the information of a dairy company. Werner's approach was adopted in the study (Çevik & Yildirim, 2010).

Regarding a study that measures the management of transportation costs with the fuzzy logic method and its effect on financial performance, it was stated that ensuring effectiveness in transportation activities depends primarily on reducing costs and improving the financial situation. Later, it was explained that many methods were used to ensure effectiveness in transportation activities and one of them was fuzzy logic. The primary purpose of the research was to show that fuzzy logic provided efficiency in a business's transportation activities and reduced transportation costs. As a result of the study, based on the number of transportations and load capacities of an enterprise, it was presented that the same workload could be achieved in less time and cost, thanks to fuzzy logic (Ergülen & Deran, 2009).

In a scientific study showing the application of fuzzy logic in cost-volume-profit analysis, the insufficiency of traditional methods was pointed out. According to the research, since the methods used today ignore the risk and uncertainty factors, their benefits are minimal. However, there is a need for a modern method that supports the decision-making mechanism by evaluating the experience and knowledge of experts on profit planning. Fuzzy logic has a key role at that point (Yuan, 2009).

In a study conducted in Spain, it was investigated whether the businesses that are strategically connected to their stakeholders display a higher social and financial performance. In this context, research was carried out on 52 Spanish companies listed on the stock exchange. In the study, the fuzzy logic method was used. The findings of the research were in line with previous studies and the study found a positive and insignificant relationship among the firms' level of strategic connection to business stakeholders and their social/financial performance (Muñoz, Rivera, & Moneva, 2008).

In research using a fuzzy logic method in the cement sector, analysis was performed on ten companies. The relationship between balance sheet and income statement items of ten companies operating in the cement industry and registered in the Istanbul Stock Exchange (ISE) for the 2003–2005 period was modeled with the fuzzy logic method. For this research, the MATLAB package program was used and the Mamdani method was utilized. It was observed that the values achieved by the fuzzy logic method are very close to the actual figures (Eleren, 2007).

According to a study dealing with the use of fuzzy logic in accounting and auditing, artificial intelligence had to be put into use in both areas. According to the research, artificial intelligence and fuzzy logic will be of great benefit in the coming years in the fields of accounting and auditing. It was stated that today's methods are insufficient in solving current accounting and auditing problems (Baldwin, Brown, & Trinkle, 2007).

In a study involving fuzzy logic applications in the field of information technologies, activity-based costing and fuzzy logic methods were included together with the value chain analysis. In other words, research integrated the three methods in question. In the study, evaluation of information technology investments was carried out with the help of fuzzy logic. It was underlined that the study would provide greater benefits especially in developing countries (economies) where uncertainty is a fact of the business environment (Roztocki & Weistroffer, 2005).

Scientific studies on the use of the fuzzy logic method in insurance activities, which are accepted as a subset of the financial sector, are run as well. According to one of these studies, the survival of insurance companies today is closely linked to the demands of customers. It is critically important to process and match the customer requests in question quickly. At this point, because of subjective evaluations, fuzzy logic comes to the fore. The total cost of the appraisers, among human resources of the insurance companies, is high and increasing. Firms, on the other hand, have begun to produce technological solutions to process customers' insurance requests, match them and detect any existing fraud. In this research, fuzzy math methodology was used (Pathak, Vidyarthi, & Summers, 2005).

There are also scientific studies that use and apply the fuzzy logic method in the aviation industry. In one of the studies mentioned, it was stated that there are some situations that are not certain in daily life. It was also reported that uncertainty and complexity are experienced in various economic, social, and technical events. The fuzzy logic theory was mentioned in the research and its application to flight control problems was actualized within the aviation sector (Kiyak & Kahvecioğlu, 2003).

In research that deals with the use of fuzzy logic in measuring fraudulent financial reporting risk, it was noted that fraud and irregularities have increased in recent years, especially in the field of financial reporting. However, it was disclosed that there is still a gap in the detection of fraud and irregularities. At this point, it was stated that the feasibility of various computerized techniques is examined. Therefore, it was emphasized that fuzzy logic would be an important aid in detecting fraud and irregularities. In fact, it was said that fuzzy logic has outperformed many statistical models and artificial neural networks in determining fraud and irregularities (Lin, Hwang, & Becker, 2003).

In a study on the use of fuzzy logic in the auditing field, it was mentioned that auditors describe risk on the basis of probabilities. According to the research, risk arises from a lack of information, and this lack of information leads to uncertainty. It was also stated that auditors are faced with many different uncertain situations. While many types of uncertainty were listed in the study, the contribution of fuzzy logic to aid operating under an uncertain environment was also mentioned. In addition, it was emphasized that fuzzy logic leads to the development of artificial intelligence. Also, the potential of fuzzy logic to guide auditors in managing uncertainty by measuring risk was indicated to be quite high (Friedlob & Schleifer, 1999).

In a study that discusses the use of fuzzy logic in the estimation of financial time series, the main purpose was stated as the automation of the logical process of the experts employed by enterprises. In other words, it was aimed to model financial forecasts. In this study, expert judgments, statistical techniques, and computer programs were also used (Castillo & Melin, 1996).

The literature review shows that the fuzzy logic method was implemented in some research focusing on a variety of sectors. Manufacturing, education, aviation, navigation, nutrition, military, accounting, finance, auditing, artificial intelligence, electrical engineering, architecture, infrastructure, real estate, health, transportation, agriculture, logistics, and human resources are some of the industries where fuzzy logic was used as the main research subject. This study applies the fuzzy logic method both in the accounting and health sectors simultaneously. The number of studies using the fuzzy logic technique on an integration point of two separate industries such as accounting and health is very limited. That is especially correct considering the related fuzzy logic literature in Turkey.

3. COST AND PROFIT THEORY

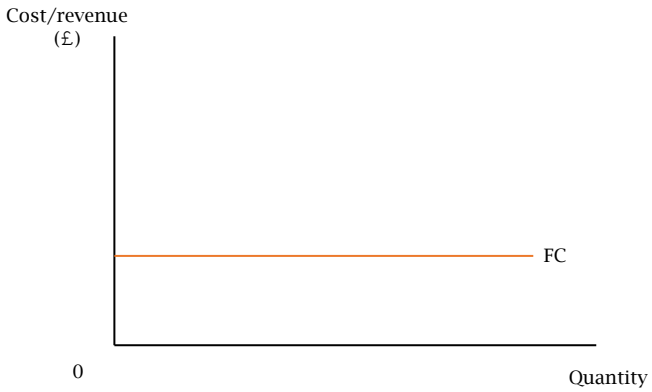
First of all, it is logical to discuss the cost and profit theory in order to support the fuzzy logic model and rules composed for this research. From the perspective of accounting, the cost is the sum of sacrifices made and the resources given up to reach a specific goal (Kizil & Kizil, 2007). The sacrifices and resources mentioned at this point are the monetary measures used to purchase a product or service (Horngren & Foster, 1987). According to another definition that considers cost in terms of accounting, the cost is a sum of sacrifices that can be expressed in monetary terms and that create value accumulation and which are incurred to achieve a certain result (Peker, 1983). At the same time, the cost is expressed as the sum of sacrifices that are incurred to reach a certain purpose, which can be expressed in money, and allow the accumulation of value (Altuğ, 2006).

Cost and profit theory is very important. The reason is that determining the cost of a good or service helps in making accurate decisions about various factors such as pricing, profitability analysis, and expenditure control. In accounting, it is expressed as the unit cost carrier in which the cost of the resource spent for each activity performed is measured. Cost elements to be loaded on the cost carrier are three. These are direct raw material and supplies expenses, direct labor expenses, and overhead expenses. The overhead expense is actually an expense pool and covers all expenses other than direct raw materials and supplies expense and direct labor expense (Küçük, 2005). However, overhead expenses are related to production activities (function), and because of its structure, it is not possible to classify these expenses as general administrative costs such as material, indirect labor, depreciation, insurance, as well as maintenance and repair costs, if these are related to sales, management and operation activities (functions) of the company (Garrison & Noreen, 1997).

According to one approach, it is possible to categorize cost types as accounting cost, opportunity cost, incremental cost, and sunk cost. Accounting cost consists of the sum of direct raw material and supplies expenses, direct labor expenses, and overhead expenses incurred by the company to produce a good or service, as mentioned earlier. Opportunity cost is the net profit missed for the desired result. The incremental cost is the sum of a change in cost caused by a change in the volume of activity. Sunk cost is defined as the cost that is not affected by the decision in question during the decision-making phase (Coşkun Arslan, 2017).

However, it would be appropriate to take a more inclusive approach for cost types. Accordingly, costs are categorized as direct raw material and supplies expenses, direct labor expenses, and overhead expenses based on their types. Costs are categorized as direct and indirect costs based on their relationship with production. In addition, the costs are categorized as fixed costs, variable costs, and mixed costs according to the changes in operating volumes (Ünal, 2002; Kizil & Kizil, 2007). At the same time, costs are divided into actual (realized) and predictive costs according to the nature of sums used. Forecasted costs are also subject to a binary distinction such as predicted and standard costs. Costs are categorized as order costs and process costs on the basis of production style. It is also possible to categorize costs systematically as absorption costing, variable costing, normal costing, and prime costing (Güngörmüş & Boyar, 2010).

Figure 1. Fixed cost curve



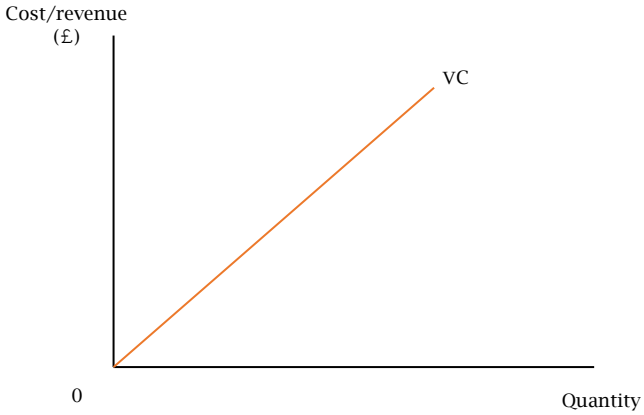
Source: http://www.sanandres.esc.edu.ar.

Fixed costs are not affected by the production and sales volumes of the firm. In other words, fixed costs are independent of production and sales volumes. Also, fixed costs are defined as the costs that are experienced continuously, regularly, and constantly as the firm continues its operations (Kotler & Armstrong, 2005). The figure above shows the fixed cost curve. As it is shown in the figure,

even though the production volume would increase/decrease, there will be a fixed/unchanged cost structure in total.

Variable costs are the ones that vary depending on the volume of activity. To put it differently, costs that vary depending on the increase/decrease in production volume are called variable costs. Variable cost increases when production volume increases and variable cost is observed as zero when production volume is zero. The figure below shows the total variable cost curve. According to accountants, the variable cost curve is linear, and according to economists, it is variable at the lower and upper points of the field of activity (Banar, 2004).

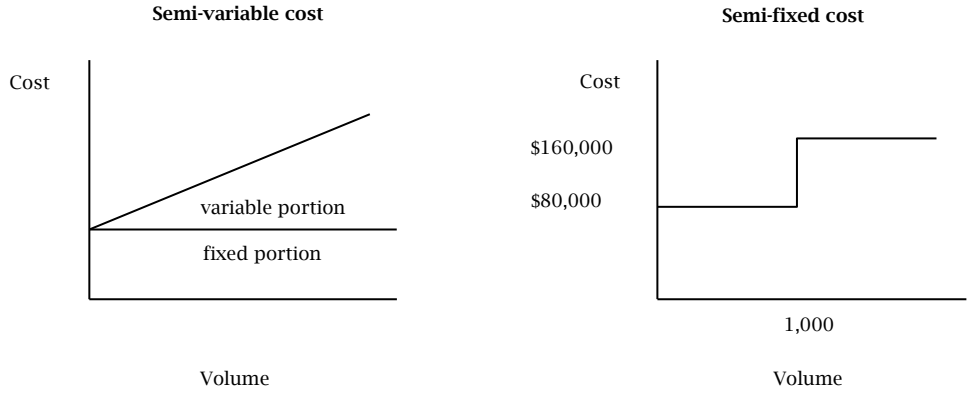
Figure 2. Total variable cost



Source: http://www.sanandres.esc.edu.ar.

Mixed costs contain both fixed and variable costs due to their characteristics. This cost group is neither literally fixed nor literally variable. They contain the properties of fixed and variable costs together. It is possible to divide mixed costs into two as semi-variable costs and semi-fixed costs (Kartal, Sevim, & Gündüz, 2003).

Figure 3. Semi-variable and semi-fixed cost curve



Source: https://www.hsph.harvard.edu/.

Semi-fixed cost consists of costs that remain constant within the capacity range, but show leaps when out of the specified ranges. As a result of the sudden jumps in question, such costs are indicated by a discrete function rather than a continuous function. These costs are also referred to as stepped costs in a number of sources (Ceran & Alagöz, 2007). Semi-fixed costs are sometimes considered as fixed, and sometimes as variable depending on the proportional size of activity ranges in which they remain constant within the normal field of activity (Büyükmirza, 2013). Figure 3 shows the semi-variable and semi-fixed cost curves.

Semi-variable costs are the ones that do not disappear completely when production volume is zero, but increase/decrease in parallel with the changes in production volume. Therefore, the costs involved here consist of two portions. These can be expressed as the increasing/decreasing variable parts and the fixed parts that occur even when production halts (Gündüz, Akar, Özgülbaş, & Önce, 2002).

$$Semi-Variable\ Cost = \frac{Fixed\ Portion + Variable\ Portion}{Fixed\ Portion + (Change\ Rate * Production\ Volume)} \quad (1)$$

Profit is generally defined as the positive difference between income and expense when viewed from an accounting perspective. However, there are still different definitions of profit. For example, since the economic profit is different from the accounting profit, the definition of profit changes naturally. There is a distinction between the accounting profit and the economic profit in determining the expenses. During the calculation of economic profit, all the resources used in business finance are evaluated. In the process of determining accounting profit, only borrowing costs (interest expenses) are included in the calculations. In the process of calculating accounting profit, equity costs are not considered as an expense. Therefore, accounting profits are higher than economic profits under the assumption that other conditions remain constant (Sayilgan & Gürdal, 2004). From an accounting perspective, the concept of profit corresponds to the positive difference between the beginning and ending equities. Profit is the difference between sales and costs. At this point, it will be wise to mention that costs are composed of fixed and variable costs (Bülbül, 2003).

$$Profit = Sales - (Fixed\ Costs + Variable\ Costs) \quad (2)$$

The main purpose of any business is to generate profit. The ability of companies to gain a competitive advantage and survive depends on their profits. Fuzzy logic comes into play at this point by providing great benefits in profitability analysis forecasting. The fuzzy logic method is also frequently used in performing uncertainty activity-volume-profit analysis. Moreover, fuzzy logic offers various advantages in realizing profit planning for companies. In an uncertain environment, it is possible for firms to estimate the results of their activities in advance and to make plans for the future with the fuzzy logic method (Aslan & Yilmaz, 2018).

4. FUZZY LOGIC THEORY

Various mathematical models are developed for finding solutions to several problems. However, it cannot be said that these mathematical models completely meet the needs today. Therefore, the fuzzy logic theory was introduced in order to meet this specified need. Fuzzy logic provides great advantages in resolving uncertainties faced today (Keskenler & Keskenler, 2017). Fuzzy logic, in its most basic form, is a theory that works with algorithms by evaluating people's experience and data and achieves results by using mathematical functions depending on the rules it creates. Fuzzy logic does not adopt Aristotle's binary value logic (Ertunç, 2012).

The fuzzy logic developed by Zadeh in 1965 is the first theory that opposes Aristotle's binary value logic by producing an alternative. Fuzzy logic was targeted by criticism, since it did not comply with classical logic science, especially in the first years it was presented. On the other hand, the suggestion and development of fuzzy logic have led to many advances in cybernetics and artificial intelligence studies (Işikli, 2008).

Therefore, fuzzy logic is actually accepted as a subset and branch of artificial intelligence. Fuzzy logic is a theory that performs control through the use of linguistic variables. At the same time, fuzzy logic is a method that is nonlinear, complex, hard modeled which provides very successful results in processes where the characteristics of information are not clearly determined (Eğrisöğüt Tiryaki & Kazan, 2007).

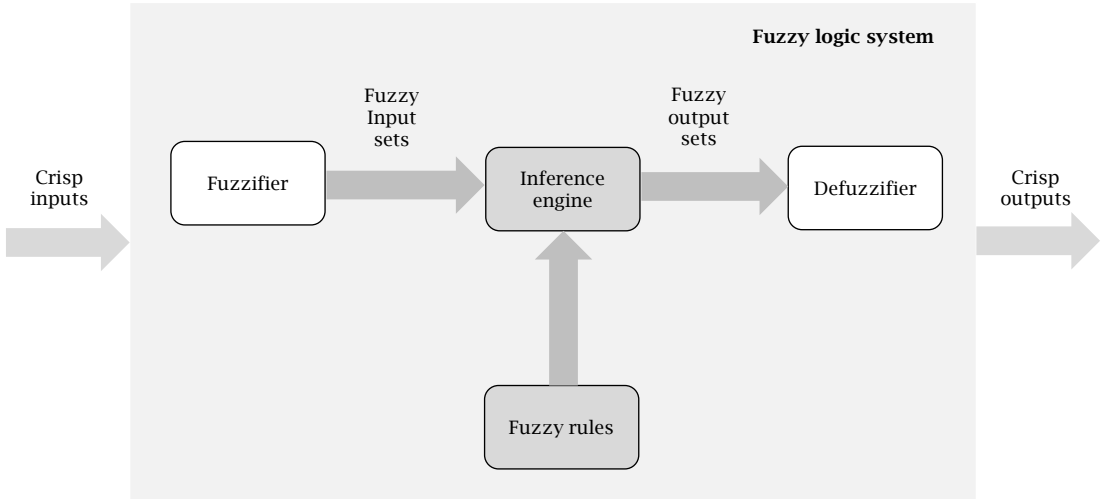
In addition, fuzzy logic is defined as a flexible calculation method (Özdemir, Alaybeyoglu, & Balbal, 2019). In other words, fuzzy logic is a method that provides solutions to problems by presenting approximate results instead of accurate results. The reason is that, in classical logic, the values are either 0 or 1. Suppose that an element is a full member of a set and its value is 1, if it does not belong to a set, its value will be automatically 0. On the other hand, due to the fact that there are many levels in fuzzy clusters, the values between 0 and 1 also exist (Sari, Murat, & Kirabali, 2005).

In fuzzy logic theory, input data are transformed into output data by passing through some stages. First of all, input data are blurred by the system. At this point, fuzzy sets and membership functions are in question (Çobanoğlu, 2000). Following the fuzzification phase, input data enter the fuzzy inference phase. The phase-in question is based on expert opinions. After the fuzzy inference phase, the defuzzification phase is started and the data are converted into numerical outputs (Balbal, 2016). One of the turning points in fuzzy logic was its precise usage in a steam engine by Mamdani and Assilian (1975).

Since the second half of the 1980s, fuzzy logic became more popular with its use in production processes in Japan. Since this date, fuzzy logic applications have increased and they have been used in almost every field today. According to fuzzy logic theory, the answer to a question is not always true or false. Fuzzy logic, which rejects classical logic, argues that there are different answers as well as true and false answers. In other words, there are partial and certain degrees of different answers in fuzzy logic. Since it is based on the human way of thinking, fuzzy logic provides good results in nonlinear systems and at the same time, it presents fast results. However, expert experience is required to correctly determine the rules in fuzzy logic. Therefore, it is not always easy to define rules and membership degrees (Maviş, 2017).

A fuzzy logic system is mainly used to convert inputs to outputs. In fuzzy logic theory, first of all, inputs and outputs should be fuzzified. The figure below shows a scheme of one fuzzy logic inference system, which can also be called the fuzzy logic system structure (Limouchi, Mahgoub, & Alwakeel, 2016).

Figure 4. Fuzzy logic system structure



Source: Limouchi et al. (2016).

It should be noted that fuzzy logic actually attempts to model logical reasoning with vague or imprecise statements. Also, fuzzy logic functions by assigning the levels of truth to propositions (Cintula, Fermüller, & Noguera, 2016). However, the fuzzy logic theory is also very flexible and a universal formalism rule does not exist for it. Separate strategies can be applied for associating elements to a specific set and the type of implementation is also very critical at this point. Plus, fuzzy set theory is definitely a subjective technique and one single element can belong to one or multiple sets. The membership set should be considered here for the fuzzy logic theory. Moreover, the fuzzy logic method provides a linguistic interpretation of a numerical measurement via assigning descriptive reasoning to a numerical value (Gross, 1996).

5. RESEARCH METHODOLOGY

In the application part of this study, the profit or loss status of the indirect Coombs blood test, which is one of the 100 blood tests performed by a health institution that started its activities in 2018, was compared to actual values by running forecasting with the fuzzy logic. The research was centered on the indirect Coombs blood test since it is the most frequently run test in the laboratory department of a healthcare organization located in Istanbul, Turkey. The fuzzy logic method was tested under uncertain conditions. Also, the success of prediction was investigated and this was used to estimate the operational results of the enterprise. The application was run using the MATLAB package program, which is also used for the fuzzy logic method. The name of the health institution which allowed to obtain application data was kept confidential. The date coverage of research is from 2018 to 2019. January–February of 2021 is the period of analysis when it was conducted.

5.1. Data, purpose, and methodology

The aim of the study was to predict the profit or loss situation of indirect Coombs blood test, which is one of 100 blood tests performed by a health institution that started its activities in 2018. Another purpose of the research was to compare values achieved by the fuzzy logic with actual values. Accordingly, the MATLAB package program was preferred to carry out the implementation part of this study. The application model consisted of 3 inputs (number of tests, cost, and selling price) and 1 output (profit). Mamdani fuzzy inference model (system) was applied in the model, and the MOM was used as the defuzzification method because it provides more realistic results.

5.2. Indirect Coombs test profitability analysis

Our inputs in indirect Coombs test profitability analysis are sales price *(satiş fiyati),* a number of tests *(test sayisi),* and cost *(maliyet).* Also, our output variable is determined as profit *(kar).* Profit (*PRO*) is the dependent variable where sales price (*SP*), number of tests (*NoT*), and cost (*C*) are the independent variables. The flow chart (input-output variables) of the research analysis is provided below.

Figure 5. Research analysis flow chart (input-output variables)

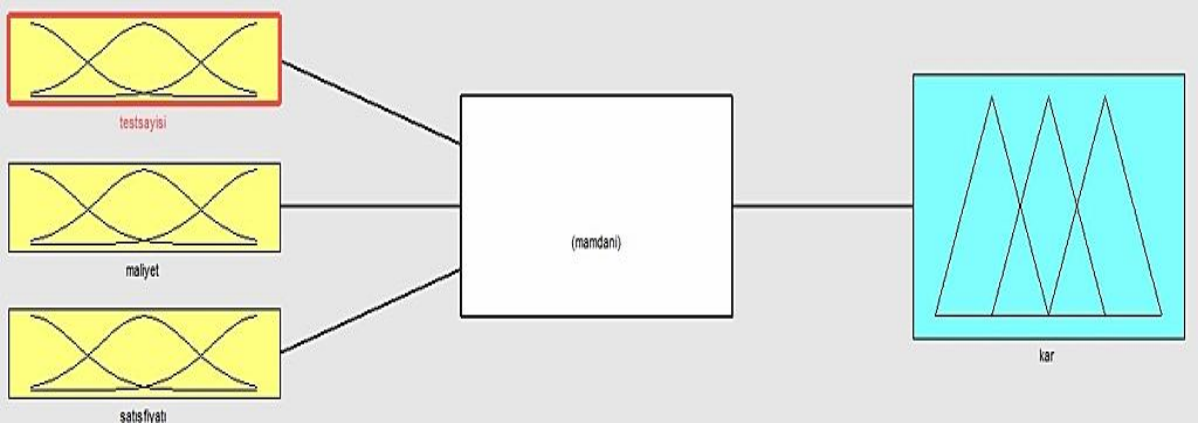
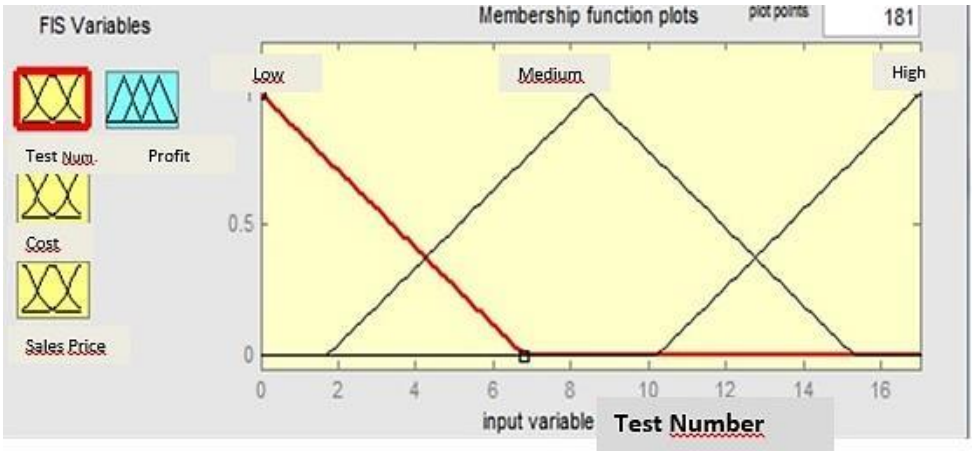


Table 1. Indirect Coombs test variables

Input variables	***Range***	***Nominal variables***	***Parameters***
SP	0–7.700 TL	Low	0–3000 TL
		Middle	900–7000 TL
		High	4900–7700 TL
C	0–5.238 TL	Low	0–2000 TL
		Middle	500–4600 TL
		High	3200–5238 TL
NoT	0–17 TL	Low	0–7 TL
		Middle	2–15 TL
		High	10–17 TL
Output variables	***Range***	***Nominal variables***	***Parameters***
PRO	0–2.461 TL	Low	0–1000 TL
		Middle	300–2300 TL
		High	1500–2461 TL

The linguistic variables determined for input and output variables required in the indirect Coombs test profitability analysis application and the value ranges of these variables are shown in Table 1 to form a triangular membership function. Parameter information was obtained from hospital managers. In the figures below, tests numbers variable ranges, cost variable ranges, sales price variable ranges, fuzzy rules, and profit results are included.

Figure 6. Number of tests variable intervals



The triangular membership variable is used for the number of tests linguistic variable. Also, the membership values showing the change intervals are shown in Table 1. If the number of tests is approximately below 2, it belongs to the low cluster with a full membership degree. If the number of tests is approximately over 15, it belongs to the high cluster with a full membership degree.

The triangle membership variable is used for the cost variable. Also, the membership values showing the change intervals are shown in Figure 8.

Figure 7. Cost variable intervals

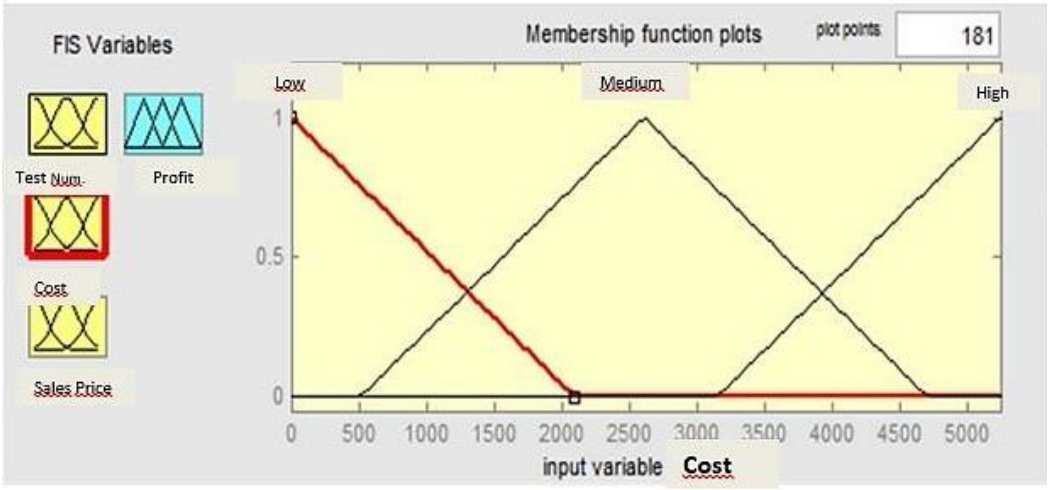
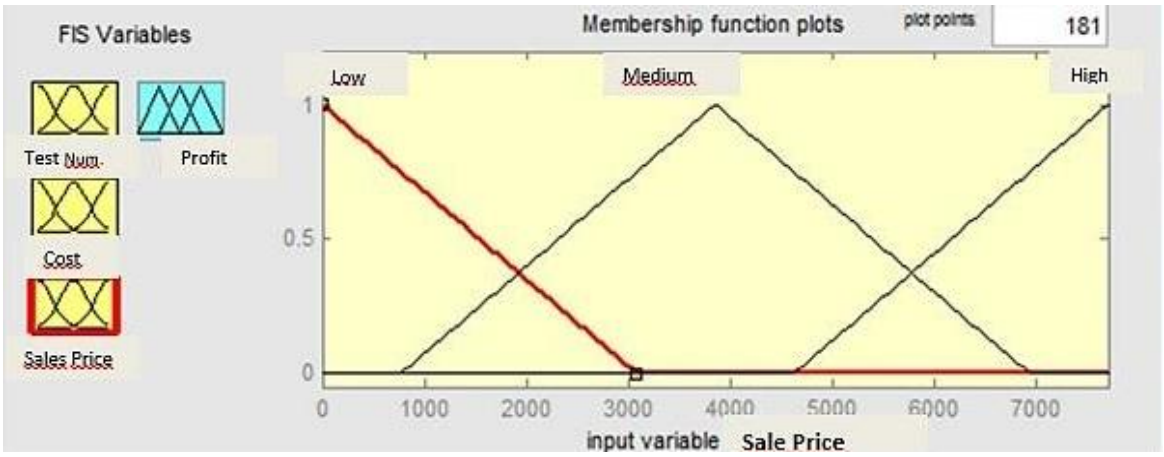
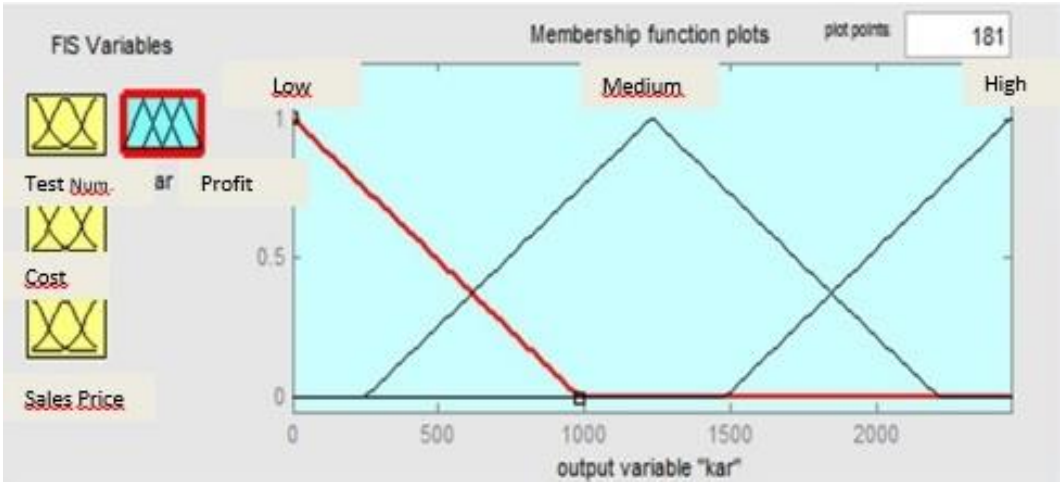


Figure 8. Sales price membership intervals



Sales price triangle membership function intervals are shown in Figure 9. Nominal variables and interval parameters were obtained by using the experience of expert managers.

Figure 9. Sales price membership intervals



The membership function and change intervals used for the profit output variable are shown in Figure 10.

5.3. Fuzzy logic rules

In the fuzzy logic system, the relationships among inputs and output are realized through the rule base. This rule base is created with if-then-else structures. And or not processors are used as fuzzy processors. In Table 2, rules created to classify the profit output of the indirect Coombs test are provided. The rules are determined with the support and experience of experts.

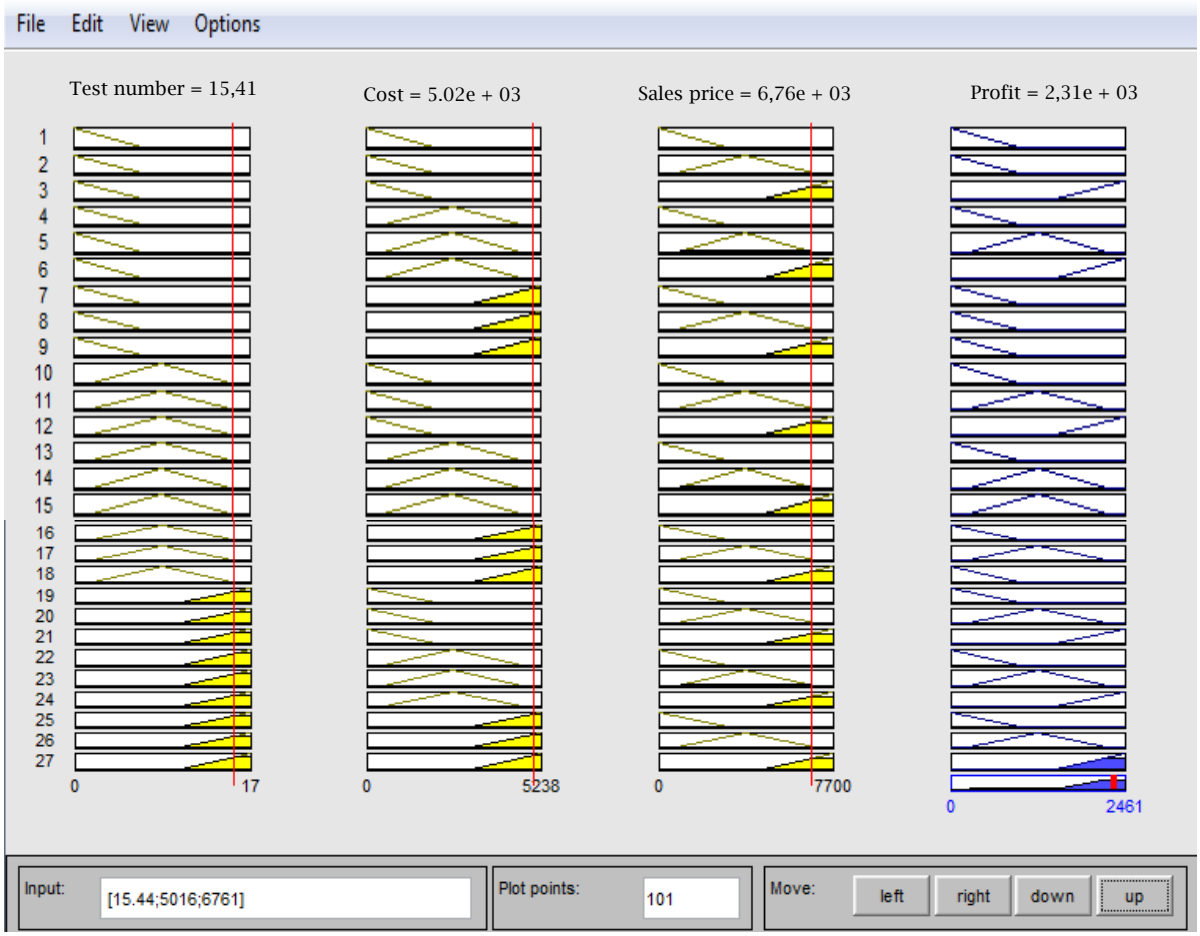
Table 2. Fuzzy logic rules

Rule No.	*Number of tests*	*Cost*	*Selling price*	*Structure*	*Profit*
1	Low	Low	Low		Low
2	Low	Low	Medium		Low
3	Low	Low	High		High
4	Low	Medium	Low		Low
5	Low	Medium	Medium		Medium
6	Low	Medium	High		Medium
7	Low	High	Low		Low
8	Low	High	Medium		Medium
9	Low	High	High		Low
10	Medium	Low	Low		Low
11	Medium	Low	Medium		Medium
12	Medium	Low	High		High
13	Medium	Medium	Low		Low
14	Medium	Medium	Medium	Then	Medium
15	Medium	Medium	High		Medium
16	Medium	High	Low		Low
17	Medium	High	Medium		Medium
18	Medium	High	High		Low
19	High	Low	Low		Low
20	High	Low	Medium		Medium
21	High	Low	High		High
22	High	Medium	Low		Low
23	High	Medium	Medium		Medium
24	High	Medium	High		High
25	High	High	Low		Low
26	High	High	Medium		Medium
27	High	High	High		Low

The rule parameters created for profit estimation of indirect Coombs test were obtained with the experience of managers and the profit result was calculated in the same way within the framework of the parameters determined by managers. In other words, since fuzzy logic is an approach providing the possibility of determining rules and setting the output based on the rules as well as membership functions, it was used for profit estimation. However, rule parameters were determined based on the support and experience of managers. Calculations and predictions of profit were done with the help of fuzzy logic.

Implications were created by making use of the rule base with fuzzy information coming from the fuzzification process. The MOM was chosen as the defuzzification method in obtaining profit results. In the analysis, this defuzzification method was compared with others and a more realistic result was obtained. Thus, the output variable (*PRO*) results were shown in Figure 10, and the results obtained were very accurate when compared with actual indirect Coombs blood test profitability.

Figure 10. Output variable profit results



5.4. Fuzzy logic and alternative methods

Alternative methods do also exist for cost-volume-profit analysis and decision-making process under risk and uncertainty. In other words, profit estimation of indirect Coombs blood test, which is among the 100 blood tests run by the laboratory department of a healthcare organization located in Istanbul, Turkey, could also be done by other techniques. Classical logic is one of them. However, it only permits and categorizes statements as true or false, which is an evident weakness compared to fuzzy logic. Probability theories could also be used in this study. However, fuzzy logic takes advantage of degrees of truth in terms of a mathematical model of vagueness. But, the probability is known as a mathematical model of ignorance (Asli, Aliyev, Sabu, & Gopakumar, 2017). In fact, fuzzy logic was developed as a response to the missing points and weaknesses of probability theory, which is not efficient under uncertainty and vagueness (Mares, 2006). The machine learning algorithm can also be used as an alternative to fuzzy logic. However, fuzzy logic lets the user determine rules and set the output based on rules and membership functions. Thus, it can be emphasized that fuzzy logic provides more control for the user and researcher compared to the machine learning algorithm. Traditional risk models are alternatives to fuzzy logic as well. However, traditional risk models are tightly related to probability and classical set theory. But, fuzzy logic functions well to analyze the risk levels under uncertainty and inadequate data (Shang & Hossen, 2013).

6. RESULTS AND DISCUSSION

This study had the goal to predict the profit or loss of indirect Coombs blood test, which is among the 100 blood tests run by the laboratory department of a healthcare organization that initiated operations in 2018 in Istanbul, Turkey. Another goal of the research was to compare the profit or loss predicted by fuzzy logic with the actual values. The date coverage of research is from 2018 till 2019. January–February of 2021 is the time interval of investigation when it was run. The research especially considered the indirect Coombs blood test, because it is the most often run test in the laboratory department of the healthcare organization.

The MATLAB package program was used for the research. The implementation model covered three inputs (test numbers, cost, and sales price) and one output (profit). Mamdani fuzzy inference system was utilized as the research model and the MOM was used as the clarification method. According to the findings of the study, the profit predicted by the fuzzy logic is close to actual values with a low error rate.

The application model included three inputs (number of tests, cost, and sales price) and

an output (profit). Mamdani fuzzy inference system was implemented for the model, and the MOM was considered as the defuzzification method because it provides more realistic results. Application results and findings were also compared with the actual profit sum. The predicted profit by the fuzzy logic method was 2.381 TL, and the actual profit was 2.461 TL. That indicated an approximation of the method with an error margin of 3%. Thus, *H1, H2,* and *H3* hypotheses were accepted.

7. CONCLUSION

The complexity of the number of events we encounter today and the more complex they will become in the future raise the need for fuzzy logic. Fuzzy logic, due to its flexible structure, is a closer theory to the human thought system. It is clear that fuzzy logic, which will develop further with the help of computers and programs, will be used more in the fields of accounting and finance.

In this study, important concepts, such as accounting, health sector, and fuzzy logic were explained. Later, a literature review related to the subject was carried out especially from the perspective of the health sector, accounting, finance, and auditing. Following this, cost and profit theories were discussed. In the next stage, the fuzzy logic theory was analyzed. Within the scope of application, a blood test profitability estimation was made. Accordingly, the profit or loss status of the indirect Coombs blood test was estimated by the fuzzy logic method. This test was one of the 100 blood tests performed in the laboratory department of a healthcare institution that started its activities in 2018 in Istanbul, Turkey. Then, the values obtained were compared with actual values. Thus, the success rate of prediction of fuzzy logic method in uncertain conditions was tested. The purpose of the study was to predict the operating results of an enterprise, which was applied to the fuzzy logic. The MATLAB package program was used while the application was being carried out. The name of the health institution that allowed obtaining application data was kept confidential. Three inputs (number of tests, cost, and sales price) and one output (profit) were used in the application model. Mamdani fuzzy inference system was chosen as the model, and the MOM was considered appropriate due to the fact that it provided more realistic results as a defuzzification method. The date coverage of research is 2018–2019. January–February of 2021 is the period of investigation when it was run.

According to the results of the research, the profit sum obtained by using fuzzy logic was close to the actual value with a low margin of error. The estimated profit by the fuzzy logic method was 2.381 TL and the actual profit sum was 2.461 TL. Therefore, the estimated profit by fuzzy logic had a 3% error margin. *H1, H2,* and *H3* were accepted. The results of the research were in parallel with Baldwin et al. (2007), Eleren (2007), Yuan (2009), and Aslan and Kizil (2018). In Eleren's (2007) and Aslan and Kizil's (2018) studies, the fuzzy logic model was used, the Mamdani method was preferred, and the prediction process was carried out with the MATLAB program. In both studies, the results were quite close to actual values within the framework of these parameters. The study of Baldwin et al. (2007) was also related to the application of fuzzy logic in the accounting discipline.

Finally, this study states that today's methods, such as classical logic, are inadequate in solving current accounting and auditing problems. In addition, this research overlaps with the study of Yuan (2009). Because in the study of Yuan (2009), fuzzy logic is used in profitability analysis within the scope of accounting area, the insufficiency of traditional methods is pointed out and the experience, as well as the knowledge of experts, are included in application analysis. Finally, future studies may also address the application of fuzzy logic in different industries other than the health sector. It is also possible to make cross-sector comparisons. Furthermore, future research can be carried out on more than one entity, not on a single healthcare institution. The findings of the fuzzy logic method can be compared with the artificial neural network method and statistical methods. Apart from the Mamdani fuzzy inference system, it is also possible to integrate other systems into the studies, as well as different techniques, other than the MOM method, as a defuzzification method. Concerning the limitations of research, future studies can conduct the research for a series of periods (years). Moreover, this paper did not take advantage of the probability theory, classical risk models, and traditional risk models. That is another limitation of the research. Future studies can integrate and use these methods simultaneously to make comparisons with fuzzy logic. Plus, this study was run on a single location of Turkey, which is Istanbul city. This can be considered as another limitation of the research and forthcoming papers can address this issue as well. Finally, the research can be carried out internationally in several countries in the future, which will allow cross-country and overseas comparisons.

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