Information Security Investment Decision-making based on Fuzzy Economics

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Abstract—Fuzzy economic models to evaluate the economic feasibility of information security investment for decision-makers is derived in this study. The Net Present Value and discounted Return on Investment models are proposed for the execution of cost-benefit analysis. Fuzzy mathematics is based on the extended principles which ensured that the resultant fuzzy number continuously maintained its fuzzy properties during the arithmetic operating procedure. Since fuzzy results are in the form of a complex nonlinear representation, and do not always provide a totally ordered set in the same way that crisp numbers do, the current paper approximates the resulting fuzzy profitability indexes by a triangular fuzzy number initially, and then uses the Mellin Transform to obtain the means and variances of the triangle fuzzy numbers in order to determine their relative ranking in a decision-making process. The performances of the proposed models are verified by considering their application to a practical illustration, which were used in a previous literature. These investigations not only confirm that the results of the fuzzy economic models are consistent with those of the conventional crisp models, but also demonstrate that the proposed models represent readily implemented possibility analysis tools for use in the arena of uncertain financial decision-making. The developed models represent readily implemented feasibility analysis tools for use in the arena of uncertain economic decision-making.

Keywords—fuzzy economics, fuzzy mathematics, information security investment, benefit-cost analysis, decision-making, possibility analysis, Mellin transform.

1 Introduction

Given the information-intense characteristics of a modern economy, whatever kind, scale of firms they are undergoing electronic business activities. The continued growth in the use of information technologies makes firms increasingly dependent on their information systems. However, firm's information assets are susceptible to risk by virtue of the fact that the information system is connected to third party networks, typically the Internet. The want and need for information security can have many different motivations. Some people and firms deal with highly sensitive information that could potentially threaten a certain people or nation. Corporations have trade secrets and business processes they do not want publicly disclosed. Banks and medical organizations have many records that could be used to steal personal identities. All of these situations require varying levels of security[1].

Any successful attack on information system and its eventual crash could result in a serious loss of data, services and business operations. This is the main reason why modern organizations are investing in *information security system* (ISS). The ISS should protect the confidentiality, integrity, and availability of the information system. Given the information-intense characteristics of a modern economy, it should be no surprise to learn that ISS is a growing spending priority among most companies. This growth in ISS is occurring in a variety of areas including software to detect viruses, firewalls, sophisticated encryption techniques, intrusion detection systems, automated data backup, and hardware devices [2, 3].

The information assets consist of hardware and software components that are the fruit of the work of a plethora of suppliers, systems integrators and internal employees. The value of the information assets comprises *tangible* and *intangible* assets [4]. The tangible component is the sum total of the cost to implement the various hardware and software elements of a system. The intangible component includes the value of the data stored in databases, the knowledge and the intellectual property stored within a system [5]. The value of the intangible assets may be difficult to calculate in monetary terms.

Losses from security breaches can be caused by a poor organization of security measures, human failures or fraud, technical failures or external events, and accordingly they are classified as financial, technical, ecological, social, psychological or other. The average disclosed loss from cyber crime in 2007 for the people that responded to the Computer Security Institute and Federal Bureau of Investigation's annual report was $350,424[6]. In the context of business operations the meaning and the importance of security failures are better understood through economic losses than with a technical analysis [3, 7, 8].

Key aspects of any economic security research should refer to [7]: 1.The frequency of security breaches – what are the symptoms and which are the indicia that compose the frequency of breaches; 2.The cost of security breaches – the resolution of a problematic cost estimation of a breach; 3.The investments to information security mechanisms – the level of expenditures for adoption and establishment of a security framework.

In order to determine how much an organization should spend on ISS and data protection it is important to know the value of the assets to be protected. This is usually done by risk management, which provides the organization with information about the consequences if appropriate protection and security solutions are not provided and about the potential losses in the case of security incident and the impact it may have on the company's overall productivity. Nowadays, the question is not whether organizations need more security, but how much to spend for added security. Each choice involves risk. Risk-based benefit is the reduction in expected loss from security failure incidents (that is, a reduction in risk). In this sense, IT security activities have a strong affinity with other activities that do not produce revenue but nonetheless provide essential and necessary support for the overall organization. As such, the relevant criterion in evaluating IT solutions is not simply the cost of implementation but how much benefit each additional dollar of investment brings, in the form of reducing the expected loss or risk.

Prior to adopting a project, potential investors must explore the soundness of the project by performing a feasibility study which investigates all aspects of the project, including its anticipated future financial and economic performance. The feasibility study mainly concerns the monetary aspects of the project and its financial rewards and profitability from the investors' perspectives. That is, an economic profitability model should be made available to potential investors to enable them to evaluate the benefit-costs of the project. The greater the economical effectiveness of a project the greater the degree of its acceptance adopted by the investor.

Classical decision-making methodologies are criticized for over-simplifying the decision-making process by forcing the experts to express their views on pure numeric scales. However, owing to the availability and subjectivity of information, it is very difficult to obtain exact assessment data as concerns the fulfillment of the requirements of the criteria or the relative importance of each criterion. It is common evidence that assessments made by experts are mostly of subjective and qualitative nature. Linguistic terms are frequently encountered in practice and are used to convey experts' assessments and beliefs. Fuzzy sets theory, originally proposed by Dr. Zadeh, is an effective means to deal with the vagueness of human judgment.

The cash flow models applied in many economic decision-making problems often involve an element of uncertainty. In the case of deficient data, decision-makers generally rely on an expert's knowledge of economic information when carrying out their economic modeling activities. The fuzzy set theory has been developed and successfully applied to numerous areas, such as control and decision making, engineering and medicine. Its application to economic analysis is natural due to the uncertainty inherent in many financial and investment decisions. However, practical applications of fuzzy number theory in the economic decision-making arena involve two laborious tasks, namely fuzzy mathematical operations and the comparison or ranking of the resultant complex fuzzy numbers.

The remainder of this paper is structured as follows: Section II introduces the fuzzy number, mathematics, and discusses the ranking of the fuzzy numbers. Section III develops fuzzy economic models to assist ISS investors in evaluating the relative benefits of ISS projects in an uncertain environment. Section IV presents the application of the proposed fuzzy evaluation models to a practical case study. Finally, Section V presents the conclusions of the present study.

2 FUZZY MATHEMATICS AND RANKING

2.1Fuzzy Number

When dealing with uncertainty, decision-makers are commonly provided with information, which is characterized by vague linguistic descriptions such as "high risk", "low profit", "high annual interest rate", etc.

The principal objective of fuzzy set theory is to quantify these vague descriptive terms. Dr. Zadeh proposed a membership function, which accords each object a grade (or degree) of membership within the interval [0, 1]. A fuzzy set is designated as $\forall x \in X, \mu_A(x) \in [0,1]$, where $\mu_A(x)$ is the grade of membership, ranging from 0 to 1, of a vague predicate, *A*, over the universe of objects, *X*. The closer the object matches the vague predicate, the higher its grade of membership. The membership function may be viewed as representing an opinion poll of human thought or as an expert's opinion.

A fuzzy number is a normal and a convex fuzzy set, and its membership function can be denoted as: $\mu_A(x) = (a_1, f_{A_1}(\alpha)/a_2, a_3/f_{A_2}(\alpha), a_4)$, where $f_{A_1}(\alpha)$ is a continuous monotonically increasing function of α for $0 \le \alpha \le 1$, $f_{A_2}(\alpha)$ is a continuous monotonically decreasing function of α for $0 \le \alpha \le 1$, $f_{A_1}(0) = a_1$, $f_{A_1}(1) = a_2$, $f_{A_2}(1) = a_3$, $f_{A_2}(0) = a_4$, and $a_1 < a_2 \le a_3 < a_4$. The Trapezoidal Fuzzy Number (TrFN) is a particular form of fuzzy number in which f_{A_1} and f_{A_2} are both straight-line segments, and in the case where $a_2 = a_3$, this TrFN becomes a Triangular Fuzzy Number (TFN). Implementing the TFN is mathematically straightforward, and more importantly, it represents a rational basis for quantifying the vague knowledge associated with most decision-making problems [9-14, 26]. The TFN of the vague predicate *A* can be expressed simply as $A = (a_1, a_2, a_3)$, where the vertexes a_1, a_2, and a_3 denote *the smallest possible value*, *the most promising value*, and *the largest possible value* to describe a fuzzy event, respectively. Of these values, the *most promising value* can be considered as the conventional (classic) crisp number. It is noted that these parameters are analogous to the lower, medium, and higher values in the domain of the triangular probability distribution. However, the parameters in a TFN represent the values accorded by human thought to the possibility of an event occurring, while the parameters in a triangular probability distribution represent the values associated with the probabilistic occurrence of that event. The membership function of the vague predicate *A* presented in Fig. 1 is described by the following linear relationships:

$$\mu_A(x) = \begin{cases} \mu_{A_1}(x) = \dfrac{x - a_1}{a_2 - a_1} & a_1 \le x \le a_2 \\ \mu_{A_2}(x) = \dfrac{a_3 - x}{a_3 - a_2} & a_2 \le x \le a_3 \end{cases} \quad (1)$$

$$x = \begin{cases} f_{A_1}(\alpha) = \mu_{A_1}^{-1} = a_1 + (a_2 - a_1)\alpha & 0 \le \alpha \le 1 \\ f_{A_2}(\alpha) = \mu_{A_2}^{-1} = a_3 - (a_3 - a_2)\alpha & 0 \le \alpha \le 1 \end{cases} \quad (2)$$

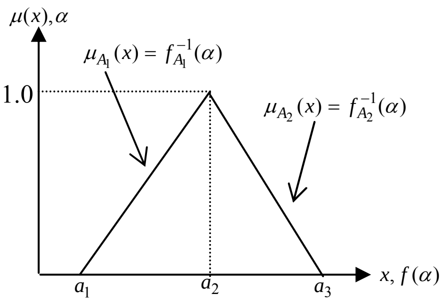

Fig. 1 Membership Function of Triangular Fuzzy Number

The α-cut of a fuzzy set *A* is a crisp set containing all the elements of the universal set *X,* whose membership grades in *A* are greater than, or equal to, the specified value of α. The α-cut of the fuzzy set *A* is given by:

$$\begin{aligned} A_\alpha &= [\, f_{A_1}(\alpha),\ f_{A_2}(\alpha)] \\ &= [\ a_1 + (a_2 - a_1)\alpha\, ,\, a_3 - (a_3 - a_2)\alpha\ ] \end{aligned} \quad (3)$$

Possibility (or confidence level) analyses is performed by using the membership function of the fuzzy number given in Eqs.(1)-(3). In this analyses, if *x* lies between a_1 and a_2, then the possibility of *x* can be obtained by substituting *x* into $\mu_{A_1}(x)$. Similarly, if x lies between a_2 and a_3, then the possibility of x can be obtained by substituting *x* into $\mu_{A_2}(x)$. At a specific membership grade or at a specific possibility α, the range of *x* can be calculated from the α-cut given in Eq.(3).

2.2 Fuzzy mathematics

Fuzzy mathematics is based on the extended principles presented in References [15-17], in which the traditional addition, subtraction, multiplication, division, power, logarithmic and exponent mathematical operations are applied to fuzzy numbers. Dubois and Prade[16] demonstrated that when performing the binary manipulation of fuzzy numbers, the resultant increasing (decreasing) part arose from binary operations on the non-decreasing (non-increasing) parts of the two fuzzy numbers. The extended operations ensured that the resultant fuzzy number continuously maintained its fuzzy properties during the arithmetic operating procedure. It is found that fuzzy mathematics tends to be cumbersome for even the more straightforward operations such as addition and subtraction. Unfortunately, financial and engineering applications involving fuzzy sets typically require the more complex nonlinear mathematical operations such as product, division, power and logarithmic manipulations [9]. In some cases, fuzzy operations of this type may require an insurmountable computational effort. Consequently, it has been proposed that approximated triangular fuzzy numbers be used to examine the resultant fuzzy profitability indexes [10].

2.3 Fuzzy Ranking

Following the manipulation of the approximated fuzzy financial function by fuzzy mathematics, the task of comparing or ranking the resultant complex fuzzy numbers can invoke another problem because fuzzy numbers do not always yield a totally ordered set in the same way that crisp numbers do. Many authors have investigated the use of alternative fuzzy set ranking methods, and these methods have been reviewed and compared by Chen and Hwang [18]. The Mellin Transform [19, 20] has been proposed as a mean to calculate the mean and variance values of the approximated fuzzy resulted indexes. A rigorous ranking of the fuzzy numbers can then be obtained by simply comparing the means and variances of the fuzzy numbers.

The probabilistic method is one of two previously published fuzzy ranking methods [9, 21-25]. In an earlier study [26], the current author suggested using the Mellin transform [34, 35] to perform the fuzzy ranking of normalized fuzzy numbers. The proportional probability density function was adopted due to its computationally straightforward nature and conceptual consistence. The proportional probability density function (*pdf*) corresponding to the membership function of a fuzzy number, $\mu(x)$, is $p(x) = h_p \mu_A(x)$, where h_p denotes the conversion constant which ensure that the area under the continuous probability density function is equal to 1.

Operational calculus techniques are particularly useful when analyzing probabilistic models as part of a decision-making process. In the probabilistic modeling context, it is often possible to reduce complex operations involving differentiation and integration to simple algebraic manipulations in the transform domain. The Mellin Transform is a useful tool for studying the distributions of certain combinations of random variables; especially for those concerned with the random variables associated with products and quotients. The Mellin Transform, $M_x(s)$, of a function *f(x)*, where *x* is positive, defined as follows:

$$M_x(s) = \int_0^\infty x^{s-1} f(x)dx \quad 0 < x < \infty \tag{4}$$

The Mellin Transform has a unique one-to-one correspondence with the transformed function, i.e. $f(x) \leftrightarrow M_x(s)$. The moments of a distribution represent the expected values of the power of a random variable with a $f(x)$ distribution. In general, the r^{th} moment of a random variable, *X*, about a real number, *c*, is defined as:

$$M_r(x) = E[(X-c)^r] = \int_X (x-c)^r f(x)dx \tag{5}$$

The moments of interest in economic analyses are those about the origin ($c = 0$) and those about the mean ($c = \mu$), typically for r =1, 2, 3 and 4. If the $\boldsymbol{r}^{\text{th}}$ moments about the origin and the mean are denoted by $E[X^r]$ and m_r respectively, then:

$$m_r = E[(X-\mu)^r] = \int_X (x-\mu)^r f(x)dx \tag{6}$$

The first moment about the origin represents the mean of the distribution, $\mu = E[X]$, while the second moment about the mean represents the variance, σ^2. Meanwhile, the skew and the kurtosis of the distribution are denoted by m_3 and m_4, respectively. Comparing Eq.(4) with Eq.(5) shows that $M_x(s)$ is a special case of $M_r(x)$, where $c = 0$ and $r = s-1$. In other words, if *f(x)* is viewed as a probability density function, the Mellin Transform, $M_x(s) = E[X^{s-1}]$, provides a means of establishing a series of moments of the distribution. Comparing the first two moments of a distribution with the Mellin Transform, allows the mean and variance to be expressed as Eqs.(7) and (8), respectively.

$$\mu = E[X] = M_x(2) \tag{7}$$

$$m_2 = \sigma^2 = Var[X] = M_x(3) - (M_x(2))^2 \tag{8}$$

The Mellin transforms of the *TFN* $A(a_1, a_2, a_3)$ were derived and summarized in Table 1 in [26]. Computing $M_x(s)$ at s=1, 2 and 3, gives the mean and variance of the triangular fuzzy number $A(a_1, a_2, a_3)$ as:

$$\mu_A = M_x(2) = \frac{a_1 + a_2 + a_3}{3} \tag{9}$$

$$\sigma_A^2 = \frac{1}{18}(a_1^2 + a_2^2 + a_3^2 - a_1 a_2 - a_2 a_3 - a_3 a_1) \tag{10}$$

Fig.1 presents a flow chart describing the proposed ranking process for fuzzy numbers. Initially, the fuzzy numbers are converted to their equivalent *pdfs*. Eqs.(9)

and (10) are then used to calculate their means and variances. Fuzzy numbers which share the same mean value are ranked using Rule 1, while the remaining fuzzy numbers are ranked using Rule 2. These two rules are summarized as follows: *Rule 1*: a fuzzy number with a lower variance is ranked above fuzzy numbers whose variances are higher. *Rule 2:* a fuzzy number with a superior mean is ranked above fuzzy numbers having inferior means. Note that when performing a least-cost analysis, a smaller mean cost is superior to higher mean costs. Conversely, in a cost-benefit analysis, a higher mean benefit is superior to lower mean benefits.

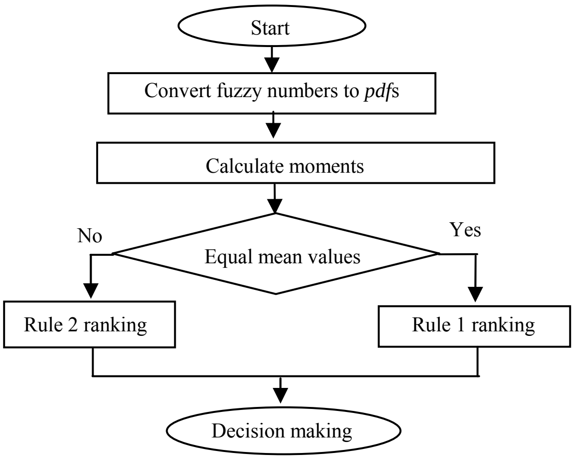

Fig.2. Flow chart of fuzzy number ranking process

3 FUZZY ISS ECONOMIC DECISION MODELS

There are many different methodologies for assessing the profitability of information security investment. Quantitative analysis attempts to assign numeric values to the likelihood and impact of the risk and to the costs and benefits related to the ISI. In this paper, only the economic evaluation method under uncertainty will be described instead of the estimated for individual security parameters. A simple analytical method for risk exposure proposes calculation of annual loss expectancy(ALE)[3,8]. The first thing in ALE calculation is determination of the monetary loss associated with the impact, or the single loss exposure(SLE). The SLE is the total amount of revenue that is lost from a single occurrence of the risk. It is a monetary amount that is assigned to a single event that represents the organization's potential loss amount if a specific threat exploits the vulnerability. The SLE is calculated by multiplying the monetary value of the information asset(AV) with the exposure factor(EF).

$$SLE = AV \times EF \qquad (11)$$

The EF represents the percentage of loss that a realized threat could have on a certain information asset. The annual rate of occurrence(ARO) is the number of times that an organization reasonably expects particular risk to occur during one year. The ALE of an information asset then calculated as:

$$ALE = SLE \times ARO \qquad (12)$$

Most of the currently used metrics for quantifying the costs and benefits of Information security investments are based on the calculated indicator such as return on investment(ROI), net present value(NPV), internal rate of return(IRR) or combinations of all of them. The cost of ISS should be considered as a compound of the system configuration specific costs and the operating costs. System configuration specific costs are typically one-time spend costs for purchase, testing and implementation of defense solution that protects information assets from possible threats. Operating costs are represented by annual maintenance (upgrades and patching of the defense solution), training users and network administrators, monitoring the solution.

On the other hand, assess or measure the benefits of ISS is difficult to define, since firewall, antivirus software and other security solution do not generate revenue that can be easily measured. The benefits resulting from ISI then measured as cost avoided that result from preventing information security breaches[3,8]. Benefits can be therefore represented as a difference between ALE without and with ISS:

$$Benefit = ALE_{without\ ISS} - ALE_{with\ ISS} \qquad (13)$$

In [2], the authors took into account the vulnerability of the information to a security breach and the potential loss such a breach occur. It is shown that for a given potential loss, a firm should not necessarily focus its investments on information sets with the highest vulnerability. Since extremely vulnerable information sets may be inordinately expensive to protect, a firm may be better off concentrating its efforts on information sets with midrange vulnerabilities. For two broad classes of security breach probability functions, the optimal amount to invest in information security should not exceed 37%($\approx 1/e$) of the expected loss due to a security breach.

In many previous literatures and many firms prefer to take a generic approach to evaluating the return on security investment for information security activities. However, this is an over-simple model to evaluate the invest activities since the opportunity cost of capital was neglected. The *opportunity cost of capital* is the expected return forgone by bypassing of other potential investment activities for a given capital. The opportunity cost of capital is an important concept for a source-limited firm to schedule any kind of investments. This paper will take both interest rate and inflation rate of monetary into account for the cost-benefit analysis of ISS decision-making in a firm.

The cash flow models applied in economic decision-making problems relating to project evaluation frequently involve an element of uncertainty. Previous researchers, including Kaufmann and Gupta [27] and Ward [28], conducted fuzzy discounted cash flow analyses in which either the periodic cash flow or the discount rate was specified as a fuzzy number. Furthermore, Buckley [29], Chiu and Park [30] and Kahraman *et al.* [31] addressed problems in which both the periodic cash flow and the discount rate were expressed as fuzzy numbers. These studies also developed various economic equivalence formulae for use in rudimentary economic calculations. However, these models have only limited application in the economic decision-making arena since they consider only a single payment, or at best, a few payments, when deriving their economic indexes. However, in real-world applications, the periodic cash flow may be subject to occasional uncertain variations. Accordingly, the present study adopts a parameter, d, to represent the inflation rate.

Those parameters are specified in the form of fuzzy numbers and are used to reflect an uncertain geometric series of cash flows. At the planning stage, a decision-maker is seldom in possession of all the information required to make an accurate assessment of the initial investment I, and the annual cash flow-in (or out) A. Therefore, it is appropriate to specify the initial investment, the periodic cash flow, the inflation rate and the interest rate as *TFNs*[32,33].

In evaluating certain projects, investors may take the cash flow-out to be the initial capital investment I, and consider the cash flow-in to be the annual net profit, A, which is calculated as the difference between the annual production revenue and the annual operating cost. The present study develops two fuzzy cost-benefit evaluation models, i.e. net present value (*NPV*), and discounted return of investment (*dROI*), to assess the profitability of ISS projects. Although the internal rate of return indicator is commonly used in conventional crisp cost/benefit analysis, it has been noted by previous researchers that this index is not applicable to the fuzzy case [12, 30].

The crisp *NPV*, and *dROI* measures are expressed in Eqs.(14), and (15), respectively. Meanwhile, the membership functions of the corresponding fuzzy models can be derived as represented in Eqs.(16) and (17), respectively.

$$NPV = -I + A^* GPVF \tag{14}$$

Where the geometric series present value factor is:

$$GPVF = \frac{1-((1+d)/(1+r))^n}{(r-d)}$$

$$dROI = \frac{\sum_{t=1}^{n} \frac{A(1+d)^{t-1}}{(1+r)^t}}{I} = \frac{A}{I}\left(\sum_{t=1}^{n} \frac{(1+d)^{t-1}}{(1+r)^t} \right) \tag{15}$$

$$\mu_{NPV}(x) = (NPV_1, f_{NPV_1}(\alpha)/NPV_2, NPV_2 / f_{NPV_2}(\alpha), NPV_3) \tag{16}$$

Where:

$$f_{NPV_i}(\alpha) = -f_{I_{(3-i)}}(\alpha) + f_{A_i}(\alpha) \frac{1-\left(\frac{1+f_{d_i}(\alpha)}{1+f_{r_{(3-i)}}(\alpha)} \right)^n}{f_{r_{(3-i)}}(\alpha) - f_{d_i}(\alpha)} \quad i = 1,2$$

$$\mu_{dROI}(x) = (dROI_1, f_{dROI_1}(\alpha)/dROI_2, dROI_2 / f_{dROI_2}(\alpha), dROI_3) \tag{17}$$

Where:

$$f_{dROI_i}(\alpha) = \frac{f_{A_i}(\alpha)}{f_{I_{(3-i)}}(\alpha)} \left(\frac{1-\left(\frac{1+f_{d_i}(\alpha)}{1+f_{r_{(3-i)}}(\alpha)} \right)^n}{f_{r_{(3-i)}}(\alpha) - f_{d_i}(\alpha)} \right) \quad i = 1,2$$

4 CASE STUDIES

The fuzzy economic decision-making procedures are briefly described. Firstly, the estimated input parameters, such as interest rate, inflation rate, investment, and operating revenue and/or cost, which are needed in economic index calculation, should be provided by the expert in form of fuzzy numbers. The fuzzy economic decision indexes are then calculated according to the models developed in Section III. The fuzzy economic decision is made finally according to the relative ranking of the resultant fuzzy economic indexes, which is performed following the process described in Fig.1.

This paper cited a plausible illustration presented in [8] to demonstrate the application of the developed models. A firm with 500 computers is decided to reduce the security risk. It is estimated that the potential annual loss from security breach would cost the organization €1,000,000. The current implemented information security controls reduces the security risk by 80%, but this is not good enough. The organization's security goal is to reduce the probability of security breach to max 10%. The investment is intended for four years, zero salvage value was considered.

The first alternative is a low cost security solution(LC alternative), which reduces the probability of a security breach to 10%. The purchase price of this solution is €60,000 and firm estimate €20,000 for yearly maintenance costs for in-house technical staff(updates, monitoring and upgrades).

The second alternative is professional solution(PRO alternative), which reduces the probability of a security breach to just 1%. Its purchase price is €100,000, while the annual renewable price is €30,000. Because this is a more professional solution, the technical staff needs training, which costs €30,000, but further yearly maintenance costs will be smaller, just €5,000.

The third alternative is outsourcing the additional security(OUT alternative). The firm providing outsourcing service assures that a security breach is no more than 7%. The company charges €150,000 for implementing security solution and €25,000 for annual maintenance and support. There is no need for extra in-house technical support.

In Table I the fuzzy initial ISS investment, annual operating costs and annual benefits are represented together for all three alternatives. All considering parameters are represented as triangle fuzzy value, e.g. the purchase price of the LC-alternative is estimated by the expert about 60k€, which can be denoted as TFN (55, 60, 65) k€ means the smallest possible value, the most promising value, and the largest possible value of the purchase price are 55k€, 60k€, and 65k€, respectively. The interest rate and inflation rate are estimated about 5% and 2%, respectively, represented in TFNs as (4, 5, 6)% and (1, 2, 3)%, respectively. The annual security benefit and yearly maintenance cost of the LC-alternative then can be denoted as (90, 100, 110)k€, (18, 20, 22)k€, respectively. Similarly, the annual security benefit and yearly maintenance and renew cost of the PRO-alternative are denoted as (173, 190, 205)k€, (33, 35, 37)k€, respectively. The purchase price and first staff training fee for this alternative are (91, 100, 109)k€, (28, 30, 32)k€, respectively. The annual security benefit and yearly maintenance and renew cost of the OUT-alternative are denoted as (118, 130, 140)k€, (23, 25, 27)k€, respectively. The purchase price of the PRO-alternative is estimated (137, 150, 162)k€.

Using the developed models of this paper, the two fuzzy economic indexes are summarized in Table II for all three alternatives. The triangle fuzzy *NPV* for all three alternatives also presented in Fig. 3. The results indicate that the PRO alternative has a higher *NPV* and *dROI* mean values. Consequently, the PRO alternative is the preferred choice, although it is the most expensive one, in this particular case.

To compares with the cited paper[8], if the inflation rate are set as (0, 0, 0)%, the *NPV* of three alternative(LC, PRO, and OUT) are (170.06, 223.68, 278.96) k€, (325.70, 416.30, 503.17) k€, and (153.32, 222.33, 287.71) k€, respectively. Meanwhile, the *dROI* of three alternative(LC, PRO, and OUT) are (3.62, 4.73, 6.07), (4.05, 5.16, 6.46), and (1.95, 2.48, 3.10), respectively. It should be noted that the most promising values of fuzzy *NPV* and *dROI* are consistent with the practice illustration demo in [8], which shown in Table II. However, in case of inflation consideration, more benefit is shown in the developed models obviously.

A possibility analysis can be performed by setting a specific confidence level in the fuzzy economic models in order to obtain a possible economic value range. For the case of the low 0.3 confidence level, the possible *NPV* ranges are calculated to be [191.4, 275.2]k€, [371.4, 501.3]k€, and [180.4, 284.5]k€, respectively, for LC-, PRO-, and OUT-alternative. Meanwhile, for the case of the higher 0.6 confidence level, the possible *NPV* ranges are calculated to be [208.8, 256.7]k€, [392.4, 471.7]k€, and [203.0, 262.5]k€, respectively, for LC-, PRO-, and OUT-alternative.

Similarly, the possible *dROI* ranges of the all three alternatives at 0.6 confidence levels are estimated to be [4.39, 5.49], [4.84, 5.90], and [2.32, 2.83], respectively. The possible *dROI* ranges of the all three alternatives at 0.3 confidence levels are estimated to be [4.03, 5.96], [4.47, 6.33], and [2.05, 3.03], respectively. It should be noted that a fuzzier (larger interval) economic index is obtained as the lower confidence level is adopted.

The economic possibility analysis shows the possible interval of the economic decision index as well as their corresponding membership grade. This analysis can be likely considered as a *subjective* sensitivity analysis in case of the conventional engineering economics. Fuzzy economic mathematics eliminates the need for complicate sensitivity analysis studies associated with input parameter variations. The economic possibility analysis is therefore an essential and effective means of evaluating the vulnerability of the profitability of a project which might deviate from the best estimates in the future. The future deviations are guessed subjectively by the experts' opinions in fuzzy number form.

TABLE I TRIANGLE FUZZY BENEFITS AND COSTS FOR ALL THREE ALTERNATIVES

Year	Alternative LC			Alternative PRO			Alternative OUT	
	Benefit(k€)	Purchase and upgrade cost(k€)	Maintenance cost(k€)	Benefit(k€)	Purchase and upgrade cost(k€)	Maintenance cost(k€)	Benefit(k€)	Purchase and upgrade cost(k€)
0		(55,60,65)			(91,100,109)			(137,150,162)
1	(90,100,110)		(20,18,22)	(173,190,205)	(29,30,31)	(38,40,42)	(118,130,140)	(23,25,27)
2	(90,100,110)		(20,18,22)	(173,190,205)	(29,30,31)	(4,5,6)	(118,130,140)	(23,25,27)
3	(90,100,110)		(20,18,22)	(173,190,205)	(29,30,31)	(4,5,6)	(118,130,140)	(23,25,27)
4	(90,100,110)		(20,18,22)	(173,190,205)	(29,30,31)	(4,5,6)	(118,130,140)	(23,25,27)

TABLE II THE FUZZY ECONOMIC COMPARISON OF THREE ALTERNATIVES

ALTERNATIVE		NPV(K€)	BCR
LC SOLUTION	TRIANGLE FUZZY VALUE	(174.0,231.9,293.8)	(3.68,4.87,6.43)
	MEAN VALUE	233.2	4.99
	STANDARD DEVIATION	24.45	0.56
PRO SOLUTION	TRIANGLE FUZZY VALUE	(332.5,432.3,530.9)	(4.11,5.32,6.76)
	MEAN VALUE	431.9	5.40
	STANDARD DEVIATION	40.50	0.54
OUT SOLUTION	TRIANGLE FUZZY VALUE	(157.8,233.2,306.5)	(1.97,2.56,3.24)
	MEAN VALUE	232.52	2.59
	STANDARD DEVIATION	30.35	0.26

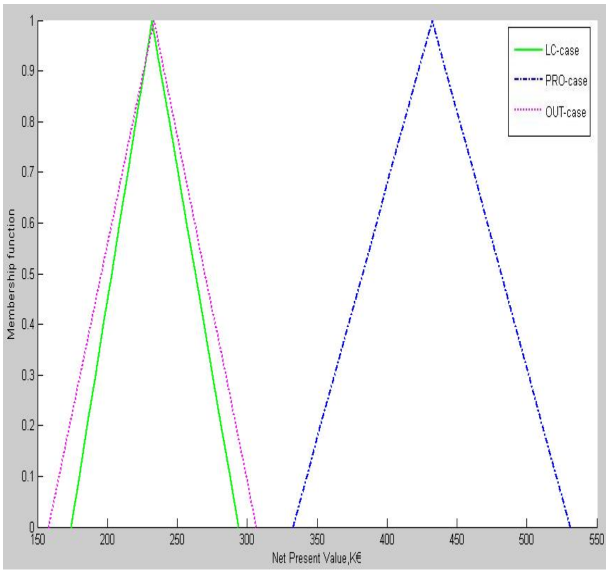

Fig. 3 Triangle fuzzy *NPV* for all three alternatives

5 CONCLUSIONS

This study has derived fuzzy economic models which enable project investors to perform an economic evaluation of information security investment alternatives. The proposed economic decision analysis method is more flexible and more intelligent than other methods since it takes the degree of confidence of the decision-makers' opinions into consideration. The cost-benefit analysis of information security investment is performed using the *NPV*, and *dROI* indexes. The moments of the resultant fuzzy indexes are derived in order to determine the relative ranking of the fuzzy economic indexes to support the decision-making process. In a cost-benefit analysis, a higher mean benefit represents a better solution than one with a lower mean benefit. Meanwhile, a computer simulation is performed to explore the main uncertainties typically encountered in this analysis. The results show that the fuzziness of the decision indexes is not significantly influenced by the change in the values of the investment and the annual cost (benefit). However, it is strongly influenced by the values of interest rate r and inflation rate d due to the presence of the n^{th} power of r and d within the economic decision indexes. The simulation also shows that a fuzzier economic index is obtained as the lower confidence level is adopted. It is found that all of two economic measures, *NPV*, and *dROI* indexes, suggest the same result, and hence any one of the economic decision indexes can be chosen for decision-making purposes.

The performances of the proposed fuzzy economic models are verified by considering their application to a practical project. It has been demonstrated that the most promising cases generated using the proposed fuzzy models are consistent with those provided by the conventional crisp models. And in case of inflation consideration, more benefit results than with no-inflation cases are shown in the developed models. The results of this present study have confirmed that the proposed methods provide readily implemented possibility analysis tools for use in the arena of financial uncertain decision-making.

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