Operating System Evaluation Using Choquet Integral in Terms of Cyber Threats

K. Göztepe* A.Ejder**

Abstract— **Operating system (OS) selection is a critical decision that can significantly affect future competitiveness and performance of an organization. It is increasingly valuable in today's current administration and businesses because of its ability to integrate the information. An operating system, especially with the weakness in security can lead to serious financial losses. The aim of this study is to develop a decision model based on choquet integral that select the appropriate operating system for critical computer systems by taking subjective judgments of decision makers into consideration. Proposed approach is based on choquet integral method. Choquet integral method is used in determining the weights of the criteria by decision makers and then rankings of the operating systems. Numerical study has also been demonstrated.**

***Index Terms*—Operating systems, choquet integral, decision making, cyber threats.**

I. INTRODUCTION

The quick evolution of IT force system security professionals to a competitive environment. Government agencies, enterprises, and even individuals, are confronted by technology replacement decisions more frequently as technology upgrades speed up. Because of this, it becomes necessary to take decisions more often for the update of the technology. Government agencies, enterprises, firms and organizations should consider the changes and update the information technologies. One of these technology-related changes occur in operating systems. Operating system is system software responsible for the direct control and management of the hardware, basic system operations and operation of applications. It provides links to the memory, input/output devices and file system [1],[2].

Operating system choice is crucial for companies or organizations in terms of IT infrastructure reliability [3]. Selection Choice of operating systems should be considered a variety of criteria. Choquet integral has been used for that reason in this case.

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II. KEY FEATURES OF OPERATING SYSTEMS

An OS should ensure tasks and service management features in order to meet enterprise computing needs. Tanenbaum [2] and Galvin [1] categorize these features as follows: Process Management, Storage Management, Protection and Security, Distributed Structure and Software Features (Fig.1).

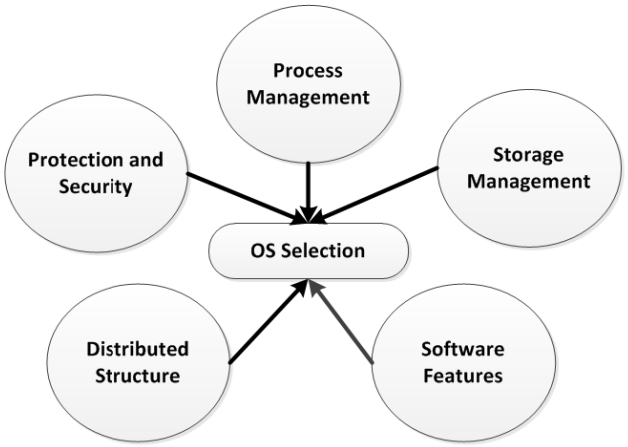

Fig. 1. Main features of an operating system.

A. Process Management (PM)

A Process is an instance of a computer program. It is being sequentially executed by a computer system. PM has the ability to run several computer programs concurrently [4]. Most modern operating systems support processes that have multiple threads.

B. Storage Management (SM)

Main memory is usually too small to accommodate all the data and programs permanently. Thus, the computer system must provide secondary storage to back up main memory. Today's computer systems use disks as the primary on-line storage medium for information. The file system provides the mechanism for on-line storage and access to both data and programs residing on the disks [4],[5].

C. Protection and Security (PS)

Protection is an internal problem. However, security must consider both the computer system and the environment. To defend the processes from cyber threats is essential for the operating systems. Protection refers to a mechanism for controlling the access of programs, processes, or users to the resources. These are determined by the computer system [2],[5]. Computer resources must be guarded against cyber

terrorists, cyber activists and special cyber attack teams.

D. Distributed Structure *(DS):*

A distributed system is a collection of processors that do not share memory or a clock. Instead, each processor has its own local memory, and the processors communicate with one another through communication lines such as local area or wide are networks. Main topics related with distributed structure are network structures, distributed system structures, distributed file systems and distributed coordination. It is important to know that it is sometimes impossible to determine the exact events order in a distributed system. Timestamps and mutual exclusion can be used to provide a consistent event ordering [2],[5].

E. *Software Features (SF)*

An operating system must provide applications and tools, bugs and coding, graphical user interface, availability and support criteria [3]. Programming Interface provides several ways for developers to access to system resources such as kernel objects, I/O devices and etc. Graphical User Interface takes advantage of the computer's graphics capabilities to make interacting user and operating system easier. Applications and tools must be always available and should be supported by developers in order to satisfy user requests [2],[5]. In this study, operating system's software features are evaluated for their specialities.

III. CHOQUET INTEGRAL

The choquet integral method can be seen as a fuzzy integral method based on any fuzzy measure that provides an alternative computational structure for aggregating information. Sugeno [6] introduces the concepts of fuzzy measure and fuzzy integral to express the grades of importance for criteria, which is useful to model the preference structure. Fuzzy measures, according to Sugeno, are obtained by replacing the additive requirement of classical measures with weaker requirements of monotonicity (with respect to set inclusion) and continuity. Sugeno and Terano [7] incorporate the λ-additive axiom to reduce the difficulty of collecting information. In literature choquet integral has been used in different studies and applications [8],[9],[10],[11].

A. Fuzzy Measure

Fuzzy measure g is a set function defined on the power set β(X) of X and satisfies the following properties [12],[13]:

If there are two criteria such as A and B;

$$g:\beta(X)\to[0,1]$$

$$g(\varnothing)=0, \qquad g(X)=1 \quad \text{(Boundary conditions)} \quad (1)$$

$$\text{if } A,B\in\beta(X) \quad \text{and} \quad A\subset B \quad \text{then} \quad g(A)\le g(B) \quad (2)$$

(Monotonicity)

$$In\ \beta(X),\ if\ A_1\subset A_2\subset A_3\subset A_4\subset,\ldots,$$
$$and\ \mathbf{U}_{i=1}^{\infty}A_i\in\beta(X),$$
$$then\ lim_{i\to\infty}g(A_i)=g(\mathbf{U}_{i=1}^{\infty}A_i)$$

(Continuity from below) (3)

$$In\ \beta(X),\quad if\ A_1\supset A_2\supset A_3\supset A_4\supset,\ldots,$$
$$and\ \mathbf{I}_{i=1}^{\infty}A_i\in\beta(X),$$
$$then\ lim_{i\to\infty}g(A_i)=g\left(\mathbf{I}_{i=1}^{\infty}A_i\in\beta(X)\right)$$

(Continuity from above) (4)

A λ-fuzzy measure g_λ is a fuzzy measure with the following property:

$$\forall A,B\in\beta(X),\quad A\cap B=\varnothing \quad (5)$$

$$g_\lambda(A\cup B)=g_\lambda(A)+g_\lambda(B)+\lambda g_\lambda(A)g_\lambda(B)$$

where $\lambda\in(-1,\infty)$ (6)

If $X=\{x_1,x_2,\ldots,x_n\}$ fuzzy density $g_i=g_\lambda(\{x_i\})$ will have the following form: (7)

$$g_\lambda(\{x_1,x_2,\ldots,x_n\})=\sum_{i=1}^{n}g_i+\lambda\sum_{i_1=1}^{n-1}\sum_{i_2=i_1+1}^{n}g_{i_1}g_{i_2}+\ldots \quad (8)$$
$$+\lambda^{n-1}g_1g_2,\ldots,g_n$$

$$=\frac{1}{\lambda}\left|\prod_{i=1}^{n}(1+\lambda g_i)-1\right| \quad for\ -1\le\lambda<\infty \quad (9)$$

If $\lambda>0$ then $g_\lambda(A\cup B)>g_\lambda(A)+g_\lambda(B)$. This means that the evaluation of the set {A,B} is larger than the sum of evaluations for sets {A} and {B}. *It is called* ***superadditivity***. i.e., the multiplicative effect exists in {A, B}.

If $\lambda<0$ then $g_\lambda(A\cup B)<g_\lambda(A)+g_\lambda(B)$ This means that the evaluation of the set {A, B} is smaller than the sum of evaluations for sets {A} and {B}, i.e., the substitutive effect exists in {A, B}. *It is called* ***subadditivity***.

If $\lambda\neq0$ indicates that the λ-fuzzy measure g_λ is ***nonadditivity*** and there is interaction between A and B.

If $\lambda=0$ then $g_\lambda(A\cup B)=g_\lambda(A)+g_\lambda(B)$. This means that the evaluation of the set {A, B} equals the sum of evaluations for sets {A} and {B} It is called additivity. If $\lambda=0$ indicates that the λ-fuzzy measure g_λ is additive, and there is no interaction between A and B.

The fuzzy measure is often used with fuzzy integral for the purpose of aggregating information evaluation.

B. Fuzzy integral

Let h be a measurable function from X to [0,1]. Assuming that $h(x_1) \geq h(x_2) \geq \cdots \geq h(x_n)$ then a fuzzy integral is defined as follows [6],[14],[15].

$$(C)\int h dg = h(x_n)g(H_n) + [h(x_{n-1}) - h(x_n)]g(H_{n-1}) + \ldots + [h(x_1) - h(x_2)]g(H_1)$$
$$= h(x_n)[g(H_n) - g(H_{n-1})] + h(x_{n-1})[g(H_{n-1}) - g(H_{n-2})] + \ldots + h(x_1)g(H_1) \quad (10)$$
$$where\ H_1 = \{x_1\}, H_2 = \{x_1, x_2\}, \ldots\ldots, H_n = \{x_1, x_1, \ldots, x_n\} = X$$

The basic concept of Eq. (2) can be illustrated as shown in Fig.2. Furthermore,

if λ=0 and $g_1 = g_2 = \cdots = g_n$ then $h(x_1) \geq h(x_2) \geq \cdots \geq h(x_n)$ is not a necessary condition. (11)

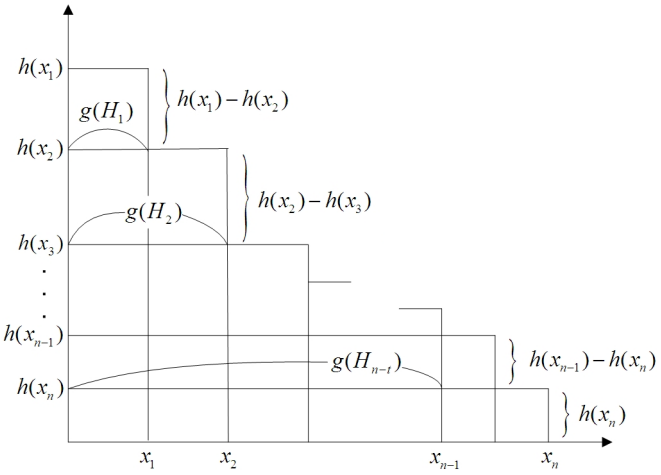

Fig. 2: The graphical illustration of choquet integral.

IV. A NUMERICAL SAMPLE

Five popular and widely used operating systems evaluated in this section. These are Ubuntu (UBT), Ms-Win (WIN), MAC, Fedora (FED) and Slackware (SLACK). Evaluation process made according to process management, storage management, protection and security, distributed structure and software features. Evaluation steps are given below (see also Appendix A).

Step1: Making pairwise comparison matrices.
A pairwise matrix calculated in order to find weight values of operating systems. Pairwise table is given below(Table1).

TABLE I
PAIRWISE COMPARISON TABLE

	PM	SM	PS	DS	SF	weights
PM	1	3	1	2	2	0.2927
SM	0.333	1	0.5	1	0.5	0.1115
PS	1	2	1	3	3	0.3240
DS	0.5	1	0.333	1	1	0.1248
SF	0.5	2	0.333	1	1	0.1467

Pairwise comparison is a widely used judgement method either for deriving criteria-weights or for evaluating alternatives according to a given criterion [16],[17].

Step 2. Determining interaction degree.
Interaction degree λ is used in the evaluation. λ=3 in model.

Step 3. Obtaining results.
Obtained results from proposed example are given in Appendix A. Evaluation scores for operating system criteria are; {PM} 0.1668, {SM} 0.0557, {PS} 0.1890, {DS} 0.0629, {SF} 0.0751. Here, PS criteria got the high score then others.

Step 4. Choquet integrated values
Operating system experts gave score to each OS for Ubuntu, MS-Win, Mac, Fedora and Slackware (Table2). Operating systems have been evaluated over 10. For instance, Ubuntu scores are PM=8, SM=7, PS=8, DS=8, SF=6 as seen Table 2.

TABLE II
CHOQUET INTEGRATED VALUES

OS	PM	SM	PS	DS	SF	Choquet Integrated Values
UBT	8	7	8	8	8	7.80898
WIN	7	6	8	7	7	6.99803
MAC	8	5	7	8	9	7.08872
FED	8	6	8	8	8	7.61796
SLACK	6	8	8	7	6	6.66806

Ubuntu OS received the highest score, 7.808, at the end of the calculation process.

Step 5. Sensitivity analysis.

From the coloured graph (Fig 3), Mac OS (Blue line) is most preferred OS when $\lambda < 0.5$. If λ value increases, $\lambda > 0.5$, then Ubuntu OS gets high score. Ubuntu is the best OS between $10 > \lambda > 0.5$ values. If λ value remains between $6 > \lambda > 0.5$, OS order of preference will be the same. When λ is $8 > \lambda > 6$, Win OS will be third one.

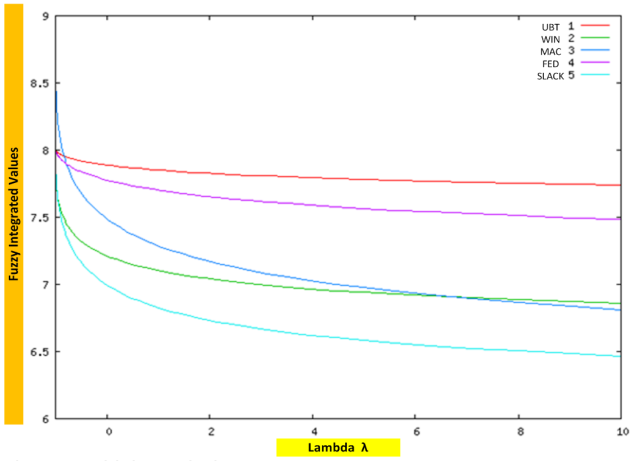

Fig. 3. Sensitivity analysis.

V. Conclusion

Today the number and impact of cyber-threats are increasing rapidly. Selection of appropriate operating system has vital importance for organizations, government agencies, and enterprises. A firm may have some positive results in its interested competition area. It is possible to get better results in costs, time-efficiency and increased work performance by using suitable OS. In this paper, choquet integral is used for evaluating selected operating systems. Pairwise matrices calculation for determining the weights of the criteria and priority values of operating systems has been done by choquet integral method. Although choquet integral has complex calculation procedure, it is a useful approach for evaluating multiple criteria alternatives. Choquet integral is one of the outranking methods for multi-criteria decision-making and can be used for ranking alternatives. This approach enables experts and users to select more suitable operating system for a specific purpose and requirement.

The researchers may compare the performance of choquet integral with other meta-heuristics (e.g. genetic algorithm, artificial neural network, fuzzy neural networks) specifically to test whether choquet integral approach has any advantage in operating system evaluation.

APPENDIX

Appendix A: Main steps of λ Fuzzy Measure and Fuzzy Integral, and Choquet Integral Evaluation Scores is given.

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APPENDIX A

Infrastructure of main steps; λ Fuzzy Measure and Fuzzy Integral [18]

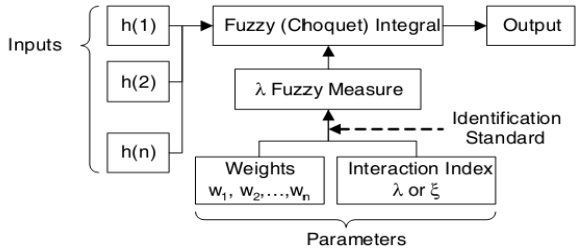

Table III
Identified Fuzzy Measure for OS Criteria

Sets	Fuzzy Measure
{}	0
{PM}	0.166869
{SM}	0.0557408
{PM,SM}	0.250515
{PS}	0.189054
{PM,PS}	0.450566
{SM,PS}	0.276409
{PM,SM,PS}	0.581652
{DS}	0.0629981
{PM,DS}	0.261405
{SM,DS}	0.129274
{PM,SM,DS}	0.360859
{PS,DS}	0.287783
{PM,PS,DS}	0.598719
{SM,PS,DS}	0.391648
{PM,SM,PS,DS}	0.75458
{SF}	0.0751959
{PM,SF}	0.279709
{SM,SF}	0.143511
{PM,SM,SF}	0.382224
{PS,SF}	0.306899
{PM,PS,SF}	0.627405
{SM,PS,SF}	0.41396
{PM,SM,PS,SF}	0.788062
{DS,SF}	0.152406
{PM,DS,SF}	0.395571
{SM,DS,SF}	0.233632
{PM,SM,DS,SF}	0.51746
{PS,DS,SF}	0.427899
{PM,PS,DS,SF}	0.808979
{SM,PS,DS,SF}	0.555195
{PM,SM,PS,DS,SF}	1