Capability Evaluation of Embedded Systems, Cell Phone Case Study

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ABSTRACT

This paper proposes a generic technique for the evaluation and comparison of the capability of Embedded Systems (ESs) as decision-making aid. The major issue in this area is conducted by comparing and evaluating success factors and the risks associated with each ES. In this regards decision-making modelling concepts are based on the identification of capability factors and finding mathematical models to describe or to prescribe best choice. The techniques utilize a combination of subjective and qualitative assumptions and mathematical modelling techniques. The digital cell phone as a sample of ES is analyzed as case study to show the application of the proposed approach. The results show the high performance of this methodology for capability evaluation of such systems.

Keywords

Embedded Systems, Capability Evaluation, Multiple Criteria Decision-Making, Fuzzy Logic, Cell Phone

1. INTRODUCTION

This paper proposes a hybrid heuristic technique (HHT) for capability evaluation and comparison of ESs. The major issues in this era can be conducted by comparing and evaluating success factors associated with their risks. In this regards decision-making concepts are based on the identification of capability factors while introducing mathematical models. The proposed technique utilizes a combination of subjective and qualitative assumptions in order to present a decision support modelling [1,2,3,4,5,6].

This approach adopts a methodical and simple criterion to system analysis from different perspectives. This technique tends to offer a generic tool for systems analysts to assess and compare industrial capability with respect to specified system features. It is therefore imperative to describe what is meant by a system and its capability. A system may be described as: "a complex and highly interlinked network of parts exhibiting synergistic properties [7]"

By introducing capability indices, the model uses established algorithms to address a particular issue, the so-called, ESs capability assessment. Capability indices proposed in this paper are the product of utilizing fuzzy relations and analytic hierarchy process (AHP) techniques.

Fuzzy relation is adopted to create a common quantitative measure to relate various factors and ESs relational concept of "capable" [8]. AHP technique is adopted to define a pair-wise comparison of different factors. This technique is implemented to assign weights to each factor based on the relative levels of importance for each factor in comparison with the others. Capability factors may vary due to the nature of the each system; the methodology discussed in this paper will be sufficiently flexible to accommodate systems' diversity. A case study is introduced to illustrate the effectiveness of the proposed approach.

In embedded system design we attempt to optimize conflicting criteria, for example maximizing performance while minimizing energy and area requirements. The optimization involves the simultaneous consideration of several incomparable and often competing objectives. Many multi-objective approaches have been proposed in the literature [9,10,11,12,13,14,15]. Although they operate at different level of abstraction and deal with different optimization objectives, the overall goal is always the same.

In section 2 capability evaluation of embedded systems is discussed. Section 3 explains mathematical modelling of fuzzy multi objective decision problem. Section 4 illustrates digital cell phones as a case study. Section 5 provides conclusions.

2. CAPABILITY EVALUATION

The proposed technique for capability evaluation of ESs will utilise a systems engineering approach to offer a tool to assist decision makers to quantify such qualitative judgements. It will not completely replace knowledge-based judgements but it will offer a platform for a more robust and sound system analysis, while it uses expert system criteria. It may be argued that the best way to measure capability is to study the degree of success of delivering final result; true. In addition to constituent elements of a system, capability evaluation technique (CET) will consider the ability to deliver the final outcome as a feature. Measurement factors may vary due to the nature of the system but a generic algorithm will be introduced that can be flexible enough to accommodate the diversity of systems. A study is presented to illustrate the potential of the proposed approach, while the novelty of proposed evaluation technique can be based upon methodical and simple criterion to systems analysis from different perspectives.

2.1 Problem Definition

For modelling simplification, this paper deals with the minimum requirements to determine the system capability among different agents that can be defined by equation 1.

$$SC_i = f(x_i^j) \qquad (1)$$

Where: SC_i : system capability for *ith* ES and x_i^j : *jth* element of the *ith* ES.

In order to quantify qualitative elements crisp and fuzzy variables can be assigned. With regards to establish a fuzzy decision-making process, it is necessary to fuzzyfy the quantifiable elements. This can be achieved by defining the suitable membership functions, in which these functions should consider the properties and behaviour of respected variables. In the following section, a background to fuzzy sets is discussed.

2.1.1 *Methodology*

The proposed technique for evaluation of systems' capability and comparison will include Fuzzy Sets Theory (FST) and Analytic Hierarchy Process (AHP) procedures. CET being designed as a transparent strategic management decision support system adopts:

- FST to conform to mainly qualitative nature of decisions factors.
- AHP for its special structure of intuitive way of problem solving and its novelty in handling Multiple Criteria Decision Making (MCDM) procedures.

2.1.2 *Fuzzy sets*

According to fuzzy set theory, each object *x* in a fuzzy set X is given a membership value using a membership function denoted by $\mu(x)$ which corresponds to the characteristic function of the crisp set where the values range between zero and one [16].

2.1.3 *Membership function*

Membership functions can be mathematically described as linear or non-linear functions [17]. A well-behaved membership function needs to be assigned for each fuzzyfied element. In most cases, linear membership functions are sufficient to explain the behaviour of the related value of elements. In cases where a linear membership function cannot satisfy the functional behaviour of the elements, a non-linear membership function is required.

2.1.4 *Fuzzy Multi Objective Decision*

Fuzzy Multi Objective Decision (FMOD) can be mathematically simulated and analysed using fuzzy rules. FMOD can be defined as a combination of Fuzzy Sets, levels of importance of decision variables, and unequal importance levels of objectives and constraints. The proposed method utilises FMOD techniques to optimise an objective function with respect to constraints.

3. MATHEMATICAL MODELING

A fuzzy decision problem, $D(x)$, can be defined as a set of N_o objectives and N_c constraints with the intent to select the best alternative from a set of X possible alternatives. The level of satisfaction by x for given criteria can be described as $\mu_i(x) \in [0,1]$ where it can be represented by a membership function, in which the higher value of a membership implies a greater satisfaction as it is shown in Figure 1.

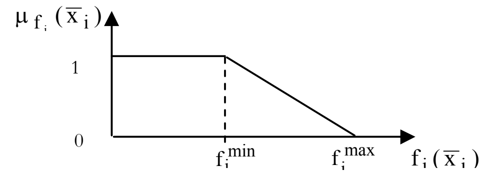

Figure 1. A Typical Membership Function

In order to determine the level to which x satisfies all criteria denoted by $D(x)$, the following statements could be made:

1. The fuzzy objective O is a fuzzy set on X characterised by its membership function:

$$\mu_O(x) : X \rightarrow [0,1] \quad (2)$$

2. The fuzzy constraint C is a fuzzy set on X characterised by its membership function:

$$\mu_C(x) : X \rightarrow [0,1] \quad (3)$$

3. The fuzzy decision D, must be satisfied by a combination of fuzzy objectives and fuzzy constraints.

The following section will discuss how equal or unequal levels of importance of goals and constraints can be applied to the proposed FMOD [18,19].

3.1 Goals and Constraints With Equal Importance

If the goals and constraints are of equal importance, x is desired where mathematical relationships (4) or (5) are satisfied:

$$\begin{cases} O_1(x)\ \&\ O_2(x)\ \&\ O_3(x)\ \&\ ....O_{N_O}(x) \\ \qquad and \\ C_1(x)\ \&\ C_2(x)\ \&\ C_3(x)\ \&\ ....C_{N_C}(x) \end{cases} \quad (4)$$

$$D(x) = O_1(x) \cap .. \cap O_{N_O}(x) \cap C_1(x) \cap .. \cap C_{N_C}(x) \quad (5)$$

Where:

$N_O(x)$: Number of objectives.

$N_C(x)$: Number of constraints.

$O_i(x)$: Fuzzy value of the *ith* objective for alternative *x*.

$C_i(x)$: Fuzzy value associated with satisfaction of the *ith* constraints by alternative *x*.

The fuzzy decision in this case is characterised by its membership function:

$$\mu_D(x) = \min\{\mu_O(x) \quad , \quad \mu_C(x)\} \qquad (6)$$

The best alternative x_{opt} can be determined by:

$$D(x_{opt}) = \max_{x \in X} (D(x)) \qquad (7)$$

Where x_{opt} satisfies:

$$\max_{x \in X} \mu_D(x) = \max_{x \in X} (\min \{\mu_O(x) \quad , \quad \mu_C(x)\}) \qquad (8)$$

$$= \max_{x \in X} (\min \begin{Bmatrix} \mu_{O_1}(x),..., \mu_{O_{N_o}}(x), \\ \mu_{C_1}(x),...., \mu_{c_{Nc}}(x) \end{Bmatrix})$$

3.2 Goals and Constraints With Unequal Importance

In case, where objective and constraints are of unequal importance it should be ensured that alternatives with higher levels of importance and consequently higher memberships are more likely to be selected. The positive impact of the levels of importance, w_i, on fuzzy set memberships is applied through the proposed criterion. It can be realized by associating higher values of w_i to objective and constraints. For example, the more important alternative the higher the value associated with it. FMOD set D(x) can be represented as equation 9, where $O^w(x)$ and $C^w(x)$ are weighted objectives and constraints sets. N is the total number of objectives and constraints and K is the number of alternatives.

$$D(x) = O^w(x) \cap C^w(x) \qquad (9)$$

Where, $w = [w_1, w_2 \ldots w_i \ldots w_N]$ and $X = [x_1, x_2 \ldots, x_K]$

$$D(x) = \min\{O^w(x), C^w(x)\} = \min\{O_1^{w_1}(x), \ldots, O_i^{w_i}(x), C_{i+1}^{w_{i+1}}(x), \ldots, C_N^{w_N}(x)\} \qquad (10)$$

Where x_{opt} should satisfy:

$$\max_{x \in X} \mu_D^W(x) = \max_{x \in X}(\min\{\mu_o^W(x), \mu_c^W(x)\}) \qquad (11)$$

This can be expressed as:

$$x_{opt} = \arg\left\{\max_{x \in X} \mu_D^W(x)\right\} \qquad (12)$$

$$x_{opt} = \text{org}\{\max_{x \in X}(\min\{\mu_{o_i}^{W_i}(x), \mu_{c_j}^{W_{N_o+j}}(x)\})\} \qquad (13)$$

$$i = 1...N_o \quad , \quad j = 1...N_c \; , \; N_o + N_c = N$$

3.3 Calculation of Exponential Weighing Values Using AHP

Analytical Hierarchy Process (AHP) [20] is a method used to support complex decision-making process by converting qualitative values to numerical values. AHP's main concept of priority can be defined as the *level of strength* of one alternative relative to another. This method assists a decision-maker to build a positive reciprocal matrix of pair-wise comparison of alternatives for each criterion. A vector of priority can be computed from the eigenvector of each matrix. The sum of all vectors of priorities forms a matrix of alternative evaluation. The final vector of priorities can be calculated by multiplying the criteria weighted vector by the matrix of alternative evaluation. The best alternative has the higher priority value. CET algorithm evaluates the relative importance of the decision variables using a pair-wise comparison matrix. The relative importance of each objective or constraints can be obtained using paired comparison of the elements taken two at a time. This method can be used to obtain the exponential weighing values that properly reflect the relative importance of the objective criteria and constraints concerning a decision problem. For the purpose of decision-making under variable importance, the paired comparison matrix P with the following properties is performed:

- A square matrix of order equal to the sum of the number of objectives and the number of constraints.
- The diagonal elements are 1.
- $P_{ij} = \dfrac{1}{P_{ji}}$
- The off-diagonal elements are specified by looking at the table of importance scale. For example, if object i is less important than object j then $P_{ji} = 3$, while if it is absolutely more important, then $P_{ji} = 9$, and so on.

To compare a set of N objects in pairs according to their relative weights, the pair-wise comparison matrix can be expressed as:

(10)

$$P = [p_{ij}] = \left[\frac{w_i}{w_j} \quad i = 1,2,...N \quad j = 1,2,...N\right] \qquad (15)$$

(11)

Where $\frac{w_i}{w_j}$ refers to the *ijth* entry of *P* which indicates how element i is compared to element j. In order to find the vector of weights $W = [w_1 \quad w_2 \quad \ldots\ldots w_N]^T$, we multiply matrix *P* by the vector *W* to get:

(12)

(13)

$$PW = \left[\frac{w_i}{w_j}\right][w_i] = \left[\sum_{i=1}^{N} w_i\right] = N[w_i] \qquad (16)$$

$$\therefore \; PW = NW \;\; \& \;\; (P - NI) = 0$$

In the above calculations if P is consistent, all eigenvalues are zero except a nonzero eigenvalue referred to λ_{max} which is equal to N (the number of objects). The estimated weights can be found by normalizing the eigenvector corresponding to the largest eigenvalue [20,21]. In the case where objectives and constraints have unequal importance, it should be ensured that alternatives with more importance are more likely to have higher impact.

4. CASE STUDY: DIGITAL CELL PHONES

As a case study to show the application and performance of the proposed approach, we are analyzing digital cell phones (a sample of ESs) with the above methodology in this section.

Here ten characteristics of Cell phones as parameters for capability evaluation of these systems are considered. These characteristics are price, facilities, storage capacity, processor speed, volume, weight, hardware reliability, software reliability, talk time and standby time. All data are extracted from the features of real cell phones made by different famous companies.

4.1 Fuzzyfication of Alternatives

A typical membership function for cell phone price is depicted in Figure 2. The degree of membership is fairly steady up to $200, but it decreases after this point to a very little value as the price is more than $900.

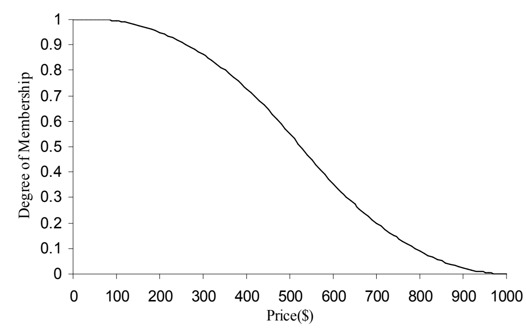

Figure 2- Membership of Cell Phone Price

Figure 3 shows membership function for the percentage of facility. This percentage shows the amount of utilities that we have in a specific cell phone model. The degree of membership is increasing as the percentage of facilities is increasing.

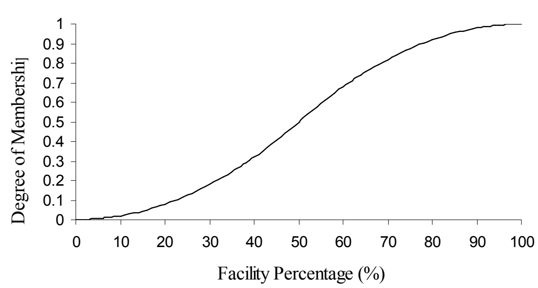

Figure 3- Membership of Facility

The membership function for storage capacity is shown in Figure 4. The degree of membership is raised linearly up to 256 MB, where reaches to 1 as ideal value for those cell phones with equal or higher amount of storage.

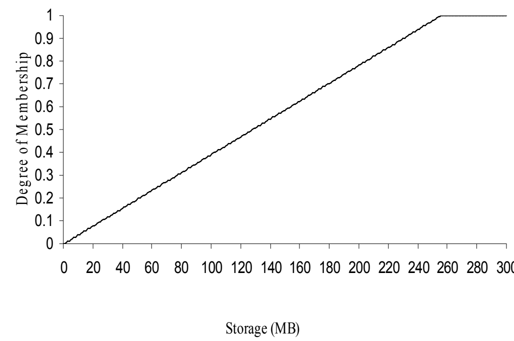

Figure 4- Membership of Storage Capacity

Another factor which is determined to evaluate the performance of cell phones is their processing speed. Membership function for this parameter would be as Figure 5. As it is shown in this figure the degree of membership tends to increase as the processing speed is increased. It is increasing sharply from 200 Mega Floating Point Operation per Second (Mflops) to 500 Mflops.

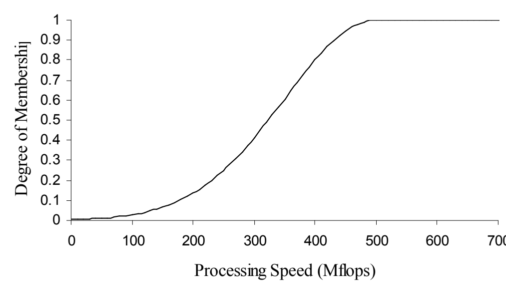

Figure 5- Membership of Cell phone Processor Speed

Two other parameters are volume and weight of cell phones. Volume and weight membership functions are depicted in Figure 6 and Figure 7 respectively. As it is shown, the degree of membership tends to decrease as volume or weight is increased.

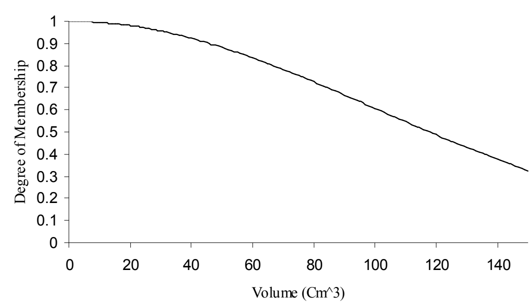

Figure 6- Membership of Cell Phone Volume

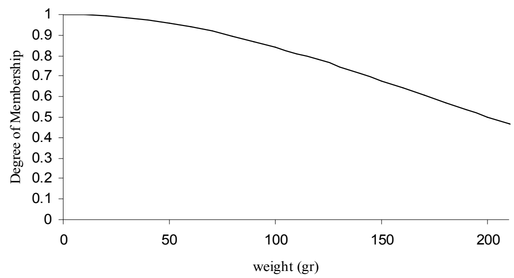

Figure 7- Membership of Cell Phone Weighting

In this regards, the cell phone size membership (μ_{Size}) is determined as the mean value of volume (μ_{Volume}) and weight (μ_{weight}) memberships, where equation 11 represents this membership:

$$\mu_{Size} = \frac{1}{2}\left(\mu_{Volume} + \mu_{Weight}\right)$$

The other features are hardware and software reliabilities. The cell phone reliability (μ_R) membership function is the average of these two memberships: hardware (μ_{HR}) and software (μ_{SR}) reliability memberships. These quantities can be determined by the Figure 8 and Figure 9 respectively. Our concerns about hardware reliability are noise protection, reception and transmission strength and protection against physical or environment impacts. The average of these factors is considered as hardware reliability percentage.

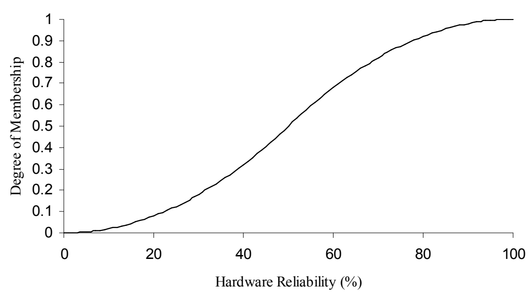

Figure 8- Membership of Cell Phone Hardware Reliability

Software reliability can be considered as number of errors per one thousand lines of code. This value is steady up to 3, but more than this value the membership function is monotonically decreasing to zero when 10 errors per one thousand lines of code occurs.

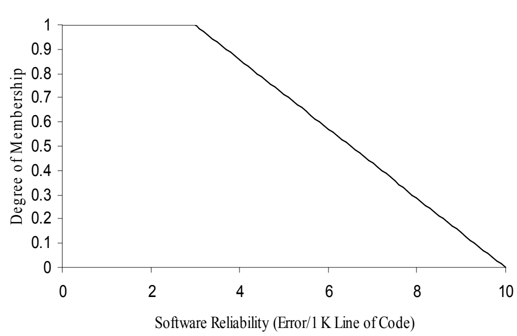

Figure 9- Membership of Cell Phone Software Reliability

The cell phone reliability can be calculated as follows:

$$\mu_R = \frac{1}{2}\left(\mu_{HR} + \mu_{SR}\right)$$

Cell phone standby and talk time are two major issues that can be considered in power management membership (μ_{PM}). In this regard the talk time is more important than standby time where the importance of talk time membership (μ_{TT}) is considered two times of standby time membership (μ_{ST}). Under this conditions the membership degree of power management can be calculated as equation 14:

$$\mu_{PM} = \frac{1}{3}\left(2\mu_{TT} + \mu_{ST}\right)$$

The talk time and standby time membership functions are specified in Figure 10 and Figure 11 respectively.

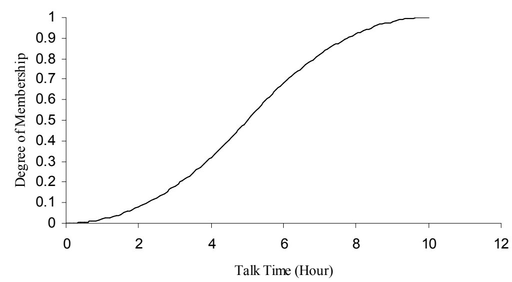

Figure 10- Membership of Cell Phone Talk Time

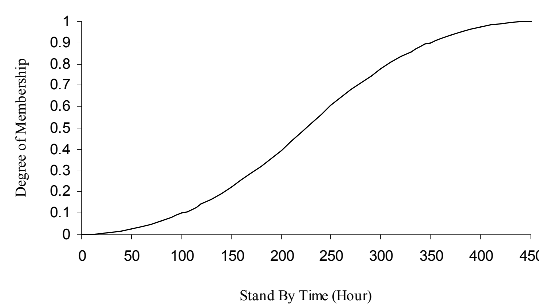

Figure 11- Membership of Cell Phone Standby Time

4.2 The Cell Phones Capability Assessment

Table 1 shows five different sample models of cell phones and ten key assessment criteria for the capability evaluation of these models. These factors are: Price, facility, storage, speed, size which is included volume and weight, Reliability (hardware and software) as well as power management that has two parameters; talk time and standby time. The sources of information are real data which can be found in date sheets of famous cell phone products.

The membership value of each criterion based on the membership function and equation that are defined in the previous section is calculated and is shown in Table.2.

A pair wise comparison matrix based on equation 15 is defined in accordance with the majority of users' idea to select the cell phone model. The relationship between different parameters is described as:

$$
\begin{array}{c} \\ p= \end{array}
\begin{array}{ccccccc|l}
\text{Price} & \text{Facility} & \text{Reliability} & \text{Power} & \text{Size} & \text{Storage} & \text{Speed} & \\
1 & 2 & 2 & 4 & 5 & 7 & 9 & \text{Price} \\
1/2 & 1 & 1 & 2 & 3 & 5 & 7 & \text{Facility} \\
1/2 & 1 & 1 & 2 & 3 & 5 & 7 & \text{Reliabilit} \\
1/4 & 1/2 & 1/2 & 1 & 2 & 4 & 5 & \text{Power} \\
1/5 & 1/3 & 1/3 & 1/2 & 1 & 2 & 4 & \text{Size} \\
1/7 & 1/5 & 1/5 & 1/4 & 1/2 & 1 & 2 & \text{Storage} \\
1/9 & 1/7 & 1/7 & 1/5 & 1/4 & 1/2 & 1 & \text{Speed}
\end{array}
$$

Table 1-Capability Factor and Their Corresponding Values for Sample Cell Phone Models

Cell Phone Model	μ_{Price}	$\mu_{Facility}$	$\mu_{Storage}$	μ_{Speed}	μ_{Size}	$\mu_{Reliability}$	$\mu_{Power\ Management}$
A	0.3	1	0.96	0.62	0.39	0.5	1
B	0.83	0.98	0.99	0.75	0.69	0.16	0.25
C	0.96	0.92	0.85	0.46	0.86	0.028	0.028
D	1	0.32	0.60	0.36	0.74	0.013	0.0073
E	0.99	0.68	0.69	0.24	0.55	0.021	0.0199

Table 2-Membership Degree for Parameters of Sample Cell Phone Models

Cell Phone Model	Price	Facility	Storage	Speed($\times 10^7$)	Size		Reliability		Power Management	
					volume	weight	Hardware	Software	Talk	Standby
A	631.51	100	128	5	150	210	80	2	5	330
B	325.48	90	42	2.5	102	116	90	2	6	350
C	174.72	80	7.8	1	54	91	90	5	3.5	348
D	48.82	40	4	0.3	98	94	80	8	3.5	250
E	120.43	60	6	0.8	151	122	70	6	3	195

Thus the maximum eigenvalue is $\lambda_{max} = 7.11$ that is approximately near to the number of objectives i.e. 7. Thus, the weighting vector "W" can be obtained as:

$W=E_n= [0.74 \;\; 0.42 \;\; 0.42 \;\; 0.25 \;\; 0.15 \;\; 0.085 \;\; 0.054]^T$

By using equation 10 the decision will be based on following function:

$$D(x) = \min\{O^w(x), C^w(x)\} =$$

$$
\min\left\{\begin{array}{l}
(A,0.40),(B,0.87),(C,0.97),(D,1.00),(E,0.99) \\
(A,1.00),(B,0.99),(C,0.96),(D,0.62),(E,0.85) \\
(A,0.98),(B,0.99),(C,0.93),(D,0.80),(E,0.86) \\
(A,0.88),(B,0.93),(C,0.82),(D,0.77),(E,0.70) \\
(A,0.86),(B,0.94),(C,0.98),(D,0.95),(E,0.91) \\
(A,0.94),(B,0.85),(C,0.74),(D,0.69),(E,0.72) \\
(A,1.00),(B,0.93),(C,0.82),(D,0.76),(E,0.80)
\end{array}\right\}
\begin{array}{l}
\text{Price} \\ \text{Facility} \\ \text{Reliability} \\ \text{Power} \\ \text{Size} \\ \text{Storage} \\ \text{Speed}
\end{array}
$$

Where,

D(x)={(A,0.40),(B,0.85),(C,0.74), (D,0.62),(E,0.70)}

Based on equation 13, the maximum of these minimums is belong to B, so the best offer is that of cell phone model "B" which has the highest membership degree among the others. If we flash back to Table.1, it can be seen that cell phone "B" has a middle range price, while we can get high facilities with sufficient memory, relatively high speed and reliability, good power management as well as acceptable size.

5. CONCLUSION

Evaluation and comparison of systems capabilities seems to be a desirable measurement tool for systems engineering and analysis. The achieved objective was to introduce a quantitative approach to address a qualitative matter. Application of a multi-objective optimisation via a heuristic technique is addressed in this paper. CET algorithm adopts fuzzy optimisation technique to evaluate and compare embedded systems (ECSs) capabilities. This paper utilises the advantages of fuzzy optimisation and AHP to address multi-objective optimisation with regard to equal/un-equal levels of importance. Relative priorities are assigned to the objectives/constraints using AHP. The digital cell phones as a case study shows the application of the proposed approach. In future other techniques such as insertion technique can be added to CET in order to reduce computational efforts. Risk factors can also be introduced as complementary parameters to improve decision-making criterion.

5. ACKNOWLEDGEMENT

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