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Complexity Index for Decision Making Method

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ABSTRACT

Complexity has been discussed in decision making, computational, task complexity, activity network, supply chain, imaging, project management and mechanical. This paper reviews the definition of complexity and the preliminary-related definitions of complexity index in decision making. It proposes a complexity index for decision making, its properties, and implementation.

Keywords: Complexity index, decision making method

INTRODUCTION

Complexity determines whether the procedure or method surpasses others in term of performance. Though complexity has been investigated measuring it in decision making methods with multi granular term sets is difficult. (Francisco Herrera, Herrera-viedma, Martinez, Mata, & Pedro, 2004; F. Herrera, Alonso, Chiclana, & Herrera-Viedma, 2009; Massanet, Riera, Torrens, & Herrera-Viedma, 2014) have addressed complexity in decision making. In this paper, a brief survey of complexity is presented and followed with a complexity index for decision making based on three factors; information, function and step. The discussion on its implementation follows and ends with the conclusion.

COMPLEXITY IN GENERAL

Decision Making

Complexity in decision making method has been addressed in Francisco Herrera et al., 2004 They claimed that decision making methods that involve multi-granular linguistic term sets are highly complex and tried to solve them by transforming each fuzzy set into a linguistic 2-tuple using a central value

computed by means of a weighted average, where the weights are the membership degrees of the fuzzy set. In F. Herrera et al., 2009 the question that has been raised is whether it is possible to minimize the computation efforts in order to obtain the final choices using multi-granular linguistic term sets. Massanet et al., 2014 proposed a less complex multi-granular linguistic term set method by transforming it to discrete fuzzy numbers to reduce the complexity of the method in terms of the linguistic representation and the aggregation.

Computational

In computational Hartmanis & Stearns, 1965 examined a scheme of classifying sequences according to how hard they are to compute. According to them, their scheme can be generalized to classify numbers, functions, or recognition problems according to their computational complexity. A sequence of the computational complexity is measured by how fast a multi-tape Turing machine can print out the terms of the sequence.

Task Complexity

Task complecity has been classified as the determinants of the performance of method. Wood, 1986 divided the task complexity into three types. The first one is component complexity which direct function of the number of distinct acts that needs to be executed in performance of the task. The general formula which captures the aggregated effects of component complexity at each levels are presented as follows:

$$TC_1 = \sum_{j=0}^{j=p} \sum_{i=1}^{i=n} W_{ij} \tag{1}$$

where n is the number of distinct acts of subtask j, W_{ij} is the number of information cues to be processed in the performance of the ith act of the jth subtask and p is number of subtask in the task.

The second type of complexity is the coordinative complexity where it is defined as the nature of relationships between task inputs and task product (Oeser & O'Brien, 1967). At this level, timing, frequency, intensity and location requirements for performances of required acts will be included. Complexity is represented by:

$$TC_2 = \sum_{i=1}^{i=n} r_i \tag{2}$$

where n is number of acts in the task and r_i is number of precedence relations between the ith act and all other acts in the tasks.

Dynamic complexity is the third type of complexity. It is due to changes in the states that have an effect on the relationship between task inputs and products. Knowledge about changes in the component and coordinative complexities of a task over time is required. The formula is as follows:

$$TC_3 = \sum_{f=1}^{f=m} \left| TC_{1(f+1)} - TC_{1(f)} \right| + \left| TC_{2(f+1)} - TC_{2(f)} \right| \tag{3}$$

where TC_1 is component complexity measured in standardized units, TC_2 is coordinate complexity measured in standardized units, f is the number of time periods over which the task is measured and TC_3 is dynamic complexity.

The overall complexity should be weighted such that a unit of TC_3 contributes more than a unit of TC_2, which, in turn contributes more than a unit in TC_1.

$$TC_t = \alpha TC_1 + \beta TC_2 + \gamma TC_3 \tag{4}$$

where $\alpha > \beta > \gamma$.

Activity Network

In activity network De Reyck & Herroelen, 1996 defined complexity index as the minimum number of node reductions necessary to transform a general activity network to a series-parallel network in activity network.

Supply Chain

Based on Efstathiou, Calinescu, & Blackburn, 2002 supply chain complexity can be divided into three types. Structural complexity is the first type and defined as the expected amount of information needed to describe the schedule state of the facility. The probability of each resource being in each of its allowed states need to be obtained as follows

$$S = -\sum_{j=1}^{M} \sum_{i=1}^{S_j} P_{ij} \, log_2 P_{ij} \tag{5}$$

where M is the number of facility (such as machines or work centres), P_{ij} is the probability of resource j being in state i and S_j is for resource j there are $S_{j\,possible}$ states.

Dynamic complexity is the second type of complexity that can be obtained using an expression similar to that for structural complexity. The formula is as follows:

$$D = -\sum_{j=1}^{M} \sum_{i=1}^{S_j} p'_{ij} \, log_2 p'_{ij} \tag{6}$$

where p' is a probability estimates based on observed states rather than scheduled states.

The final type of complexity in supply chain is the decision-making complexity. The definition can be viewed in two perspectives. The first one is from a production process perspective where a systematic characteristic which integrates fundamental dimensions of the manufacturing world, including size, variety, concurrency, objectives, information, cost and value. The second perspective is from an information-theoretic perspective. It is defined as a measure of the volume and structure of the information that needs to be taken into account when creating the schedule for a given period or equivalently, as the difficulty embedded in creating the schedule. The formula is as follows:

$$DM = -\sum_{i=1}^{m} \sum_{j=1}^{m} \sum_{k=1}^{2^r-1} \sum_{l=1}^{n} \widetilde{\pi}_{ijkl} \, log \, \widetilde{\pi}_{ijkl} \tag{7}$$

where m is total number of operations associated with a part mix, n is the number of parts to be concurrently produced in the manufacturing system, r is total number of resource associated with a given part set and $\widetilde{\pi} = \left\{ \widetilde{\pi}_{ijkl}, \forall_i = \overline{l,m}, \forall_j = \overline{l,m}, \forall_k = \overline{l,r}, \forall_l = \overline{l,n}, \right\}$ represent the normalized set of processing requirements with $\sum_{i=1}^{m} \sum_{j=1}^{m} \sum_{k=1}^{2^r-1} \sum_{l=1}^{n} \widetilde{\pi}_{ijkl} = 1$.

Imaging

In imaging, complexity is not only relevant to the stimulus spatial properties but as an emerging factor affecting the human perceiver's cognitive operations, it can also include the temporal dimensions (Cardaci, Gesù, Petrou, & Tabacchi, 2006). The formula proposed is as follows

$$G_0(\pi) = -\frac{1}{log(2)} \times \left(\pi log(\pi) + (1-\pi)log(1-\pi) \bullet [7]z\right) \tag{8}$$

$$G_1(\pi) = \frac{2\sqrt{e}}{e-1}\left(\pi e^{1-\pi} - \pi e^{\pi-1}\right) \tag{9}$$

$$G_2(\pi) = 4\pi(1-\pi) \tag{10}$$

where $\pi = \frac{1}{n}\sum_{i=1}^{n}|h_i|$ and h_i are the grey levels of the image pixels normalized is the range [0,1].

Project Management

Vidal, Marle, & Bocquet, 2011 defined complexity as the property of a project which makes it difficult to understand, foresee and keep under control its overall behaviour, even when given reasonably complete information about the project system in project management. They introduced project complexity index based on the following formula

$$CI_i = \frac{S(i)}{\max(S(i))} \rightarrow 0 \leq CI_i \leq 1 \tag{11}$$

where $S(i)$ is the priority source of alternative A_i obtained from to Analytic Hierarchy Process (AHP) calculations $(0 \leq CI_i \leq 1)$.

Mechanical

In mechanical area Little, Tuttle, Clark and Corney (1998) proposed the complexity index for quantifying the geometric complexity of a three-dimensional solid model. This measure may be compared one with another, in relation to their relative complexity using the following formula

$$FCI = C. \, D_v T \quad \text{(summation)} \tag{12}$$

where FCI is Feature Complexity Index, *T* is an alphabetic one design to indicate the types of geometry found in a body; a is planar faces, b is cylindrical faces, c is other geometry type.

COMPLEXITY INDEX FOR DECISION MAKING METHOD

In this section, a method to measure the complexity for decision making method is proposed. The contributory factor, preliminary related definitions, the proposed complexity index, properties and implementation are presented accordingly.

Contributory Factor

There are several complexity contributory factors that has been listed out by researches. Wood, 1986 listed three types of task complexity: component complexity, dynamic complexity and coordinative complexity. The component complexity is a direct function of the number of distinct acts that need to be executed in performance of the task. In activity network, Kolisch, Sprecher and Drexl (1992) stated that the number of activities (steps to be taken) is the factor that resulting in a higher complexity. In 1996, De Reyck and Herroelen (1996) mentioned that the number of node (activity) needs to be reduced in order to transform a general activity network to a series-parallel network. In developing an algorithm, Chakraborty and Choudhury (2000) stated that the execution time and minimum number of operations to compute a given function is necessary to reduce the complexity of the algorithm.

Efstathiou et al. (2002) listed three types of complexity for a supply chain. One, structural complexity, defined as the expected amount of information needed to describe the schedule state of the facility. Two, dynamic complexity obtained using an expression similar to structural complexity. Three, is defined as a systematic characteristic which integrates fundamental dimensions of the manufacturing world, including size, variety, concurrency, objectives, information, cost and value. Meanwhile, Fortnow and Homer (2003), claimed that time can be measured by the number of steps as a function of the length of the input. On the other hand, Guo and Nilsson (2004) defined the algorithm complexity as the average number of search sub-lattices per symbol vector. The number of computational steps required in order to achieve a pre-determined fixed probability of success is defined to be the complexity of an algorithm (Shenvi, Brown, & Whaley, 2003).

The number of evaluation on line per symbol vector is defined by (Guo & Nilsson, 2004) as the definition of algorithm complexity. Jongho, Park, Lee and Song (2011) chose minimum integer in order to keep the computational complexity as low. Meanwhile, Herrera et al. (2009) raised a question that "Is it possible to minimize the computation efforts required to obtain the final choices using multi-granular linguistic information?" (p.354). In project management, Vidal et al. (2011) defined project complexity as the property of a project. Table 1 summarized the complexity contributory factors.

Table 1

The Summary of Complexity Contributory Factors

References	Factors		
	Information	**Function**	**Step**
Hartmanis & Stearns, 1965	√	√	
Wood, 1986		√	
Kolisch et al., 1992			√
De Reyck & Herroelen, 1996			√
Chakraborty & Choudhury, 2000		√	√
Efstathiou et al., 2002	√	√	
Shenvi et al., 2003			√
Fortnow & Homer, 2003			√
Guo & Nilsson, 2004			√
Jongho et al., 2011		√	
F. Herrera et al., 2009			√
Vidal et al., 2011		√	

Preliminary Related Definitions

This section listed the related definition and remarks that will be utilized in the proposed complexity index for decision making method.

Definition 1. The complexity index in decision making is the summation of quantity of information and also step times by function of a proposed method.

To calculate the complexity of a method, the following elements are taken into consideration: unification, aggregation and evaluation.

The Proposed Complexity Index

The proposed formula is based on the three contributory factors that are variable, function and step. Based on Wood (1986), the complexity index can be defined as a summation of the three types of complexity (Eqn. 1-4) and the proposed complexity index will be based on the same approach.

According to Efstathiou et al. (2002), one of the factors contributing to complexity in the supply chain is the expected amount of information needed to describe the schedule state of the facility. In decision making, the amount of information is the quantity of the input that can be translated into the number of variables involved. The formula, definition and properties of quantity of information are as follows.

$$\text{variable} = \sum v \ , \quad 0 < v < \infty \tag{13}$$

where v is considered as the number of information.

Definition 2. The quantity of information, v is the number of variables used in a method.

Assumptions

1. The quantity of information is in between zero to infinity ($0 < v < \infty$)
2. Since the evaluation in decision making maybe in the form of fuzzy numbers, the number of variables will depend on the chosen type of fuzzy numbers. For example, a triangular fuzzy number (*a*, *b*, *c*) is considered to have three information meanwhile a trapezoidal fuzzy number (*a*, *b*, *c*, *d*) has four information.
3. For each section, if the information is redundant from the previous section, it counts as a number of information in the new section. However, if the same information is used repeatedly in the same section, it is considered as only one information.

Several researchers (Hartmanis & Stearns, 1965), (Wood, 1986), (Chakraborty & Choudhury, 2000), (Efstathiou et al., 2002), (Jongho et al., 2011) and (Vidal et al., 2011) claimed that the function used in decision making method is one of the contributory factors for complexity. Function in decision making method is translated into quantity of formula. However, an argument of simply counting the number of operations is not enough is valid if the operation is different making it necessary to give an index to the number of operations.

In solving mathematical formulation, it is frequent to question where to begin (in terms of the operations of arithmetics). BODMAS is an acronym creates to help memorize the ordering of the operations of arithmetics. According to Gamble, 2011 BODMAS stands for Brackets, Orders, Division, Multiplication, Addition, Subtraction. There are also other acronyms exists such as;

 i. BIMDAS (Brackets, Indices, Multiplication, Division, Addition, Subtraction),
 ii. BEDMAS (Brackets, Exponents, Division, Multiplication, Addition, Subtraction)
 iii. PODMAS (Parentheses, Orders, Division, Multiplication, Addition, Substraction)
 iv. *Please Excuse My Dear Aunt Sally* (Parentheses, Exponents, Multiplication, Division, Addition, Substraction),

Based on (Holt, 2015), there are three levels in BODMAS. The three levels are as follows; Brackets (First Level); Order, Divide and Multiply (Second Level); Addition and Subtract (Third Level)

As mentioned earlier, indices and exponent (taken from other acronyms) are synonymous for orders which implies to be in the second level. In addition, Gamble (2011) mentioned that for each level, it has the same precedence. Such as addition and multiplication are on the same level, thus it has the same precedence which implies the same weightage (index). The other level (higher level) includes order, indices, exponents, division and multiplication are on the other level.

Since the third level (addition and subtraction) is the lowest level, thus for the purpose of the index of formula operation, the index is one. The second level that includes order, indices, exponents, division and multiplication are index two. For the exponent with power more than two, the index depends on the power since it may result in longer operation due to it embedded the multiplication process in it. For example; $a^3 = a \times a \times a$, this implies multiplication operation

is involve for the three elements. Thus, the index is three. For other mathematical operation such as absolute and maximum and minimum, the index is one since it involves a simple mathematical operation only. For each of the function involves, the operation is index proposed according to Table 2.

Table 2
The Index of Formula Operation

	Operation	Index
1	Addition	$1w$
2	Subtraction	$1w$
3	Multiplication	$2w$
4	Division	$2w$
5	Exponent; Power of less than 1	$2w$
	Exponent; Power of 2	$2w$
	Exponent; Power of 3	$3w$
	Exponent; Power of n	nw
6	Trigonometric, logarithmic	$2w$
7	Absolute	1
8	Min, Max	1

where w is the number of element of in the type of number used. For real/crisp number, w is considered as 1, a triangular fuzzy number has three elements (a, b, c), thus, w is 3 and for trapezoidal fuzzy number, it has four elements (a, b, c, d), where w is 4.

Example

Example of calculation of index of operation is as follows:

Let $x = \dfrac{f}{\sqrt{a+b}}$ be a function used in method where f is a triangular fuzzy number (p, q, r) and a, b are scalars. The ' $a+b$ ' addition has index of 1. ' $\sqrt{a+b}$ ' square root has index of 2. Since

f consists of three values (p, q, r) and each of the value undergo the division process, thus there are six operations involved. Thus, the total index for this operation is 1+2+6= 9.

According to Chakraborty and Choudhury (2000), developing the least asymptotic execution time algorithm is important for a method to be effective. The time can be measured by the number of steps as a function of the length of the input (Fortnow & Homer, 2003). For Shenvi et al. (2003), the number of computational steps required in order to achieve a pre-determined fixed probability of success is defined as the complexity of an algorithm. On the other hand, Guo and Nilsson (2004) defined the algorithm complexity as the average number of search sub-lattices. Meanwhile, Jongho et al. (2011) chose minimum integer in order to keep the computational complexity as low. In addition, Herrera et al. (2009) raise the question: "Is it possible to minimize the computation efforts required to obtain the final choices using

multi-granular linguistic information?" (p.354). Thus, the quantity of step is considered from both computational and non-computational part.

In decision making, the usage of the function relates to the number of steps. Hence for each step, the index of function is embedded together in the step. If the step does not require any formula, it is considered as one. The formula, definition and properties of quantity of function and steps are as follows.

$$\text{function and step} = \sum fs \ , \ 0 < f < \infty \ , \ 0 < s < \infty \qquad (14)$$

where f is the number of function and s is the number of step.

Assumptions

1. The quantity of function is in between zero to infinity ($0 < f < \infty$)
2. The quantity of step is in between zero to infinity ($0 < s < \infty$)
3. The index of operation is counted as per applied in each step.
4. If the step does not involve any formula, it is considered as 1.

The summation of the contributory factors is divided by 1000 for capping purposes so that the output index has a reasonable and acceptable value. Any calculated value of more than 1000 may be considered as highly complex which is due to partially or fully by the contributing factors. Hence, the overall complexity index, CI is defined as the summation of quantity of information, v, function, f and step, s and is given as

$$CI = \frac{\sum v + \sum fs}{1000}. \qquad (15)$$

The result of the complexity index may be categorized as; $(0, 0.25)$ = low complexity, $[0.25, 0.5)$ = marginal complexity, $[0.5, 1)$ = medium complexity and $[1, \infty)$ = high complexity.

Remark

1. The measurement of the complexity index is considered the worst-case scenario.
2. The complexity index of any two methods can only be compared when the basis is equal, for instance, the number of alternatives, criteria and sub-criteria under consideration are equal.

Properties

The proposed complexity index has the following properties;
1. $CI \neq 0$ since v, f and $s > 0$

2. $\sum fs + \sum v = \sum v + \sum fs$

3. $\sum fs = \sum sf$

4. $\sum v + \sum fs \geq 2$ since v, f and $s > 0$, the min value for v, f and s is 1. Thus;

$$CI = \sum v + \sum fs = 1 + 1(1) = 2$$

5. $CI \in [0.002, \infty)$ since in relation to properties no. 4, the minimum value of $\sum v + \sum fs$ is 2.

Illustrative Examples

In order to implement the complexity index, the index will be implemented to crisp model of Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and Analytic Hierarchy Process (AHP) first. Then the complexity index will be implemented to decision making method that used fuzzy numbers.

This research will implement Shyur (2006), and Ding and Kamaruddin (2014) for TOPSIS and for AHP (Chaghooshi, Janatifar, & Dehghan, 2014; Escobar & Moreno-Jimenez, 2007). For decision making method based on fuzzy numbers it will implement the index to single decision maker by Tseng and Klein (1989). For homogeneous group decision making method, this research will implement the method of Hanif et al. (2013) and Chen and Chen (2009). As for heterogeneous group decision making is used (Herrera, Herrera-Viedma, & Martínez, 2000; Jiang, Fan, & Ma, 2008; Massanet et al., 2014). The results are illustrated in Table 3 and 4 respectively.

Table 3

Single Versus Group Decision Making Crisp Topsis Method

Method	DM	Alt	Crt	CI
Shyur, 2006	1	3	3	0.291
Ding & Kamaruddin, 2014	3	3	3	0.362

DM-decision maker, Atl-alternatives, Crt-criteria.

Table 4

Single Versus Group Decision Making Crisp Ahp Method

Method	DM	Alt	Crt	CI
Chaghooshi et al., 2014	1	3	3	0.541
Escobar & Moreno-Jimenez, 2007	3	3	3	1.316

DM-decision maker, Atl-alternatives and Crt-criteria.

The method of Shyur, 2006 has lower complexity index compared with Ding and Kamaruddin (2014) because it is a single decision maker method while that of Ding and Kamaruddin (2014) is a group decision making method of TOPSIS. With similar argument, for AHP Chaghooshi et al. (2014) has lower complexity index compared with Escobar adandoreno-Jimenez (2007). In general, TOPSIS has lower complexity index (smaller range) compare to AHP (bigger range). Table 5 shows the result of complexity index for single versus group decision making fuzzy number method.

Table 5
Single Versus Group Decision Making Fuzzy Number Method

Method	DM	Alt	Crt	CI
(Tseng & Klein, 1989)	Single	3	1	0.111
(Hanif et al., 2013)	GHM	3	3	0.339
(Chen & Chen, 2009)	GHM	3	3	0.245
(F. Herrera et al., 2000)	GHT	3	1	0.861
(Jiang et al., 2008)	GHT	3	1	0.212
(Massanet et al., 2014)	GHT	3	1	0.557

DM - decision maker, Atl-alternatives, Crt-criteria, GHM-group homogeneous method, GHT-group heterogeneous method.

From Table 5, the method of Tseng and Klein (1989) has the lowest complexity index as it is a single decision making method. As for homogeneous group decision making (Hanif et al., 2013) has complexity index of 0.339. Meanwhile, it has 0.245 for complexity index (Chen & Chen, 2009). For heterogeneous group decision making, (Herrera et al., 2000) 0.861 complexity index. Herrera et al. (2000) proposed among the earliest method of heterogeneous group decision making. It is also a heterogeneous group decision making but with a low complexity index of 0.212, according to Jiang et al. (2008). Their method is based on fuzzy set and goal programming methods and claimed to have lower complexity due to this. According to Massanet et al. (2014), this is based on heterogeneous group decision making with a 0.553 complexity index. Their method used discrete fuzzy number which produces a lesser complexity index.

CONCLUSION

This paper elaborates general complexity in decision making, computational, task complexity, activity network, supply chain, imaging, project management and mechanical (what? Describe). A complexity index for decision making is proposed based on three factors which are the quantity of information, v, function, f and step, s. The complexity index proposed may justify the complexity level for the decision-making method. Illustrative examples are included in this paper to describe its usefulness. Since this is the first attempt to introduce a complexity index for decision making method, more improvement needs to be made in the future.

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