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New TFN Based Method for Evaluating Quality and Reusability of Learning Objects*

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The aim of the paper is to present a new TFN (Triangular Fuzzy Numbers) based method for the expert evaluation of the quality and reusability of learning objects (LOs). This novel method consists of the consecutive application of Fuzzy numbers theory to establish the ratings (values) of the LO quality criteria, a new TFN based method to establish the weights of the LO quality criteria, and MCEQLS (Multiple Criteria Evaluation of the Learning Software) approach to create the LOs quality model and obtain the final evaluation results. Several practical examples of LOs alternatives have been practically evaluated against the proposed method. Research results have shown that the proposed TFN based method is quite objective, exact and easy to use while selecting qualitative reusable LOs alternatives in the market.

Keywords: triangular fuzzy numbers; learning objects; quality, expert evaluation; reusability; multiple criteria decision analysis

1. Introduction

The aim of the paper is to investigate, propose, and demonstrate examples of practical application of TFN (Triangular Fuzzy Numbers) based method for the expert evaluation of the quality and reusability of learning objects (LOs).

This problem is of very high practical relevance for the educational sector that needs exact, clear and easy to use models and methods of evaluating the quality and reusability of LOs in the market, both proprietary and open ones. These proper quality evaluation models and methods have to meet all the educational stakeholders' (i.e. educational institutions, policy makers, content creators / publishers, researchers) needs. The authors create comprehensive and coherent quality model for reusable LOs in EU-funded eQNet project [1].

LO is referred here as 'any digital resource that can be reused to support learning' [2]. LOs are the elements of a new type of computer-based instruction grounded in the object-oriented paradigm of computer science. Object-orientation highly values the creation of components (called 'objects') that can be reused in multiple contexts. This is the fundamental idea behind LOs: instructional designers can build small (relative to the size of an entire course) instructional components that can be reused a number of times in different learning contexts. Additionally, LOs are generally understood to be digital entities deliverable over the Internet and any number of people can access and use them simultaneously. Moreover, those who incorporate LOs can collaborate on and benefit immediately from the new versions. The idea of LOs is now a widely accepted concept for the delivery of the modularized e-learning content [3].

The various approaches to LOs attempt to meet two common objectives: (1) to reduce the overall costs of LOs, and (2) to obtain better LOs.

Both these objectives agree with the notion of LOs reusability. LOs reusability is one of the main features achieving the high LOs effectiveness and efficiency level. The need for reusability of LOs has at least three elements [3, 4]:

(1) Interoperability: LO is interoperable and can be used in different platforms.
(2) Flexibility in terms of pedagogic situations: LO can fit into a variety of pedagogic situations.
(3) Modifiability to suit a particular teacher's or student's needs: LO can be made more appropriate to a pedagogic situation by modifying it to suit a particular teacher's or student's needs.

Reusability of LOs (or their ability to 'travel well' between different contexts and education systems) is considered by the authors as a part of the overall quality of LOs. This means that any high quality LO has some reusability level (or potential to 'travel well'), but this does not mean that any reusable LO is quality one [4].

2. Research methods

2.1 MCEQLS approach

LOs should be evaluated against a number of the quality criteria [3, 4]. These criteria are often conflicting. Some LOs could be of excellent quality

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against the particular criteria, and poor—against the other ones, and vice versa. Therefore, evaluation of the LOs quality is a typical case where Multiple Criteria Decision Analysis (MCDA) methods should be applied.

MCDA is a group of problem solving methods to find consensus and compromises between conflicting goals (i.e. multiple criteria) in complex problems. MCDA is also known as multiple criteria decision aid or Multiple Criteria Decision Making (MCDM). The general goal of MCDA is to assist individual or groups of decision makers to choose the best alternative. MCDA is defined as a collection of formal approaches which seek to take into account the multiple criteria in order to help decision makers to explore different decision alternatives [5]. Quoting [6], 'there is a wide range of multiple criteria decision making problem solution techniques, varying in complexity and possible solutions. Each method has its own strength, weaknesses and possibilities to be applied'. MCDA is applied in a wide range of tasks, from planning different software development projects [7] to determine the inside climate of the premises, where people work, and to define measures to be taken to improve their environment [6].

Evaluation is a process by which people make judgements about value and worth [8]. Quality evaluation is a systematic examination of the extent to which an entity (part, product, service or organisation) is capable of meeting specified requirements. Expert evaluation is referred here as multiple criteria evaluation of learning software aimed at the selection of the best alternative based on score-ranking results [3].

In the paper, MCDA approach used by the authors is based on the experts' additive utility function (1). This function includes the weights and the ratings (values) of the quality criteria of LOs alternatives. This MCEQLS (Multiple Criteria Evaluation of the Learning Software) approach was presented for the first time in [3] and applied in [4].

$$f(X) = \sum_{i=1}^{m} a_i f_i(X) \tag{1}$$

Here f_i (X) is the rating (i.e. non-fuzzy value) of the criterion i for the each of the examined LOs alternatives X. The weights here should be 'normalised' according to the 'normalisation' requirement:

$$\sum_{i=1}^{m} a_i = 1, a_i > 0. \tag{2}$$

According to this approach, in order to evaluate the quality of LOs, we should use three consecutive stages: (a) identify LOs quality criteria (i.e. create LOs quality model), (b) identify a suitable method for evaluating the quality of LOs alternatives expressed by formula (1), and (c) apply this method by calculating the evaluating results of formula (1) by adding all the numerical ratings (values) of the quality criteria multiplied by their weights.

This method represented by the experts' additive utility function (1) is well-known in the theory of optimisation methods and is named 'scalarisation method' [4]. A possible decision here could be to transform multiple criteria task into one-criterion task obtained by adding all criteria together with their weights. It is valid from the point of view of the optimisation theory, and a special theorem exists for this case [4].

2.2 *Triangular fuzzy numbers*

Now let us focus on one of the Fuzzy methods called Triangular Fuzzy Numbers (TFN) method. According to [4], it is suitable to establish the numerical values of the LOs quality criteria.

There is scientific evidence that this method is convenient for evaluating the quality of many different kinds of software alternatives in the market. This method for evaluating the quality of learning software was used in [3, 4].

According to [9], the wide-used measurement criteria of the decision attributes quality are mainly qualitative and subjective. In this context, decisions are often expressed in the natural language, and evaluators are unable to assign exact numerical values to different criteria. Assessment can be often performed by the linguistic variables such as 'bad', 'poor', 'fair', 'good' and 'excellent' [4].

These linguistic variables allow reasoning with imprecise information, and they are commonly called fuzzy values. Integrating these different judgments to obtain a final evaluation is not evident. In order to solve this problem, [9] suggest using the fuzzy group decision making theory to obtain final assessment measures. According to [9], first, linguistic variable values should be mapped into fuzzy numbers, and, second, into non-fuzzy values.

According to [10], TFNs are a class of the fuzzy set representation. A triangular fuzzy number (TFN) is expressed by three real numbers M = (l, m, u); the parameters l, m and u, respectively, indicate the lower, the mean and the upper possible values (Fig. 1). TFNs membership functions are as follows:

$$\mu_M(x) = \begin{cases} \frac{x-l}{m-l}, & \text{if} \quad x \in [l, m], \\ \frac{x-u}{m-u}, & \text{if} \quad x \in [m, u], \\ 0, & \text{if} \quad x \notin [l, u]. \end{cases} \tag{3}$$

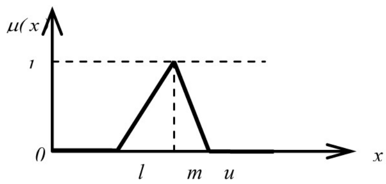

Fig. 1. TFNs (according to [10]).

According to [10], conversion of these qualitative values into TFNs (non-fuzzy values) is as follows:

Excellent	(0.700, 0.850, 1.000)
Good	(0.525, 0.675, 0.825)
Fair	(0.350, 0.500, 0.650)
Poor	(0.175, 0.325, 0.475)
Bad	(0.000, 0.150, 0.300)

Therefore, according to [4], in the case of using the average triangular fuzzy numbers, linguistic variables conversion into triangular non-fuzzy values of the evaluation criteria should be as follows:

Excellent/extremely valuable, essential	0.850
Good/very valuable	0.675
Fair/valuable	0.500
Poor/marginally valuable	0.325
Bad/not valuable	0.150

These triangular non-fuzzy values to establish the ratings (values) of LOs quality and reusability criteria should be used while applying formula (1) to obtain the final evaluation results.

2.3 Weights of the quality criteria

Let us try to use TFN based method also for establishing the proper weights of the LOs quality criteria.

If an expert evaluator establishes a weight of the criteria i in a form of a linguistic variable, we can convert it into the triangular fuzzy number m_f^i [11].

According to [11], if we have t experts we can calculate it using the experts' average (4):

$$m_j^i = \frac{1}{t}\sum_{k=1}^{t} m_k^i \tag{4}$$

If we want to normalise the weights of the quality criteria, we should apply formula (5):

$$a_i = \frac{m_j^i}{\sum_{s=1}^{m} m_f^s} \tag{5}$$

In our case, we have two experts-evaluators, i.e. the authors of the paper.

The main idea of this section is that triangular non-fuzzy values presented in Section 2.2 are also suitable to establish the weights of LOs quality and reusability criteria, and they should be also used while applying formula (1) to obtain the final evaluation results.

Now we have all the necessary data (i.e. the TFN based ratings (values) and weights) to perform practical evaluation of the LOs quality and reusability level.

3. Presentation of the results

3.1 Learning objects quality model

According to [3, 4], in order to create a proper quality model, one should apply several principles and methods to create a comprehensive and coherent criteria system.

The following principles of identification of quality criteria are relevant to all MCDA approaches: (1) value relevance; (2) understandability; (3) measurability; (4) non-redundancy; (5) judgmental independence; (6) balancing completeness and conciseness; (7) operationality; and (8) simplicity versus complexity [5].

On the other hand, according to the technological quality criteria division principle [4] (based on the international software quality standard ISO/IEC 9126-1:2001(E)), we can divide technological quality criteria into internal quality and quality in use criteria of the educational software such as LOs.

Internal quality is a descriptive characteristic that describes the quality of software independently from any particular context of its use, while quality in use is evaluative characteristic of software obtained by making a judgment based on criteria that determine the worthiness of software for a particular project.

Any LOs quality model should provide the experts (decision makers) the clear instrumentality who (i.e. what kind of experts) should analyse what kind of LOs quality criteria in order to select the best LOs suitable for their needs. Internal quality criteria should be mainly the area of interest of the software engineers, and quality in use criteria should be mostly analysed by the programmers and users taking into account the users' feedback on the usability of software [4].

The model proposed includes three groups of the quality criteria, namely, technological, pedagogical and IPR criteria. The model consists of 10 quality criteria, four of them dealing with technological quality of LOs, five—with their pedagogical quality, and one—with IPR issues.

The model fits MCDA criteria identification principles, particularly Non-redundancy, Judgmental independence, Balancing completeness and conciseness, Operationality, and Simplicity versus complexity. The model also fits the technological quality criteria division principle. While creating the model, three elements of LOs reusability (see Section 1) were also taken into account.

In their previous works [3, 4], the authors have identified suitable LOs technological quality criteria. These criteria are based on the existing models' analysis [12–14]. In the model proposed, internal quality criteria are as follows:

(1) Technological interoperability and reusability (interoperability—metadata accuracy, compliance with the main e-content import/export standards [15]; decontextualisation, LO aggregation (granularity) level, LO modularity; LO cultural and learning diversity (adaptability), LO flexibility, LO internationalisation level; LO suitability for localisation; LO accessibility (design of controls and presentation formats to accommodate disabled and mobile learners));
(2) Architecture (is LO architecture layered in order to separate data, presentation and application logics?);
(3) Robustness, technical stability (i.e. having help functions that identify common user problems and their solutions; having navigational actions that can be undone; giving quick, visible and audible responses to user actions; allowing the user to exit at any point, etc.).

Quality in use criterion is (4) Design and usability (design of visual and auditory information for enhanced learning and efficient mental processing): aesthetics; navigation; user-friendly interface; structured information; personalisation.

On the other hand, the authors have analysed a number of existing sets of LOs quality and reusability criteria for evaluating pedagogical quality of LOs [1, 12, 14]. Suitable criteria for a comprehensive and coherent model were identified as follows:

(5) Trans-national or multidisciplinary / cross-curricular topic,
(6) Interactivity, strong visual structure (animations, images and short videos are travelling best);
(7) Language independence or low language dependence (easily translatable) or multilinguality;
(8) Ease of use, intuitiveness, and
(9) Additional methodological support for teachers is not needed.

According to [3, 4], Intellectual property rights (IPR) and cost-effectiveness criterion (10) should also be considered in the model.

3.2 Example of evaluating the quality of LOs

The weight a_i of the evaluation criterion reflects the expert's opinion on the criterion's importance level in comparison with the other criteria [3].

If the quality criteria are equally important for the experts-evaluators (let us call it 'general case'), they should use the same weights (see matrix (6) below) for all criteria according to normalisation requirement (5). If the experts-evaluators consider all criteria 'very valuable' (i.e. TFN = 0.675), we'll have the following weights of the LOs quality criteria:

$$a_i = \frac{m_f^i}{\sum_{s=1}^{m} m_f^s} = \frac{0.675}{6.750} = 0.100 \qquad (6)$$

$$a_g = (0.100 \quad 0.100 \quad 0.100 \quad 0.100 \quad 0.100 \quad 0.100 \quad 0.100 \quad 0.100 \quad 0.100 \quad 0.100)$$

In real life situations different criteria are of different importance. In this case, the experts-evaluators should use different weights for different criteria. If we pay special attention to LOs reusability level, we should establish higher weights to the 1st, 5th, 7th and 9th quality criteria (see Table 1), because those criteria deal with LO reusability mostly. Therefore, according to formula (4), if we should establish 'extremely valuable/essential' weights to these reusability criteria, and leave 'very valuable' weights to the other quality criteria in Table 1, we'll get the following weights:

$$m_f^{1,5,7,9} = 0.850, \text{ and } m_f^{2,3,4,6,8,10} = 0.675.$$

After normalisation of these weights according to formula (5), we'll get the final weights (7) as follows:

$$a_{1,5,7,9} = \frac{m_f^{1,5,7,9}}{\sum_{s=1}^{m} m_f^s} = \frac{0.850}{7.450} = 0.114$$

$$a_{2,3,4,6,8,10} = \frac{m_f^{2,3,4,6,8,10}}{\sum_{s=1}^{m} m_f^s} = \frac{0.675}{7.450} = 0.091 \qquad (7)$$

$$a_r = (0.114 \quad 0.091 \quad 0.091 \quad 0.091 \quad 0.114 \quad 0.091 \quad 0.114 \quad 0.091 \quad 0.114 \quad 0.091)$$

For the practical demonstration of application of the TFN based method, a number of probably qualitative reusable Mathematics LOs have been identified in LRE [16] and evaluated against the method proposed. Those LOs alternatives are as follows:

- LO_1: 'Mixed Numbers' [17];
- LO_2: 'Practice with Tangents and Circles' [18];
- LO_3: 'How to Construct a Tangent to a Circle' [19].

Table 1. Learning objects quality and reusability model

Criteria group	Nr.	Quality criteria
Technological quality criteria		
'Internal' quality	1	Technological interoperability and reusability
	2	Layered architecture
	3	Technical stability and robustness
Quality' in use'	4	Design and usability: aesthetics, navigation, user-friendly interface and information structure, personalisation
Pedagogical quality criteria		
	5	Trans-national or multidisciplinary / cross-curricular topic
	6	Interactivity, strong visual element
	7	Language independence
	8	Ease of use, intuitiveness
	9	Additional methodological support for teachers is not needed
IPR criterion		
	10	Clear license: open, free to use, cost-effective

LOs quality criteria ratings (values) obtained while evaluating the analysed LOs using TFNs are presented by matrix (8):

$$f_i(X) = \begin{pmatrix} 0.675 & 0.850 & 0.850 \\ 0.850 & 0.675 & 0.500 \\ 0.500 & 0.675 & 0.675 \\ 0.675 & 0.325 & 0.675 \\ 0.675 & 0.850 & 0.675 \\ 0.850 & 0.675 & 0.850 \\ 0.675 & 0.500 & 0.675 \\ 0.500 & 0.675 & 0.500 \\ 0.850 & 0.675 & 0.850 \\ 0.850 & 0.850 & 0.850 \end{pmatrix} \tag{8}$$

Results of the experimental evaluation of the analysed Math LOs in general case applying formula (1) and matrixes (6) and (8) are presented by matrix (9):

$$a_g \cdot f(X_j) = \begin{pmatrix} 0.7100 & 0.6750 & 0.7100 \end{pmatrix} \tag{9}$$

Results of the experimental evaluation of the analysed Math LOs in the case of different weights of the quality criteria applying formula (1) and matrixes (7) and (8) are presented by matrix (10):

$$a_r \cdot f(X_j) = \begin{pmatrix} 0.7122 & 0.6804 & 0.7163 \end{pmatrix} \tag{10}$$

The obtained evaluation results (9) mean that LO_1 meets 71.00% general (g) quality in comparison with the ideal, LO_2 – 67.50%, and LO_3 – 71.00%.

According to (10), they also mean that LO_1 meets 71.22% reusability (r) level in comparison with the ideal, LO_2 – 68.04%, and LO_3 – 71.63%.

4. Discussion

Using TFN based method presented in the paper, one could see that both LO_1 and LO_3 are the best alternatives (among the evaluated ones) from general quality point of view, and LO_3 is the best one from reusability point of view.

Overall, TFN based method is convenient in the case when there are many probably qualitative alternatives in the market. One could rank the alternatives according to their quality, to see the difference of the evaluated alternatives in per cent, and also the difference between the quality of the alternatives and the ideal quality.

Research results presented in the paper show that the original method of TFN application to establish both weights and ratings (values) of LOs quality criteria (a) is applicable in real life situations when educational institutions decide on using particular LOs for their education needs, and (b) could significantly improve the quality of the expert evaluation of LOs by noticeably reducing the expert evaluation subjectivity level.

The original method of TFN application could be useful in engineering education when educational institutions have to decide on purchasing and applying reusable learning objects created in the other countries for the other educational systems.

5. Conclusions

Experimental evaluation results show that new TFN based method proposed is quite objective, exact, and easy to use for selecting qualitative reusable LOs alternatives.

On the other hand, proposed LO quality and reusability evaluation approaches are applicable for the aims of eQNet project in order to select LOs suitable to apply in different education systems in different countries. Therefore, these approaches have been recommended by the authors to be widely used by European policy makers, publishers, practitioners (teachers), and experts-evaluators both inside and outside eQNet project.

TFN based method proposed is convenient in the case when there are many probably qualitative alternatives available.

Method of TFN application to establish the quality criteria weights presented in the paper is absolutely novel, and this new element makes the given work distinct from all the other earlier works in the area.

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