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Formalizing and validating the web quality model for web source quality evaluation

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ABSTRACT

The proposed web quality model (WebQM) is formalized with ISO/IEC Z language and empirically studied based on the Structural Equation Modeling (SEM) approach. By building the sample data set and constructing the structure equation model, the goodness-of-fit of WebQM is analyzed based on generalized least square method. A web source quality evaluation process based on validated WebQM is implemented and verified as more objective and credible, because the weights of quality criteria are automatically produced in the validation procedure, which avoids the subjective weight assignment in some classic assessment approaches. The model validation and implemented evaluation show that WebQM fits the real web source quality data and is feasible, reliable, and effective for web source quality evaluation.

1. Introduction

The web source quality is the most critical factor for the performance of E-business and E-government and can contribute to the success of a variety of web-based applications. Quality oriented web resource evaluation and selection is vital for efficient use of web information, knowledge discovery, information analysis and decision making.

Web source quality evaluation and selection should be guided by model and criteria. However, a number of information evaluation approaches used in the past have not integrated some critical features of web resource qualities yet, such as autonomy, dynamics, openness, and heterogeneous data structure. It is necessary to build a scientific and reasonable web source quality evaluation model, which fulfills the quality requirements of web source, web content and web application context. Additionally, the model should be feasible, effective and fit to the actual web quality status. A web source quality evaluation model (WebQM, Web quality model) had been proposed in our previous work (Zhu, 2004). This model covers 3 quality dimensions, such as autonomy and dynamics of web source, openness and heterogeneity of web content and extensive context of various applications. 13 evaluation criterias are used to define quality dimensions. In this paper we discuss the formal specification of WebQM and the validation of feasibility and effectiveness of the model.

Based on literature review, Aladwaniam and Palvia (2002) assessed the web quality based on a 4 dimensions and 25 criteria model: Technical adequacy, specific content, content quality and web appearance. However, some of the criteria contribute less to the web quality, e.g. finding people without delay and finding site maintainer. A few of them conflict with each other, e.g. uniqueness and extensiveness. The web quality model of Lowry, Vance, Moody, Beckman, and Read (2008) has 6 dimensions: Responsiveness, competence, quality of information, empathy, web assistance and callback systems. The Structural Equation Modeling analysis was adopted to establish the factorial validity of their model. However, some of their 6 dimensions cannot be implemented easily for assessing web quality, for example, competence or empathy. Sun and Lin (2009) proposed 3 quality dimensions and 12 criteria to evaluate the competitive advantages of on-line shopping sites. Then, they employed the fuzzy TOPSIS method to determine the weights of different criteria for the online shopping websites, therefore the results were significantly influenced by the experts who evaluate the websites. To make the web quality assessment more objective, we use questionnaires rather than expert evaluation to the web source quality assessment score. Yoo and Donthu developed SITEQUAL (Yoo & Donthu, 2001) to evaluate on-line shopping websites based on 9 dimensions. They gathered fifty-four unique items and then reduce the items to nine for measuring four factors (ease to use, design, processing speed, and security) by using exploratory factor analysis. But SITEQUAL's original item set was too narrowly based, and most of its final factors were measured by only two items. In another model WEBQUAL (Loiacono, Watson, & Goodhue,

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2007), the Theory of Reasoned Action and the Technology Acceptance Model were employed, which has 12 dimensions. To check reliability and discriminant validity, a confirmatory factor analysis was conducted by using LISREL. Cao, Zhang, and Seydel (2005) used five dimensions to evaluate e-commerce website and the exploratory factor analysis to check for factorial structures. In Orehovacki, Granic, and Kermek (2013), the authors employed logging actual use method to measure the estimated website quality. They combined retrospective thinking aloud method with an online questionnaire to assess the perceived quality. However, the model orients just a few kinds of websites, such as websites providing services for mind mapping and diagraming. It is hard to generalize their model to all types of web applications, because each kind of web 2.0 applications has its specific features. Baloglu and Pekcan (2006) applied content analysis to study the websites of hotels in terms of site design and marketing characteristics using a binary variables of yes-or-no (one-or-zero). The shortcoming of this approach is that they cannot express the quality performance on each criterion.

Generally speaking, there are similarities between their work and ours, especially in the quality evaluation model construction. However, the above studies mainly focused on the criteria design and concepts, few of them formalized the model. Besides, some of the model criteria cannot be quantized, e.g. past experience and proficiency. The most outstanding feature of our work is that the WebQM takes the differential weighting into consideration and each criterias weight can be automatically generated. Additionally, the web quality models described above mostly were developed on the perspectives of web developers and designers, but not on that of web users. It is undeniable that the users play an increasingly important role in web quality. Our model defines web quality from user's perspective. The goodness-of-fit of the model is analyzed by Structure Equation Model approach based on the questionnaire made by 213 users.

As to the model formalization, there are few related literature. Authors of paper (Cheng & Wang, 2008) formally modeled the combination pattern of the semantic web services based on Colored Petri Net, and proposed an algorithm to validate the syntax of the combined model. Different from their work, we discuss the formal specification of WebQM and validate the feasibility and effectiveness of the model.

The major contributions of this paper are as follows:

1. Specify the WebQM using formal Z language to avoid ambiguity, which has precise semantics and is standardized by ISO/IEC.
2. Verify the feasibility and effectiveness of WebQM using the Structural Equation Modeling (SEM) approach.
3. Generate the quality criteria weights of WebQM in goodness-of-fit analysis, which improve the objectiveness of the quality assessment based on WebQM.
4. Validate the reliability, objectiveness and feasibility of WebQM by implementing a web source quality evaluation process.

2. Formal specification of WebQM

Z is a formal specification language of ISO/IEC JTCI/SC22. It is based on the first-order logic and Zermelo–Fraenkel set theory. It usually contains 3 parts:

1. Grammar, which specifies the representation method of the language.
2. Semantics, which defines the full domain of objects in the description system.
3. A set of relationships, which defines rules, with which the specific objects should be consistent.

In order to precisely define and explicitly represent WebQM (as shown in Fig. 1), we use Z language to formally define the structure, data type and evaluation pattern of the WebQM.

Definition 1. The tree structure of WebQM is expressed as Z child function. The child function represents the partial function (1:N relationship) between the node sets, i.e. child: NODE ↦ NODE.

Given WebQM∈dom (child), WebSQ∈dom (child), WebIQ∈dom (child), WebAQ∈dom (child), then dom {WebQM ↦ WebSQ} = {WebSQ}, and so on.

The general formal definition of WebQM is: child = {WebQM ↦ WebSQ, WebQM ↦ WebIQ, WebQM ↦ WebAQ, WebSQ ↦ Availability, WebSQ ↦ Accessibility, WebSQ ↦ Durability, WebSQ ↦ Timeliness of Information, WebIQ ↦ Reliability, WebIQ ↦ Correctness, WebIQ ↦ Completeness, WebIQ ↦ Objectivity, WebIQ ↦ Understandability, WebIQ ↦ Validity of Information, WebAQ ↦ Relevance, WebAQ ↦ Presentation, WebAQ ↦ Information Acquisition}

$$
\begin{array}{l}
\textit{QualityEvaluation} \\
\hline
\textit{quality} : \mathbb{P}\ \textit{Dimensions} \\
\textit{WebSQ}, \textit{WebIQ}, \textit{WebAQ} : \mathbb{P}\ \textit{Criteria} \\
\textit{Availability}, \textit{Accessibility}, \cdots, \textit{InformationAcquisition} : Z \\
\textit{Weight} : Z \\
\textit{correlation}\ \textit{quality} \mathrel{+\!\!\!\!\rightarrow} \textit{Dimensions} \\
\textit{correlation}\ \textit{Dimensions} \mathrel{+\!\!\!\!\rightarrow} \textit{Criteria} \\
\textit{correlation}\ \textit{Criteria} \mathrel{\rightarrowtail\!\!\!\!\!+} \textit{weights} \\
\hline
\mathrm{dom}\ \textit{WebSQ} \subset \textit{quality} \wedge \\
\mathrm{dom}\ \textit{WebIQ} \subset \textit{quality} \wedge \\
\mathrm{dom}\ \textit{WebAQ} \subset \textit{quality} \wedge \\
\mathrm{dom}\ \textit{Criteria} \subseteq \textit{Dimensions} \wedge \\
\textit{weight} > 0
\end{array}
$$

Definition 2. The descendant inheritance relationship of the WebQM can be constructed using the transitive closure operator of Z according to the Definition 1 as follows:

descendent = child^{+}.

descendent = {WebQM ↦ WebSQ, WebQM ↦ WebIQ, WebQM WebAQ, WebQM ↦ Availability, WebQM ↦ Accessibility, ..., WebQM ↦ Information Acquisition, ...}

Definition 3. WebQM pattern is specified above. Web quality is specified by a set of quality dimensions. A quality dimension is defined as the set of criteria. Non-leaf node entries have a set type P, leaf nodes have a basic type Z. There is partial relationship (⇸) between the quality and the dimensions and between the dimensions and the criteria. There is partial projection relationship (i.e. 1:1, ⤔) between the criteria and their weights.

Web resource quality evaluation based on WebQM is defined through specifying dynamic operations. Definition 4 is an example of quality evaluations.

Definition 4. In Z language, the web resource quality evaluation value is defined as output, denoted as *q*!. The evaluation score in terms of each quality criterion is defined as input, denoted as c_i?, the weights of the quality criteria are defined as input, denoted as w_i?. Quality value computation is formally defined above. Changeable quality state pattern is denoted as △*Quality*.

QualityEvaluation

$\Delta Quality$

$c_{Availability}? : Z;\ c_{Accessibility}? : Z;\ \cdots;\ c_{Competeness}? : Z;$

$c_{Objectivity}? : Z;\ \cdots;\ c_{InformationAcquision}? : Z$

$w_{Availability}? : Z;\ w_{Accessibility}? : Z;\ \cdots;\ w_{Competeness}? : Z;$

$w_{Objectivity}? : Z;\ \cdots;\ w_{InformationAcquision}? : Z$

$q! : Z$

$c_{Availability}?, c_{Accessibility}?, \cdots, c_{InformationAcquision}? \in Criteria \wedge$

$w_{Availability}?, w_{Accessibility}?, \cdots, w_{InformationAcquision}? \in Criteria \wedge$

$q! = c_{Availability}? * w_{Availability}? + \cdots$

$\quad + c_{InformationAcquision}? * w_{InformationAcquision}?$

3. Fitness analysis of WebQM

Having formally specified the relationship between dimensions and criteria of WebQM, analyzing whether the quality dimensions and criteria of WebQM with the actual web quality status is necessary. Structural Equation Modeling (SEM) (Barrett, 2007, Nusair & Hua, 2010, Song & Lee, 2012, Qiu & Lin, 2009) is an advanced statistical modeling technique for assessing potential interrelationships between a model and the actual situation. It integrates techniques including multiple regression analysis, path analysis and confirmatory factor analysis. The most commonly used validation approaches in SEM are maximum likelihood (ML) and generalized least squares (GLS).

We use the observable variables of SEM to define the actual web source quality states and the latent variables to represent the quality dimensions of the WebQM. By computing the variance and covariance difference between the variables, namely residual, the difference between WebQM and actual web quality is measured and the goodness of fit of the model is verified. The definition of SEM is as follows:

$$SEM = \begin{cases} measurement: & \begin{cases} x = \Lambda_x \xi + \delta \\ y = \Lambda_y \eta + \varepsilon \end{cases} \\ structural: & \eta = B\eta + \Gamma\xi + \zeta \end{cases} \quad (1)$$

Where x is the exogenous observable variable; Λ_x is the relationship between x and the latent variables ξ; y is the endogenous latent variable; Λ_y is the relationship between y and the latent variables η; ε is the measurement error; η is the endogenous latent variable; B is the relationship between the endogenous variables; ξ is the exogenous latent variables; Γ represents how the exogenous latent variables influence the endogenous latent variables; ζ is the unexplained part about the variables and their relationship in the model.

3.1. Sample data set construction

The sample data of the actual web source quality is collected by surveying 4 online bookstores in terms of 13 criteria. The questionnaire reflects the various aspects of web quality which is measured using five-point Likert Scales. For example, the Availability can be marked as one of very poor, poor, general, good or very good which is correspond to the score of 1, 2, 3, 4 and 5 respectively. We collected 213 valid samples. Before using these data, we calculated the Cronbach value, the Cronbach value for measuring the reliability of data is calculated with Eq. (2).

$$\alpha = \frac{n}{n-1} \cdot \left(1 - \frac{\sum \sigma_i^2}{\sigma_x^2}\right) \quad (2)$$

Where, n is the question number in the questionnaire, $\sum \sigma_i^2$ is the sum of variance of each questions observed score, and σ_x^2 is the variance of total scores. The smaller α is, the lower reliability of the questionnaire data. If $0.70 \leqslant \alpha \leq 0.98$, the reliability is high. The α value of our observed data set is 0.906, so the data set has high reliability.

3.2. The structural equation model of WebQM

In WebQM, the WebSQ, WebIQ and WebAQ are exogenous latent variables and are decided by 13 criteria such as accessibility, durability, and completeness, so they are endogenous latent

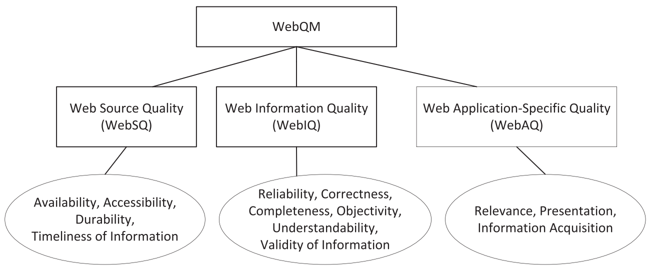

Fig. 1. Web quality model-WebQM.

variables. Because the exogenous latent variables of WebQM do not have observable variables, there exists no exogenous variable *x* in the SEM function of WebQM (as in Eq. 1). There is no inter influence between the endogenous latent variables, so $B = 0$. η_i(i = 1, 2, 3) is used to represent WebSQ, WebIQ and WebAQ. Hence, the SEM model at Eq. 1 is converted as follows.

$$\begin{cases} \eta = B\eta + \Gamma\xi + \zeta_Y \\ Y = \Lambda_X\eta + \epsilon \end{cases} \quad (3)$$

where $\eta = \begin{bmatrix} \eta_1 \\ \eta_2 \\ \eta_3 \end{bmatrix}, B = 0, \quad \Gamma = \begin{bmatrix} \gamma_1 \\ \gamma_2 \\ \gamma_3 \end{bmatrix}, \xi = [\xi], \quad \zeta = \begin{bmatrix} \zeta_1 \\ \zeta_2 \\ \zeta_3 \end{bmatrix},$

$$Y = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_{13} \end{bmatrix}, \Gamma_x = \begin{bmatrix} \lambda_{11} \\ \lambda_{21} \\ \lambda_{31} \end{bmatrix}, \epsilon = \begin{bmatrix} \epsilon_1 \\ \epsilon_2 \\ \vdots \\ \epsilon_{13} \end{bmatrix} 2$$

A SEM model of WebQM is illustrated as in Fig. 2. The initial weight of each path is 1. The small circles labeled from e1 to e13 are the measurement error.

3.3. Model validation

WebQM and the actual web quality conditions have been modeled with SEM varianceCcovariance matrix in above sessions. The

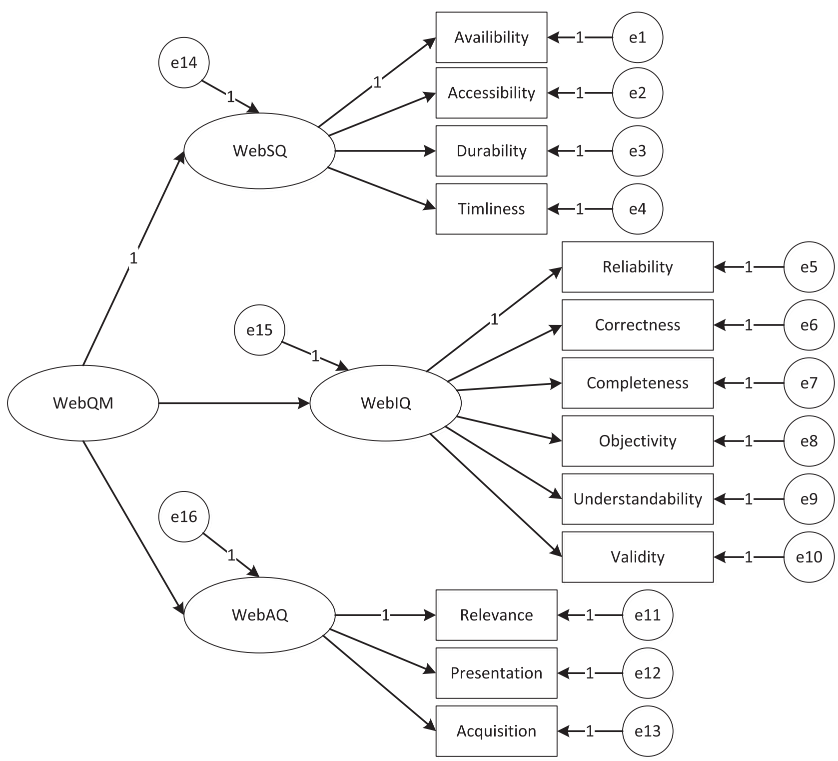

Fig. 2. SEM of WebQM.

Table 1
Correlation matrix of the observed sample set.[a]

	Avail	Acce	Dura	Time	Reliab	Correct	Compl	Obj	Under	Valid	Relev	Pres	Acqui
Avail	1												
Acce	0.5213	1											
Dura	0.4316	0.3966											
Time	0.3714	0.3475	0.3959	1									
Reliab	0.2792	0.3186	0.3302	0.3858	1								
Correct	0.3180	0.3156	0.2930	0.2970	0.4410	1							
Compl	0.3854	0.3157	0.3324	0.3246	0.3288	0.3620	1						
Obj	0.3310	0.2993	0.3085	0.3551	0.4370	0.3600	0.3590	1					
Under	0.3055	0.3921	0.3143	0.3658	0.3260	0.2675	0.3145	0.3288	1				
Valid	0.2964	0.2775	0.2809	0.3771	0.3558	0.3720	0.2796	0.2765	0.2958	1			
Relev	0.3172	0.3651	0.2282	0.2978	0.3284	0.3010	0.3458	0.2820	0.3335	0.3928	1		
Pres	0.3001	0.2339	0.2669	0.3062	0.3372	0.3455	0.2289	0.3098	0.2874	0.3462	0.2877	1	
Acqui	0.2977	0.3010	0.2650	0.2961	0.2644	0.2835	0.3303	0.2683	0.3191	0.2361	0.3379	0.3163	1

[a] Note: due to table space limit, Availability, Accessibility, Durability, Timeliness of Information, Reliability, Correctness, Completeness, Objectivity, Understandability, Validity of Information, Relevance, Presentation and Information Acquisition are abbreviated as Avail, Acce, Dura, Time, Reliab, Correct, Compl, Obj, Under, Valid, Relev, Pres and Acqui.

Table 2
Result of the fitness analysis.

	P	CMIN/DF	GFI	AGFI	CFI	RMSEA
Before modification	0.000	1.854	0.920	0.882	0.950	0.065
After modification	0.042	1.345	0.944	0.911	0.981	0.042

SEM varianceCcovariance matrix is a function containing a set of parameters being estimated. The residual between latent and observed variables is calculated by GLS method. The smaller the residual is, the better WebQM is approximate the actual quality condition.

For the y in Eq. (3), the covariance matrix can be calculated using the equation

$$\sum_{yy}(\theta) = \Lambda_y E(\eta\eta')\Gamma_y' + \Theta_\varepsilon \tag{4}$$

where θ is a fitting parameter, Θ_ε is the covariance matrix of ε. Transforming the $\eta = B\eta + \Gamma\xi + \zeta$ in Eq. (3) as the follows.

$$\eta = (I - B)^{-1}(\Gamma\xi + \zeta) = \widetilde{B}(\Gamma\xi + \zeta) \tag{5}$$

where, $\widetilde{B} = (I - B)^{-1}$ implies that $I - B$ is an invertible matrix. The expect value can be calculated with Eq. 6:

$$E(\eta\eta') = \widetilde{B}(\Gamma\Phi\Gamma' + \Psi)\widetilde{B}' \tag{6}$$

Combining with Eqs. 4 and 6, we get

$$\sum_{yy}(\theta) = \Lambda_y\widetilde{B}(\Gamma\Phi\Gamma' + \Psi)\widetilde{B}'\Lambda_y' + \Theta_\varepsilon \tag{7}$$

where, Φ is the covariance matrix of latent variable ξ; Ψ is the covariance matrix of the resident term ζ. Finally, we get:

$$\sum(\theta) = \begin{pmatrix} \sum_{yy}(\theta) & \sum_{yx}(\theta) \\ \sum_{xy}(\theta) & \sum_{xx}(\theta) \end{pmatrix} \tag{8}$$

In Eq. (8), $\sum_{yx}(\theta)$, $\sum_{xy}(\theta)$ and $\sum_{xx}(\theta)$ are zero matrix because x does not exist in WebQM.

The covariance matrix of the observable variables is show as Table 1. The GLS function is defined as

Table 3
Weights of criteria (W′).

Relationship	Estimated weight
WebSQ←WebQM	0.896
WebIQ ←WebQM	0.991
WebAQ ←WebQM	0.897
Availablity ←WebSQ	0.653
Accessibility ←WebSQ	0.644
Durability ←WebSQ	0.784
Timeliness ←WebSQ	0.706
Reliability ←WebIQ	0.723
Correctness ←WebIQ	0.680
Completeness ←WebIQ	0.724
Objectivity ←WebIQ	0.678
Understandability ←WebIQ	0.651
Validity ←WebIQ	0.628
Relevance ←WebAQ	0.661
Presentation ←WebAQ	0.620
Acquisition ←WebAQ	0.680

$$F_{GLS} = \frac{1}{2}tr\left([S - \sum(\theta)W^{-1}]^2\right) \tag{9}$$

where, $S - \sum(\theta)$ is residual matrix; W is positive definite matrix or random matrix which convergence in positive definite matrix. We usually let $W^{-1} = S^{-1}$. θ is the generalized least square estimation, which is obtained by minimizing the value of $F_{GLS} = 0$ in the iterations. If $F_{GLS} = 0$, the residual matrix is a zero matrix, which indicates a model can fit the actual data perfectly, and this is an ideal situation.

Table 2 lists the fitting parameters obtained using AMOS software. P in Table 2 denotes significance, which is a probability calculated with the different value and freedom degree. If P is greater than 0.050, the model fits the data moderately.

CMIN/DF is the ratio of discrepancy to freedom degree. The less the value, the better the fitness is.

GFI is the goodness of fitting criterion. The more GFI approaches to 1, the better the model fits the data. GFI $>$ 0.900 is usually used as the threshold.

The more the AGFI (the Adjust Goodness of Fit Criterion) value approaches to 1, the better the model. AGFI $>$ 0.900 is usually used.

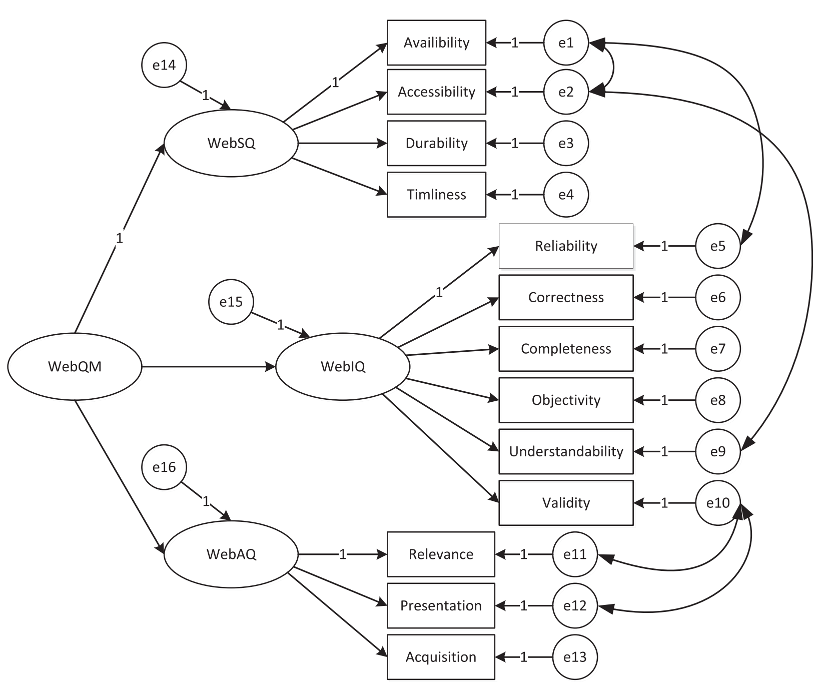

Fig. 3. SEM of WebQM after modification.

The value of the CFI (Comparative Fit Criterion) is between 0 and 1. CFI equals 1 if the model fits the data perfectly.

RMSEA, the Root Mean Square Error of Approximation, is squared residual and can overcome the drawback of the overall different value influenced by the estimated parameters in model validation. RMSEA is less than 0.05 when the fitness of the model is good. RMSEA is greater than 0.1 when the fitness of the model is bad and modification is needed. RMSEA between 0.050 and 0.100 means the model is not much satisfied but acceptable.

The first row at Table 2 gives the initial result of the model validation. P, CFI and RMSE are not satisfied with the thresholds and model needs modification.

The further study shows that a few pairs of error (e.g. e1, e2) have covariance (correlation).In order to annotate the correlation explicitly, double arrows are used to link them as shown in Fig. 2. We validate the goodness-of-fit based on modification again. The second row at Table 2 gives the final results, where GFI, AGFI, CFI and RMSEA meet the thresholds well. CMIN/DF decreases. P is still less than 0.050. This is because Chi-square value is influenced by the number of observable variables. If the number increases, P will approach to 0. WebQM has many criteria which results in P approaching to 0. In such a case, 0.042 is acceptable.

In summary, the modified WebQM can fit the actual web source quality well. The path values are calculated in the fitness analysis based on the initial value 1 as in Fig. 3. The produced path values shown in Table 3 represent how much each criterion contributes to each quality dimension and how important of each criterion is in the whole quality model. Apparently, the produced path values are the weights of quality criteria. These weights are produced by constructing SEM, which improves the objectiveness of the quality assessment.

4. Web source quality evaluation based on validated WebQM

4.1. Principle of web source quality evaluation

The problem of assessing the quality of web sources falls into the domain of MCDM (Multi-Criteria Decision Making) (Zhu, 2004). MCDM can be divided into Multi-Objective Decision Making (MODM) and Multi-Attribute Decision Making (MADM). MODM focuses on designing one or more alternatives satisfying multiple objectives under some constraints, while MADM selects the qualified alternatives from a set of predetermined decision alternatives with regard to multiple criteria. Web source evaluation is a kind of MADM problems. Several classic approaches can be applied to evaluate the quality of web source and content, such as, AHP (Analytic Hierarchy Process) and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution).

The TOPSIS method was developed by Hwang and Yoon in 1981. Its basic approach is to find the best one of a group of alternatives, which is closest to the ideal solution and farthest to the negative-ideal solution in a multi-dimensional computing space that is specified by a set of criteria as dimensions. The different values of the criteria determine the topological positions of those alternatives. The ideal solution represents a virtual alternative with a set of possibly best synthetic scores in terms of each criterion, while the negative-ideal solution is a virtual alternative with a set of worst scores. Physically, they are two points in the computing space with extreme values.

We conduct a web source quality evaluation using TOPSIS to discuss the feasibility, effectiveness, and credibility of validated WebQM. An evaluation matrix should be built to define the quality score of each web source with regard to each weighted criterion. As usual, the two kinds measures (quality values of web sources and criteria weights) in the matrix are assigned subjectively by the evaluators. However, in our work the criteria weights have been computed automatically through computing the path value between the observable and latent variables (shown in Table 3). In our implementation, the valid sample data of the actual web source quality has also been obtained by surveying 4 online bookstores in terms of 13 criteria as discussed in 3.1. Thus, our implementation based on WebQM avoids subjective assignment of two kinds measures and improves the credibility of the model.

Table 4 is an example of assessment values of web source quality obtained by the questionnaire.

4.2. Web source quality evaluation using TOPSIS

a. **Normalizing Q and W**

Q and W will be normalized using Eqs. (10) and (11).

$$w_i = \frac{w_i'}{\sqrt{\sum_{i=1}^{13} w_i'^2}} \tag{10}$$

where i denotes the number of criteria and w_i' is the weight of ith criterion computed in Table 3.

$$y_{ij} = \frac{q_{ij}}{\sqrt{\sum_{i=1}^{4} q_{ij}^2}} \tag{11}$$

where, i denotes the number of web sources. j is the number of criteria. q_{ij} denotes the quality measure of the ith web source in terms of the jth criterion.

b. **Constructing the normalized weighted decision matrix**

The normalized weighted decision matrix will be calculated as:

$$M = W \times Y = \begin{bmatrix} w_1 y_{11} & w_2 y_{12} & \ldots & w_{13} y_{113} \\ w_1 y_{21} & w_2 y_{22} & \ldots & w_{13} y_{213} \\ w_1 y_{31} & w_2 y_{32} & \ldots & w_{13} y_{313} \\ w_1 y_{41} & w_2 y_{42} & \ldots & w_{13} y_{413} \end{bmatrix} = \begin{bmatrix} 0.0351 & 0.0230 & \ldots & 0.0330 \\ 0.0323 & 0.0351 & \ldots & 0.0340 \\ 0.0420 & 0.0463 & \ldots & 0.0492 \\ 0.0377 & 0.0376 & \ldots & 0.0355 \end{bmatrix} \tag{12}$$

c. **Determining the ideal and the negative-ideal solutions**

The ideal solution P^+ represents a virtual source with a set of possibly the best synthetic values in terms of each criterion, namely to select the best value in M in terms of each criterion. The negative-ideal solution P^- is built by selecting the worst value in M in terms of each criterion.

$$P^+ = \{p_1^+, p_2^+, \ldots, p_{13}^+\}, \quad P^- = \{p_1^-, p_2^-, \ldots, p_{13}^-\} \tag{13}$$

where, $p_1^+ = \max_{i=1,\ldots4}(m_{i1}),\ldots,p_{13}^+ = \max_{i=1,\ldots4}(m_{i13})$,and $p_1^- = \min_{i=1,\ldots4}(m_{i1}),\ldots$, $p_{13}^- = \min_{i=1,\ldots4}(m_{i13})$. m_{ij} is the element of M, i denotes 4 web sources.

Table 4
Evaluation matrix Q of web source quality.

	Avail	Acce	Dura	Time	Reliab	Cor	Compl	Obj	Under	Valid	Relev	Pres	Acqui
A	3.42	2.44	2.73	3.23	2.80	3.07	2.88	3.35	2.30	3.12	3.89	3.95	3.21
B	3.14	3.72	3.82	3.02	3.67	3.89	3.71	2.90	3.69	3.37	2.74	2.89	3.30
C	4.09	4.91	3.69	4.69	4.69	4.43	3.61	3.74	4.20	4.90	3.42	4.04	4.78
D	3.67	3.99	4.68	3.74	3.74	4.21	4.28	4.21	4.91	3.29	4.59	3.95	3.45

In the example, $P^+ = (0.0420, 0.0463, 0.0584, 0.0503, 0.0487, 0.0433, 0.0480, 0.0451, 0.0465, 0.0466, 0.0462, 0.0379, 0.0492)$, $P^- = (0.0323, 0.0230, 0.0391, 0.0324, 0.0301, 0.0300, 0.0323, 0.0311, 0.0218, 0.0297, 0.0276, 0.0271, 0.0330)$.

d. **Finding the Euclidean distances of each source with P^+ and P^-**

In this step, the similarity (Euclidean distance) of each web source to two solutions (P^+ and P^-) will be calculated, separately:

$$d_i^+ = \sqrt{\sum_{j=1}^{13} (p_j^+ - w_j y_{ij})^2} \quad d_i^- = \sqrt{\sum_{j=1}^{13} (w_j y_{ij} - p_j^-)^2} \quad i = 1 \ldots 4 \tag{14}$$

In our example, $D^+ = (0.0585, 0.0451, 0.0207, 0.0250)$, $D^- = (0.0164, 0.0262, 0.0512, 0.0530)$

e. **Calculating the relative closeness to the ideal solution**

The relative closeness of the ith web source with respect to the ideal solution is defined as follows. If the source itself is the positive ideal solution, $C = 1$; if the web source itself is the negative-ideal solution, $C = 0$

$$C_i = \frac{d_i^-}{d_i^+ + d_i^-} \quad 0 \leqslant C_i \leqslant 1, \quad i = 1 \ldots 4 \tag{15}$$

f. **Evaluating all alternatives**

The goal of evaluation is to find a web source closest to the positive ideal solution and farthest to the negative-ideal solution in the space that criteria have specified. The larger the relative closeness value C, the closer to the ideal solution and the farther to the negative solution. In the evaluation example, the relative closeness value of the 4 on-line book stores are: **A: 0.2191, B: 0.3739, C: 0.7117, D: 0.6793**. C is the top quality web source of four resources. This result is compatible with the observation of user group (213 survey samples).

5. Conclusion

In this paper, we formalize the proposed WebQM with ISO/IEC Z language to mathematically specify the web source quality evaluation, and verify the feasibility, effectiveness, and reliability of the model. To the best of our knowledge, the work in this paper is the first contribution of the formalization of web source quality model and empirical research of the web quality model validation based on SEM and TOPSIS approach.

By formally specifying the WebQM using Z language, the structure, schema, semantics and the syntax of WebQM can be precisely described to avoid ambiguity and to guarantee the reliability of the model. By analyzing the goodness-of-fit of WebQM using the Structural Equation Modeling (SEM) approach, the feasibility and effectiveness of the model is validated. A value-added contribution of this paper is that the weight of the quality evaluation criteria is generated with the validation analysis. The advantage of this distinctive achievement is to boost the objectiveness of the actual quality assessment by up to the 50% in comparison with many conventional approaches, in which the weight of each criterion needs to be assigned subjectively. Besides, the quality measurement of the web sources in terms of criteria is obtained by 213 data samples in this paper, which contributes to the objectiveness of the assessment once again by using independent multiple user scoring.

Our future research directions focus on the usage of validated WebQM and the improvement of WebQM, which include (i) integrate WebQM into the quality-driven Web anomaly mining, which is our on-going work and has already yielded some good results. (ii) develop software tools for web source quality evaluation and assurance based on WebQM. (iii) analyze the robustness of web quality evaluation on WebQM, in order to improve the objectiveness of evaluation approaches. (iv) design and validate models in other domains, e.g., QoS-oriented web service model based on the achievement of this paper.

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