An Online Auction Trust Model for Based on the Contextual Information

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Abstract — **This paper introduced a trust model based on reputation (user's evaluation after performed transactions) and on examination of properties of possible fraudulent behavior in online auctions. The evidence is expressed and combined using belief functions. The case study shows that the proposed approach can be valid and may be applicable in real online auctions.**

Keywords: Reputation, trust, online auction, belief functions, Dempster's rule.

I. INTRODUCTION

Communication within Internet online auction systems generally takes place without users being in a physical contact or knowing anything of each other. Therefore, they have to rely on mechanisms implemented within these online systems – reputation systems. Most of such mechanisms are based on the creation of trustworthy environment with the help of additional attributes associated with users and their roles. These attributes are constructed based on previous transactions or recommendations (positive or negative comments regarding such transactions). The creation of trust in the online auction environment is the basis for proper functioning of these environments. Our paper describes a trust model which also includes information of additional behavior within respective online (Internet) auctions. We also discuss experiments performed on Aukro auction [1].

II. DEMPSTER-SHAFER THEORY

Information related to decision making based on trust is often uncertain and incomplete. Hence it is of vital importance to find a feasible way to make decisions under uncertainty. Desirable properties of trust representations in Internet auction (and in all online systems) are:

1. Trust representation should integrate different uncertainties: uncertainty about the outcome of a transaction and uncertainty resulting from the fact that we use second-hand experiences.
2. Trust representation should allow for decision making and should have the following properties:
   - Allow ranking of alternatives;
   - Enable comparison with own standards.

Dempster-Shafer theory [2], a imprecise probabilistic reasoning technique, is designed to deal with uncertainty and incompletion of available information. It is a powerful tool for combining accumulated evidence and changing prior knowledge in the presence of new evidence. Dempster-Shafer theory has been used widely for fraud detection and system verification. For example, authors of [3], [4] and [5] proposed to use belief theory for calculation of reputation value and demonstrated the effectiveness of the Dempster-Shafer theory for their applications. In this paper, we propose a unique trust model based on Dempster-Shafer theory which combines the evidence of reputation with the evidence of possible illegal behavior during an Internet auction (for example shilling or shielding) [6].

III. SUGGESTED TRUST MODEL BASED ON CONTEXTUAL INFORMATION

Our model consists of two steps. The first step begins with modeling belief functions. One belief function represents a reputation based on testimonies from reliable witnesses (from users who had performed transactions with the respective user). The other is the belief function associated with individual properties of possible fraudulent behavior (shilling). In the second step, these belief functions are combined using the Dempster's rule.

The proposed model is innovative in the sense that it connects all accessible information related to the behavior of a given user in online auction with the goal to ascertain the trustfulness of that user.

A. The determination of belief functions based on evaluations by other users (reputation)

The user's reputation is based on evaluations by individual participants upon completion of each transaction. The users of the online auction are given a form (which can also include space for comments) which they fill out upon completion of a transaction. The users (buyers, bidders) assign points to other users (sellers) and evaluate the following aspects: the description of the sold item on the auction website (whether it corresponds to the actual item), the quality of communication with the seller, the speed of delivery, and the quality of delivery. Subsequently, users can add other remarks into the text window provided in the form.

The reputation of a given user is based on the rating by users who have completed a transaction with the given user and expresses the mean rating of the given user.

Let's assume that seller *j* offered a number of products/services in an auction, altogether *m* items. The results of the auctions are evaluated by users who have conducted transactions with the evaluated seller (the seller *j* is evaluated by *n* users). The overall rating of the seller *j* is represented by the set $S_{Rp_j} = \{s_{1j_1}, s_{2j_2}, \ldots, s_{ij_1}, \ldots, s_{ij_k}, \ldots, s_{nj_m}\}$. The term s_{ij_k} is the rating of the *k*-th transaction. This rating s_{ij_k} is calculated the following way:

We denote Θ = {*T*, ¬*T*} as a frame of discernment concerning the reputation; m_{Rp} is the mass function obtained from all entities which evaluate the quality of services (sold products) of a given seller.

Power set of the set Θ (the set of all subsets) 2^{Θ} has three elements (we do not consider the empty set):

$2^{\Theta} = \{\{T\}, \{\neg T\}, \Theta\}$

{*T*} means that the given seller is trustworthy;

{¬*T*} means that the given seller is not trustworthy

{Θ} denotes uncertainty. It means that we cannot judge whether a given seller is trustworthy, for example if evaluations of transactions are neutral (neither positive nor negative).

We further define two thresholds th_l and th_h ($th_l \leq th_h$) which are defined as a lower and upper threshold for reputation. For example, the seller (or his services) can be evaluated on a scale like -2, -1, 0, 1, 2. Hence -2 means very bad, -1 not very good, 0 neutral (unsure), 1 acceptable, and 2 means outstanding. As th_h we could take the value 1 and as th_l the value -1. The belief function formula will be:

$$m_{Rp_j}(\{T\}) = \frac{\sum_{i=1}^{n} \sum_{k=1}^{m} |s_{ij_k}|, \text{ where } s_{ij_k} \geq th_h}{\sum_{i=1}^{n} \sum_{k=1}^{m} |s_{ij_k}|}$$

$$m_{Rp_j}(\{\neg T\}) = \frac{\sum_{i=1}^{n} \sum_{k=1}^{m} |s_{ij_k}|, \text{ where } s_{ij_k} \leq th_l}{\sum_{i=1}^{n} \sum_{k=1}^{m} |s_{ij_k}|} \quad (1)$$

$$m_{Rp_j}(\Theta) = 1 - m_{Rp}(\{T\}) - m_{Rp}(\{\neg T\})$$

Where s_{ij_k} is the rating of the *k*-th transaction (seller *j*, bidder *i*)

$m_{Rp_j}(\{T\})$ represents the trust in the hypothesis that the seller *j* „has a good reputation on the market“ and „has been positively evaluated by many users.“

Belief function m_{Rp_j} defines the degree of trust in seller *j* based on reputation, i.e. based on the experiences of other users dealing with seller *j*. This belief function is then complemented with a belief function expressing illegal behavior (shill bidding) to determine the total trustworthiness of a user.

B. Belief functions representing illegal behavior (shill behavior)

This is a method when the seller agrees in advance to cooperate with other users (known as shills) to raise the price of sold merchandise. "The shill" participates in the auction and bids for the auctioned item. A user who tries to obtain the auctioned item and is not in on the "game", tries to outbid the "shill" and offers higher price. This way, the price of the item increases. In case the "shill" wins the auction, the item will remain in the possession of the seller. The seller will likely put the item up for auction again claiming that the "shill" failed to pay for the item. Such behavior is called "shill behavior" [7, 8, 9, 10, 11 and 12].

One of the first efforts describing the use of the Dempster-Shafer theory to detect "the shill" is an essay [7], using an approach similar to the one described in this paper. In our model, we have also chosen an approach based on an application of the Dempster-Shafer theory (DST). We assume that in this case, the use of DST corresponds to the character of the modeled process. It corresponds to the type of modeled uncertainty and conveniently allows to combine and to update characteristic attributes of shill behavior. We found out typical attributes (it is possible to define other ones as well, but it is too difficult to verify them):

1. Loyalty to the seller;
2. Timing of bids;
3. Small amount of won auctions;
4. Similarity of identification details of the seller and bidder.

1) Loyalty to seller

This trait shows that the bidder „shill“ concentrates on one or two sellers. The belief functions have the following form:

$$m_{Ve}(\{shill_i\}) = v_1 \frac{N_i}{\sum_{j=1}^{n} N_{ij}}$$

$$m_{Ve}(\{\neg shill_i\}) = 0 \quad (2)$$

$$m_{Ve}(\Theta_i) = 1 - v_1 \frac{N_i}{\sum_{j=1}^{n} N_{ij}}$$

v_1 is the weight of this evidence. We can intuitively read this weight as a reliability of this evidence.

N_i – the number of bids by bidder i in online auction of a certain seller.

n is the total number of sellers with whom the bidder conducted transaction (bids).

With this equation, we have expressed the loyalty to the seller. Usually, the higher the number of bids made by bidder i to certain seller, compared to the number of his bids to other sellers j, the higher the suspicion that the bidder is a „shill“. Therefore, we assume that the equation reflecting the loyalty to the seller, does not show that the bidder is not a „shill”, i.e. $m_{Ve}(\{\neg shill_i\}) = 0$.

2) Timing of bids

Bidders-shills typically do not make bids when auctions are nearing the end to avoid the risk of wining the auction. Belief functions have the following forms:

$$m_C(\{shill_i\}) = v_2 \frac{T_k - T_i}{T_{total}}$$
$$m_C(\{\neg shill_i\}) = 0 \qquad (3)$$
$$m_C(\Theta_i) = 1 - v_2 \frac{T_k - T_i}{T_{total}}$$

T_k is the time when the auction is scheduled to finish.

T_i is the time when the observed bidder i places her last bid.

T_{total} is the duration of the auction.

It is valid that the higher the time difference between when the auction ends and when bidder i places her last bid, compared to the overall duration of the auction, the higher the suspicion that the bidder is a „shill.“ Therefore, we also assume that the given equation does not indicate that the bidder is not a „shill“, i.e. $m_C(\{\neg shill_i\}) = 0$. The parameter v_2 is in these equations the weight of evidence. We can intuitively interpret this weight as the reliability of the given evidence.

3) Small number of won auctions

Due to their role, bidders-shills win a limited number of auctions. The goal of the bidder-shill is not to win an auction but to drive up the price as high as possible. We use the following relations to express the assumption that the user is a shill.

$$m_{Mva}(\{shill_i\}) = v_3 \frac{\sum_{j=1}^{n}(N_{ij} - Nv_{ij})}{\sum_{j=1}^{n} N_{ij}}$$
$$m_{Mva}(\{\neg shill_i\}) = 0 \qquad (4)$$
$$m_{Mva}(\Theta_i) = 1 - v_3 \frac{\sum_{j=1}^{n} Nv_{ij}}{\sum_{j=1}^{n} N_{ij}}$$

Nv_{ij} is the number of wins in auctions with the participation of bidder i and seller j;

N_{ij} is the number of bids of the bidder i in auctions of the seller j;

n is the total number of sellers with whom the bidder conducted transaction (bids).

In these equations, the v_3 parameter is the weight of evidence. We can intuitively interpret this weight as the reliability of the given evidence.

The higher the ratio of the difference between the number of bids and the number of wins of the bidder i at the seller j, the higher the suspicion that the bidder is a „shill”. Therefore, we assume that the equation does not show that the bidder is not a „shill”, i.e. $m_{Mva}(\{\neg shill_i\}) = 0$.

4) Similarity of identification details of bidder and seller

Judging by online auction websites [9] and websites dedicated to fraud behavior in online auctions [12], this is a surprisingly common sign of shill behavior. Believe functions have form:

$$m_{Po}(\{shill_i\}) = v_4 \frac{Nci_{ij}}{Nc_{ij}}$$
$$m_{Po}(\{\neg shill_i\}) = 0 \qquad (5)$$
$$m_{Po}(\Theta_i) = 1 - v_4 \frac{Nci_{ij}}{Nc_{ij}}$$

Nci_{ij} is the number of characters in the identifier of the bidder i, which coincide with the characters of the identifier of the seller j;

Nc_{ij} is the total number of characters in the identifier of the seller j.

The v_4 parameter is the weight of evidence. We can intuitively interpret this weight as the reliability of the given evidence.

The higher the ratio of identical characters in identifiers (user names) of bidder i and seller j to the total number of characters in the identifier (user name) of seller j, the higher the suspicion that the bidder i is a „shill”. We assume also that the equation does not show that the bidder is not a „shill”, i.e. $m_{Po}(\{\neg shill_i\}) = 0$.

5) Combination of characteristic signs (proofs) of shill behavior

Once we obtain the belief functions, we combine them in a consistent manner to get a more complete assessment of what the whole group of signs indicates. The combination of belief functions is done with the help of the Dempster's combination rule. We express the assumption that a given bidder i is a shill with the help of belief function $m_v(\{shill_i\})$. We calculate the value $m_v(\{shill_i\})$ using the combination of single belief functions expressing appropriate evidence:

$$m_v(\{shill_i\})=(m_{Vc}\oplus m_C\oplus m_{Mva}\oplus m_{Po})(\{shill_i\})$$

The operator ⊕ is the Dempster's rule of belief function combination.

We perform the combination of multiple proofs according to the Dempster's rule – first we combine two belief functions, then we combine the result with the third belief function, fourth belief function and so forth.

For example, the following rules combine the first and second belief functions:

$$(m_{Vc}\oplus m_C)(\{shill_i\}) =$$
$$\frac{1}{K}[m_{Vc}(\{shill_i\})m_C(\{shill_i\})+m_{Vc}(\{shill_i\})m_C(\Theta)+m_{Vc}(\Theta)m_C(\{shill_i\})]$$
$$(m_{Vc}\oplus m_C)(\{\neg shill_i\}) =$$
$$\frac{1}{K}[m_{Vc}(\{\neg shill_i\})m_C(\{\neg shill_i\})+m_{VC}(\{\neg shill_i\})m_C(\Theta)+$$
$$m_{Vc}(\Theta)m_C(\{\neg shill_i\})]=0$$

$$(m_{Vc}\oplus m_C)(\Theta)=\frac{1}{K}[m_{Vc}(\Theta)m_C(\Theta)] \tag{6}$$

where K:

$$K=1-(m_{Vc}(\{\neg shill_i\})m_C(\{shill_i\})+m_{Vc}(\{shill_i\})m_C(\{\neg shill_i\}))$$

or

$$K=(m_{Vc}(\{shill_i\})m_C(\{shill_i\})+m_{Vc}(\{shill_i\})m_C(\Theta)+m_{Vc}(\Theta)m_C(\{shill_i\})+$$
$$m_{Vc}(\{\neg shill_i\})m_C(\{\neg shill_i\})+m_{Vc}(\{\neg shill_i\})m_C(\Theta)+m_{Vc}(\Theta)m_C(\{\neg shill_i\})+$$
$$m_{Vc}(\Theta)m_C(\Theta))$$

When constructing belief functions, we assume that they do not reflex that a given bidder is not a „shill" (they do not prove that bidder i is not a „shill"). It is valid that $m(\{\neg shill_i\})=0$. After calculating the belief value that bidder i shows character of shill behavior, the value $m(\{shill_i\})$ is assigned to bidder i as a measure which indicates the strength of the conviction that the user i is a shill.

6) *Determination of the degree of user's trustworthiness based on determination of shill behavior*

Shill behavior is the sign of user's untrustworthiness because a user performing shill bidding could engage in other illegal activities in an online auction (while selling or bidding in certain online auctions). We now express the trustworthiness of a user based on the belief function representing shill behavior. For this purpose we use a belief function as well. It has the form:

$$m_v(\{\neg T\}) = \eta_v \cdot m(\{shill\}) \tag{7}$$

where the parameter η_v is the weight of the given evidence. Hence it is the weight of the evidence that the given user is untrustworthy because he performs shill bidding.

We also assume that the evidence that the user does not perform shill bidding has no influence on the trustworthiness of this user. We can write: $m_v(\{T\}) = 0$. This is also based on the premise that $m(\{\neg shill\}) = 0$.

We can write further for m_v:

$$m_v(\Theta) = 1 - m_v(\{\neg T\}) = 1 - \eta_v \cdot m(\{shill\}) \tag{8}$$

C. *Calculation of total trustworthiness*

We have two proofs concerning the trustworthiness of a user. The first proof is the evaluation of a seller by buyers following the completion of a transaction. The second proof is contingent with symptoms of illegal behavior during an online auction. We define relevant belief functions on the basis of the mentioned proofs. The belief function m_{Rp} indicates reputation-based evaluation of other users. Belief function m_v indicates possible illegal behavior in an online auction. The combined belief function m_D (expressing the total trustworthiness of a user) is then calculated $m_D = m_{Rp} \oplus m_v$.

We have defined the belief function based on mentioned evidence, for example like this:

$m_{Rp}(\{T\}) = 0.95$ $m_{Rp}(\{\neg T\}) = 0.04$ $m_{Rp}(\Theta) = 0.01$

$m_v(\{T\}) = 0$ $m_v(\{\neg T\}) = 0,2$ $m_v(\Theta) = 0.8$

We can use Demspter's combination rule:

$m_D = m_{Rp} \oplus m_v$

$$m_D(\{T\})=\frac{\sum_{t_i\cap t_j=\{T\}} m_{Rp}(\{T\})m_v(\{T\})}{1-\sum_{t_i\cap t_j=\phi} m_{Rp}(\{T\})m_v(\{T\})}$$

$$=\frac{m_{Rp}(\{T\})m_v(\{T\})+m_{Rp}(\{T\})m_v(\Theta)+m_{Rp}(\Theta)m_v(\{T\})}{1-(m_{Rp}(\{T\})m_v(\{\neg T\})+m_{Rp}(\{\neg T\})m_v(\{T\}))}$$

$$=\frac{0.95\times 0+0.95\times 0.8+0\times 0.01}{1-(0.95\times 0.2+0\times 0.04)}=0.938272$$

$$m_D(\{\theta\})=\frac{m_{Rp}(\Theta)\times m_v(\Theta)}{1-(m_{Rp}(\{T\})\times m_v(\{\neg T\}+m_{Rp}(\{\neg T\})\times m_v(\{T\}))}$$

$$=\frac{0.01\times 0.8}{1-(0.95\times 0.2+0\times 0.04)}=0.009877$$

$$m_D(\{\neg T\})=1-m_D(\{T\})-m_D(\Theta)=0,051852$$

We treat the measure (metric) of trustworthiness as a criterion of to what degree a member of a group is viewed as trustworthy by other members of the same group. The mathematical representation is often used to represent various levels of trust, properties of trust and also some degree of uncertainty [14]. We used the continuous variable in interval [0,1] for trust representation. It corresponds best to the usage of belief function, see the Figure 1.

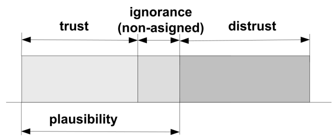

Figure 1. Trust representation via belief function

We describe the level of trustworthiness of a user by means of belief $m_D(\{T\})$. Belief $m_D(\{T\})$ indicates the trustfulness of a user in the sense that this user will conduct her activity correctly and according to expectations. On the contrary, $m_D(\{\neg T\})$ means that we do not belive this user will perform this activity correctly and according to expectations. Belief $m_D(\Theta)$ means that we are not sure what the user will do (whether he will or will not perform the activity correctly and according to expectations).

The selection of the right approach for the representation of the trustworthiness (reputation) varies based on the requirements of individual online auction systems [14]. However, an approach which is able to represent uncertainty (e.g. the Dempster-Shafer approach) allows us to obtain results that are intuitively correct.

IV. CASE STUDY AND ANALYSIS OF RESULTS

We studied data from current auctions on the Czech online auction platform Aukro [1]. We explored the bidding history of multiple auctions and reputation of sellers and bidders participating in these auctions. We studied and counted total number of positive and negative comments, total number of bids, number of bids of single bidders in respective auction, number of wins, time of duration of auction, timing of bids, characters of identifiers of sellers and bidders etc. We had to investigate all information manually because Aukro does not have (in contrast to eBay [15]) any API interface enabling automatic gathering of information. The results of our investigation are presented in the table I and III.

First we tried to reveal the shill behavior of bidder *i* in an auction of seller *j* (using bidder *i* for shilling). Then, we investigated reputation of seller *j* (comments written by other users after conducting a transaction with seller *j*). Then, we calculated the total trustworthiness of seller *j* based on two proofs concerning the trustworthiness of this seller: evaluations of the seller after performed transactions (reputation) and possible evidence of illegal behavior during an online auction (shilling).

Table I

AUCTION DATA COLLECTED FROM CZECH ONLINE AUCTION AUKRO [1]

Bidder *i*	Number of bids of bidder *i* in the auction of *j* seller	Total number of bids in all auctions in which the bidder *i* participated	Time from last bid of bidder *i* to the end of auction (min)	Total time of auction duration (min)	Number of wins of the bidder *i* in all auctions he participated	The ratio of the same characters in the bidder *i* and seller *j* identifiers and the total number of characters in the seller *j* identifier
v***a	2	4	2160	14400	0	1/11
P***e	2	3	760	11520	0	1/7
m***4	2	4	690	7200	0	2/8

The belief of shill behavior and uncertainty of shill behavior are calculated using equations (2), (3), (4) and (5). Calculations are presented in the table 2. The weights of evidence v_1, v_2, v_3 a v_4 were set as 0.8, 0.8, 0.7 and 0.95. The values correspond to our survey of the relevance of single described characteristics and correspond to a certain degree to the data from the literature [7].

Table II

THE BASIC MASSES ASSIGNED TO SINGLE SHILL BEHAVIOR CHARACTERISTICS (EQ. (2), (3), (4) AND (5)

Seller *j* using bidder *i* as a shill	Bidder *i* suspect of shilling	$m_{ve}(\{shill\})$	$m_c(\{shill\})$	$m_{Mva}(\{shill\})$	$m_{Po}(\{shill\})$	$m(\{shill\})$	$m(\Theta)$
T***t	v***a	0.40	0.65	0.70	0.09	0.94	0.06
m***2	P***e	0.53	0.74	0.70	0.14	0.96	0.04
r***n	m***4	0.40	0.75	0.70	0.48	0.98	0.02

We performed an experiment in a real online auction, Aukro, where a user's evaluation is based on a three-value scale. Negative evaluation is -1, neutral 0 and positive 1. We investigated data of those sellers that we suspected of engaging in shilling. The belief functions are calculated using (1).

Table III

REPUTATION AND BELIEF FUNCTION FOR SELLERS SUSPECTED OF USING SHILLS

Seller *j*	Number of positive comments	Number of negative comments	Number of neutral comments	$m_{Rp}(\{T\})$	$m_{Rp}(\{\neg T\})$	$m_{Rp}(\Theta)$
T***t	48	1	3	0.92	0.02	0.06
m***2	156	2	1	0.98	0.01	0.01
r***n	67	1	10	0.86	0.01	0.13

Then, we calculated the total trustworthiness of seller *j* from two belief functions expressing reputation (evaluations of performed transactions) and possible illegal behavior during an online auction (shilling). In this step, it is important to set the value of the parameter η_v. This parameter is the weight of the evidence that the given user is untrustworthy because he performs shill bidding. We set the values of this parameter as 0.5 (we will discuss this value in the next section).

Table IV
CALCULATION OF TOTAL TRUSTWORTHINESS FOR CHOSEN SELLERS

Seller	$m_D(\{T\})$	$m_D(\{\neg T\})$	$m_D(\Theta)$
T***t	0.87	0.08	0.05
m***2	0.96	0.03	0.01
r***n	0.76	0.11	0.13

The seller m***2 has a good reputation. The belief (suspicion) that she uses shilling is greater than that of seller T***t. Nevertheless the total trustworthiness remains very high due to the deciding role of reputation. The total trustworthiness of the seller r***n decreased notably and her untrustworthiness increased considerably. The belief (suspicion) that the seller r***n uses shilling is very high. Table III also shows that the reputation of seller r***n is not very high (0.86). But her neutral reputation is 0.13, and she has low negative reputation (0.01). We can deduce on the basis of these reputation data that the user is to a certain extent trustworthy, and it is possible to conduct transaction with her in online auction. However, we must be aware of some uncertainty ($m_D(\Theta) = 0.13$) connected with this user and must be take precautionary measures (make sure that her identity is properly verified etc.). But when we take into account the belief that this seller uses shilling (table IV), then our consideration will change. The untrustworthiness of this seller is now high (0.11) and we would probably avoid conducting any transactions in online auction with this user.

V. CONCLUSION AND FUTURE WORK

In our work, we presented a computational model to derive interpersonal trust connectivity based on the trust value (expertise) for a seller and her possible fraudulent behavior. In our trust model, we can increase the prediction of trust connectivity by combining direct experience with a reputation based on an individual user's direct experience, compared to using either direct experience or a reputation, and also with evaluation of possible fraudulent behavior (shilling).

In our future research, we want to experiment with integrating additional pieces of evidence that indicate the reputation value of users. We want to further explore the dependence of fraudulent behavior on the value of untrustworthiness of a user (see parameter η_v in eq. 7). We have estimated the value of this parameter η_v, but additional research is needed.

We want to implement our own experimental auction system which we would use also for the education purposes. Such experimental device is necessary because not all necessary experiments are possible to perform in real auction and also evaluations (users' reputations) in real auctions are unrealistically positive [13].

We are convinced that trust modeling provides benefits not only to potential bidders but also to sellers and online auction operators. The trust model serves the role to differentiate between users and is advantageous to sellers who provide high quality products and services. Our study has contributed to the deepening of our understanding of trust, which is an important concern in e-commerce. We are also convinced that the use of the Demster-Shafer theory can provide a practical approach and can be used for calculation of users' trustworthiness in real online auctions.

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