

# Design of Reputation Systems in Online Auction Marketplaces: A Comparative Market Study

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## ABSTRACT

*Reputation systems aim at facilitating the emergence of trust between transaction partners in online auction marketplaces. In this paper the reputation systems of the six largest online auction marketplaces in the German market are evaluated. To this end, a catalogue of criteria regarding design options for reputation systems was developed. Since eBay is widely criticized for shortcomings of its reputation system, it was assumed that its five competitors have a vital interest in distinguishing themselves in this important aspect of auction platform design. The results of the empirical analysis however point to the contrary: Reputation systems largely show a dominant design with only marginal deviations in detail. The reasons for this, the actual differences between the reputation systems, as well as general limitations of reputation systems are discussed.*

## INTRODUCTION

Online auctions have developed into a successful and widely used trade channel among consumers and businesses. Online auction marketplaces (e.g. eBay) have several advantages for trading partners such as easy market access, fast transactions, or price transparency. However, these advantages come at the cost of several risks, especially from the perspective of the buyer. The buyer cannot see and evaluate the product and thus has to trust in the seller's honesty when determining a bidding strategy. Furthermore, the buyer has to pay the seller upfront and thus to take the risk of being defrauded by not being delivered with the described product.

The auction platform provider is only responsible for running the platform but not involved in the actual transactions. Any transaction risks are borne by the trading partners (Resnick *et al.*, 2000). In order for successful transactions to actually happen, some form of trust has to emerge between the trading partners. Auction platform providers have developed reputation systems in order to facilitate trust emergence and to provide incentives for trading partners to engage in positive trade behavior (Dellarocas, 2003).

### The Role of Reputation Systems in Trust Formation

In traditional business relationships trust originates from recurring personal contacts. However, in online platforms anonymous buyers and sellers meet to engage in one off deals. Reputation systems function as mediators between buyers and sellers by allowing the necessary levels of immediate trust to emerge (Dellarocas, 2000; Resnick *et al.*, 2000). Reputation systems collect, distribute, and aggregate feedback about the conduct of market participants (Resnick *et al.*, 2000).

A reputation reflects the past behavior and serves as an indicator for the future behavior of a user ("shadow of the future") (Friedman and Resnick, 2001). A reputation originates from a collection of assessments of past transactions and manifests itself as a score and a list of comments which together are part of the so-called user profile. By doing so, past experiences are shared and made available for all users in the marketplace as a form of public good (Dellarocas, 2004). The reputation of a seller can be seen as a measure of his trustworthiness that holds a certain value (Melnik and Alm, 2002; Shmatikov and Talcott, 2005). This is reflected in the willingness of buyers to pay a higher price for the same item in cases where the seller shows a better reputation (Lucking-Reilly *et al.*, 2000; Resnick *et al.*, 2002).

A well-working reputation system is not only important for the actual trading partners, but also for the auction provider whose aim it must be to achieve and maintain a critical mass of buyers and sellers on the platform. If sellers are motivated to behave cooperatively by the reputation system this has a spill-over effect on the reputation of the entire platform. Consequently, a reputation system is a vital component in attracting new users. For the trading partners, the reputation system reduces the uncertainty in transactions over distance; it provides mechanisms that negatively mark deceitful and positively acknowledge cooperative behavior. Moreover, existing user profiles resemble switching costs and increase customer retention. Hence, online auction providers should have a vital interest in the success of their reputation systems.

### A Comparative Market Study

Existing reputation systems, especially the one of the market leader eBay, are criticized for a range of shortcomings. Firstly, it is comparatively easy for a seller with criminal energy to forge a reputation of positive feedback by setting up a large number of fake or very low priced transactions or by joining criminal circles of users who exchange positive feedbacks. Secondly, the eBay system allows the users to dish out so-called revenge assessments; it allows the seller to return to the buyer a negative rating out of spite even in cases where the buyer gave a legitimate negative feedback. This opens the door for putting pressure on the buyer. Finally, setting up fake accounts under a false identity is also a considerable problem. This might potentially damage the reliability of the whole reputation system. Given that the eBay reputation system is all but perfect the question arises how other providers go about the design of their reputation systems. How do they differentiate from the incumbent player and which conclusions can be drawn from this for the improvement of the eBay platform?

To pursue these questions, the paper reports on an expert evaluation of reputation systems in the German market for online auctions. Its main research question is: "How do competitors use their reputation systems to differentiate from the incumbent player eBay in order to attract users on the basis of a more advanced and secure reputation system?" This question is based on the assumption that competitors should have an interest to create a more trustworthy environment in order to win over change-willing users. To deal with this question, design aspects of reputation systems were identified based on a combination of literature analysis and empirical investigation. In the following paragraphs a brief overview of these requirements is provided before the evaluation is discussed.

## DESIGN REQUIREMENTS OF REPUTATION SYSTEMS

Designing reputation systems is challenging: Buyers want reliable and rich information that supports the identification of trustworthy sellers (Resnick and Zeckhauser, 2001). Reputation systems should ensure fairness in the rating process and encourage the seller to comply with the descriptions of the auction offering and to engage in cooperative behavior (Dellarocas, 2000). Sellers on the other hand want the reputation system to distinguish between good and bad reputations in order to be rewarded for cooperative behaviour. Finally, auction providers want the reputation system to encourage trustworthy behaviour that leads to a cooperative code of conduct on the platform. According to Resnick *et al.* two phases can be distinguished in a reputation process: 1) In the feedback or rating process users

are assessed by other users and feedback is stored in a database. 2) In the decision process the condensed feedback of all transactions is presented as a seller's profile to support a buyer decision. The following design aspects form the criteria catalogue for the empirical evaluation of the six reputation systems.

### Design of the Rating Process

At the end of an auction transaction users have to be motivated by the reputation system to rate their counterparts in a fair and honest manner. In designing the rating processes providers have to take into consideration the following aspects:

- Who is entitled to give feedback (Kollock, 1999)? In a bidirectional feedback process both parties are allowed to rate the quality of the transaction. However, such an approach is prone to the problem of revenge assessments.
- Does the platform provide incentives to give feedback (Resnick and Zeckhauser, 2001)? Here, it is a matter of avoiding the "free-riding" problem by which users benefit from positive ratings of other users but do not place assessments themselves.
- Is the rating mandatory, i.e. are there sanctions for users otherwise?
- How is the assessment structured (Kollock, 1999), i.e. in which way is the feedback extracted, by selecting a judgment from a drop-down list, by allocating point values, by text comments etc.?
- How is a single feedback incorporated in the user profile? Does the system provide a percentage value of positive ratings?
- Is it possible to make amendments to an existing feedback? In case of a conflict does the provider allow to delete a feedback?
- Is it possible to comment on a feedback? This can be helpful in documenting a dispute so that other users are able to judge for themselves.
- Does the system encourage honest ratings (Dellacorras, 2003; Resnick and Zeckhauser, 2001)? Which mechanisms are provided in this context?
- Can feedbacks be hidden? If so, users might be able to hide comments to guise a negative reputation.

### Design of the Decision Process

The design of the decision process is crucial, because the usefulness of a reputation system is determined by how good a buyer is supported in accessing existing user profiles. The following aspects have to be dealt with:

- How are potential buyers informed about the feedback mechanism and its role in establishing trust?
- How are the feedback profile and the feedback score presented? Is the buyer able to immediately comprehend the reputation of the seller on the actual auction page?
- How can the buyer access additional information on the seller's reputation?
- How is the feedback history presented? An aggregate score (e.g. the difference of positive and negative ratings) does not reflect the particularities of the underlying auction transactions. Further information on the feedback history is necessary.
- Is there a filter with which the buyer can search in the detailed profile (history) of the seller, e.g. is it possible to filter for negative feedback?
- The profile might be accomplished with additional data on the seller, e.g. information on the registration date or whether the seller is active as a commercial trader or as a private person.
- In addition, the provider might allow users to undergo a specific registration process that incorporates an official identification to confirm the identity of the user and thus to enervate problems of anonymity.
- Is the reputation profile always displayed besides the user name, or only if the user is active as a seller (Resnick and Zeckhauser, 2001)?

## RESULTS OF EMPIRICAL EVALUATION AND DISCUSSION

In order to investigate our research questions we evaluated the reputation systems of the six largest online auction providers in Germany. Since Germany is the second largest online auction market<sup>1</sup> our results should be typical of and thus transferable to other Western countries. Using the criteria presented above the following platforms were analyzed: eBay.de, Hood.de, Auxion.de, BesteAuktion.de, Ricardo.ch and Azubo.de<sup>2</sup>. All platforms were evaluated by two experts independently. The results were then discussed; in the few cases where results differed agreement was reached by further specifying the evaluation criteria. Detailed evaluations of the six providers can be found in the appendix; we focus our discussion on significant overlaps and differences.

### Dominant Design of Reputation Systems across all Six Platforms

The initial assumption of this study was that competitors should have an interest in differentiating their reputation systems to avoid a range of problems well-known from eBay, and more importantly to gain a competitive advantage to attract new customers. However, this assumption cannot be confirmed based on our study. To the contrary, it turns out that the reputation systems show very strong similarities in nearly all design aspects. This holds true for both the rating process as well as the decision process:

- User assessments on five of the six platforms consist of a text comment plus a rating in the categories "positive" (+1), "neutral" (0) or "negative" (-1). Then an aggregate score is calculated, mostly by adding positive and subtracting negative ratings or by calculating a percentage. Only Azubo came up with a different way of extracting customer assessments (see later).
- All platforms follow the distinction in short user profiles available on the actual auction page and a detailed history accessible on one or more separate pages.
- On all platforms profiles are only shown on the actual auction page; it is not possible to use user reputations as a search or selection criterion in browsing for products.
- The representation of the short profiles generally follows the same patterns although numerical values and symbols vary slightly with most of the competitors showing even less information than eBay.
- On the history page all user comments and ratings are listed and most providers show a breakdown of all ratings as a matrix of the three categories (+ / o / -) and time periods.
- Most platforms provide a function for filtering the list of comments.

Overall, the deviations between the platforms are limited to details and mostly manifest in the fact that the five competitors lack behind eBay in terms of range of features as well as their presentation. Only few features indicate some form of independent development. By and large, we see a dominant design of reputation systems in the market for consumer-oriented online auctions.

A dominant design of a product or a service exists when it permeates a marketplace to the extent that it forces all actors in the market to standardize, e.g. to adhere to the dominant design (Abernathy, 1978). Players newly entering such a market feel immediately constrained in their design freedom while having to take over the established design features (Utterback, 1994). If a dominant design has emerged, design variations only take place within narrowly defined margins. Dominant designs often appear by way of imitation in cases where one dominant player controls the majority of the market (Voss, 2004). Clearly, this well-describes the market for online auction marketplaces in Germany. Moreover, with its transparency and openness the Internet lends itself to imitation processes making it easy for competitors to copy front-end features (e.g. reputation systems) since their design is well visible to the public.

Reasons for competitors imitating the eBay reputation system can lie in reducing the design uncertainty; the auction providers need not experimenting with mechanisms when the dominant player already demonstrates their successful functioning. On the other hand, it can be assumed that eBay's dominance exerts a conditioning effect on consumers. Many consumers have already learned and are accustomed to the interaction with the particular design eBay has chosen for its reputation system. If a competitor wants to deviate significantly from the dominant design, he risks not being able to connect with the established customs inherited by customers. He might thus lose the ability to attract customers who are willing to switch over from eBay. In line with this interpretation, the six reputation systems are found to follow design patterns dominated by eBay with rather marginal differences that lie within the borders of an otherwise uniformly interpreted reputation systems design.

### Design Differences in Detail

Drawing from the differences presented in table 1 it can be argued that eBay is one step ahead of its competitors in some important aspects of reputation systems design. This can be seen as typical for a market leader. eBay provides the most comprehensive set of features for buyers to evaluate the past behavior and transaction history of a seller. Only a combination of various types of information about the seller and his activities puts the buyer in a position to comprehend the level of seller reputation, to make an informed decision, and hence to avoid unpleasant surprises. The short profile and rating score is only one source of information

Table 1. Areas in which eBay is ahead of most of the competitors

Design aspects	Explanation
Assessments are counted only from different users (only one per user)	This is an important precondition to prevent problems of friendly assessments with the intention to construct a positive reputation profile. Nevertheless, for smaller auction providers with only few active users in particular product groups of the platform the problem arises that profiles are built much more slowly. This may significantly delay the achievement of a critical mass of users.
Additional user information	eBay provides the most comprehensive list of additional information on the seller while two of the competitors do not even give information about the registration date of the user (is it a newly registered or long established user?).
Underlying auction can be accessed from the comments list in order to learn about the product and its value	The value and type of products sold by a seller in the past gives a good account of his activities: Were many cheap items purchased or sold to quickly build up a profile? Did the seller auctions a different type of product in the past and recently switched to another branch? This can be an indicator for an account that has been hijacked by someone else or for dishonest intentions of the seller (e.g. seller switching from baby clothes to high value tech items).
Profile of the assessing user is displayed in the list of ratings (on the history page)	By doing so, it becomes obvious if a seller receives a lot of assessments of newly registered user that were only set up to artificially improve the profile. Besides, the buyer can see in the profiles of other users if it is likely that the seller will engage in revenge assessments once a problem occurs and the buyer places a negative rating.
Number of withdrawn bids is displayed	How does the seller behave as a buyer? This additional context information can be a valuable jigsaw piece to judge the seller as a person.
Detailed rules of conduct and information on the assessment system available	Education of the users is an essential precondition to avoid cases of misconduct, deception, and fraud. Here, eBay as the market leader is at the center of user fraud and thus is confronted with the majority of security problems. Hence, eBay is very active in the communications department.

which has to be complemented with other information, e.g. on the type and value of products of the underlying auctions that the seller received positive feedback for and the reputation of the users who gave their feedback. Only then is the buyer able to detect cases in which users tried to artificially enhance their profiles. In regards to these features the five competitors all show significant room for improvement. This holds also true for the ways in which the reputation system and its features, the ways of using the system, and means of avoiding problems are communicated by the platform provider (for detailed results please refer to the appendix).

While the incumbent is clearly leading the way in most areas of reputation systems design, some of the differences between the platforms nevertheless reflect some independent development by the competitors. At the same time these differences mark areas in which eBay could further improve its reputation system (see table 2). In particular, the specific filtering options on the detailed history pages are to be mentioned here. These filters allow users to quickly gain an overview of negative assessments, a feature that further improves the buyer's situation in establishing a comprehensive picture of the seller's past behavior. Another feature that can reduce fraud on auction platforms is a mandatory user identification process by means

Table 2: Measures of competitors that go beyond the features of eBay

Design aspects	Explanation
Mandatory user identification by mail, phone or bank account	A secure identification of the users can help to prevent multiple identities and to expel dishonest users permanently from the platform. However, for a market leader like eBay this can lead to considerable expenses and in the short term might hamper platform growth.
Additional visualization of detailed profile	A bar chart visualization (like the one used by Azubo) can assist the user in quickly comprehending the development of a user's reputation over time.
Possibility to fast and easily filter for negative ratings	This is an important feature to get a comprehensive picture of the seller and his activities. In combination with an easy access to the profile of an assessing user this helps uncovering sellers who engage in revenge assessments.
Differentiation of the judgment in several dimensions (see Azubo.de)	A differentiation in behavior of the seller (communications and shipment) and the product quality allows a better evaluation of a seller. It also allows handing in critical judgments without having to place an entirely negative assessment, which most users want to avoid. Hence, this feature might lead to a more honest rating behavior and richer information.
Incentives to place assessments quickly	The more time elapses until users hand in their assessments the longer can seller misconduct go uncovered. Timely information is essential to limit fraud.
No time restrictions for handing in assessments	An artificial time restriction leads to unwanted tactics like users waiting up to the last second to place negative assessments in order to not having to fear a revenge assessment.

of postal address (Ricardo.ch), telephone number (BesteAuktion), or passport photocopy (auxion.de); introducing such a feature would significantly increase the cost of setting up fake identities at eBay. Finally, Azubo's compulsory and sophisticated feedback mechanism might inspire eBay to move towards a more differentiated way of eliciting feedback in order to give the user a mechanism to utter dissatisfaction with particular seller actions without having to place an overall negative assessment. Without such a mechanism negative conduct might go uncovered since users might simply follow the path of least resistance and place a positive feedback. This might especially be the case when the buyer has to fear negative revenge assessments. However, no competitor had any mechanism in place to prevent such revenge assessments.

## LIMITATIONS OF THE REPUTATION SYSTEMS

Besides the dominant design of their reputation systems the six platforms in our sample also share a set of important limitations, some of which were already mentioned at the beginning of the paper. A comprehensive list of all possible problems would go beyond the scope of this paper; some typical problems however became obvious during the course of our enquiry.

A typical problem mentioned in the literature is the artificial creation of positive profiles by means of so-called 'profile baking circles' in which users exchange positive assessments based on low-value transactions deliberately setup for this purpose (Bhattacharjee and Goel, 2005; Dellarocas, 2000). In order to raise the cost for this kind of tactics eBay decided to only count one assessment per user in calculating rating scores. The competitors however did not follow this measure so far; one reason might be that this would significantly limit the growth of feedback profiles, which is a problem for smaller platforms with only limited numbers of users.

Another problem is that the current profile might not truly reflect a seller's actual behavior at any given point in time, reason being that there is a time lag between the end of a transaction and the buyers handing in their assessments. In addition, the formal clarification process demanded by the providers in case of a dispute also delays the publication of negative assessments. One way to speed up the feedback process is to give incentives for timely assessments, e.g. in terms of an extra quarter point added to the score (see BesteAuktion) and by marking in the profile the existence of an ongoing dispute.

Another significant problem of the reputation systems lies in the possibility of unwarranted revenge assessment. While all providers permit commenting on a negative feedback using a short statement, a deletion of unwarranted assessments is tedious and only possible in special cases and with mutual consent of both parties. Such a process might even reward a seller for putting pressure on a buyer who placed a justified negative feedback. Hence, the risk remains that buyers are blackmailed or that sellers have their reputation damaged by competitors who bid on the seller's auction in order to deliberately harm their reputation (Dellarocas, 2000). Revenge assessments can be prevented by means of making the assessments available only when both parties have finished submitting their feedbacks. Of course, this has to be combined with making feedback mandatory and with speeding up the process. Otherwise users might be able to prevent the other party's feedback from being published by not submitting their own feedback, which would allow them to suppress negative feedback.

## CONCLUSIONS

The contribution of this study is twofold. Firstly, a criteria catalogue for evaluating online auction reputation systems was compiled. Secondly, the empirical evaluation of the six largest auction platforms in Germany revealed a dominant design of reputation systems that is shaped and dictated by eBay as the incumbent player. Not only are the competitors not able to differentiate from eBay in this important area of platform design, they even lack behind in terms of range and quality of features. Consequently, eBay is not only able to demonstrate market leadership in economic terms, but also in the design of crucial aspects of the trading platform. It can be argued that, albeit the problems discussed above, eBay's reputation system is up to the task and fulfils customer needs to a satisfactory level as other studies have shown (Resnick and Zeckhauser, 2001; Resnick et al., 2000). However, online reputation systems still have certain limitations in simulating trust mechanisms well-known from traditional off-line markets (Bolton et al., 2004). As we have argued above, there is still considerable room for improvement to tackle some of the most prevalent problems that allow or even abet online auction



fraud. This leaves room for further research on the design of reputation systems, especially since our study took an outside perspective using expert evaluation to rate the reputation systems. Further research should extent our work in two directions: Experimental studies should explore the perspective of average users while international comparative studies should aim at contrasting the situation in different national markets.

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ENDNOTES

<sup>1</sup> [http://investor.ebay.com/downloads/12105\\_ebay\\_GS.pdf](http://investor.ebay.com/downloads/12105_ebay_GS.pdf)

<sup>2</sup> Following recent statistics [May 2006] from [www.auktionssuche.de](http://www.auktionssuche.de) these are the six largest consumer-oriented auction providers in Germany; eBay features 15,000,000 auctions while the runner-up Hood.de only accounts for 900,000 auctions.

APPENDIX

Table 3: Detailed evaluation results, part 1

	eBay.de	hood.de	auxion.de	BesteAuktion	ricardo.ch	azubo.de
Rating process (profile building)	Who is eligible to give feedback?	Buyer and seller	Buyer and seller	Buyer and seller	Buyer and seller	Buyer and seller
	Is there an incentive/compensation for giving feedback?	no	no	yes, user gets a quarter scoring point	no	no
	Is giving feedback mandatory?	no	no	Yes. When buyer does not give feedback, the seller automatically receives a positive rating.	no	no
	Structure of the feedback?	Three categories (positive/neutral/negative) plus short comment	Three categories (positive/neutral/negative) plus short comment	Three categories (positive/neutral/negative) plus short comment	Three categories (positive/neutral/negative) plus short comment	Answering of three questions regarding seller user behavior (Answers good/med/poor)
	How is a rating incorporated in the profile?	A score is calculated by adding positive and subtracting negative ratings; only one rating per member is counted	Like eBay, but all ratings are counted	Number of positive, neutral and negative ratings are added up as scores; all ratings are counted	Number of positive, neutral and negative ratings are added up as scores; all ratings are counted	A percentage of positive ratings in relation to all ratings is calculated
	Is it possible to modify or delete an existing feedback/rating?	no, deleting a comment is only possible in special cases and when both parties agree	no, deletion is only possible in special cases (offensive ratings, advertising)	no	no	no, deletion is only possible in special cases (offensive ratings, advertising)
	Comments on feedback possible?	yes	yes	yes	yes	yes
	Feedback guidelines: how is fairness and honesty be encouraged?	Detailed guidelines and rules of conduct	Detailed guidelines and rules of conduct	Very limited / no information	Very limited / no information	Detailed guidelines and rules of conduct
	Is it possible to hide ratings or comments?	No, a user can only declare his profile private and hide ALL ratings.	no	no	no	no

Table 4: Detailed evaluation results, part 2

	eBay.de	hood.de	auxion.de	BesteAuktion	ricardo.ch	azubo.de
Decision process (feedback usage)	Where can information regarding the reputation system be found?	Following the link "help" and "ratings" detailed information can be found	Like eBay, but information is quite limited	Only limited information, hidden somewhere in the "help" pages.	Following the link "help & hints" and "other" information can be found (but very limited)	Following the link "help" - "extra" - "rating system"; information is very limited
	How is the rating score visualised?	Score value, plus coloured star symbol (starting with a score of 10). Powerseller symbol for high volume sellers.	Score value, plus up to 7 stars depending on number of positive ratings (starting with 5), plus percentage value.	Number of positive, neutral and negative ratings are displayed as scores.	Number of positive, neutral and negative ratings are displayed as scores, plus star and crown symbols in gold, silver, bronze depending on number of positive ratings	Percentage value plus a number of up to 4 stars, displayed in 5 different colours. Diamond symbol in addition, when score > 99%.
	How can further information be accessed?	By clicking on the score value or a dedicated link a page with a detailed profile can be accessed	By clicking on the score value or a dedicated link a page with a detailed profile can be accessed	By clicking on the score value or a dedicated link a page with a detailed profile can be accessed	By clicking on the user name a page with a detailed profile can be accessed	By clicking on the user name a page with a detailed profile can be accessed
	How is the feedback history be presented?	Table with number of pos/neutral/neg ratings in different time periods / List of ratings, user comments with short profile of this user, date, and link to the resp auction, and whether user was buyer of seller	Table with number of pos/neutral/neg ratings in different time periods (plus chart) / List of ratings, user comments, date, and link to the resp auction, and whether user was buyer of seller (profile of user cannot be accessed)	Number of pos/neutral/neg ratings / List of ratings, user comments, date, and link to the resp auction, and whether user was buyer of seller (profile of user cannot be accessed)	More or less a list of ratings with comments and short profile of this user, date, and whether user was buyer of seller (no link to auction or info whether user was seller or buyer)	Table with number of pos/neutral/neg ratings in different time periods / List of ratings, user comments with short profile of this user, date, and whether user was buyer of seller (but no link to auction)
	Is there a filter to search for positive of negative feedback or to change the appearance of the profile?	Filtering for seller/buyer comments and for different time frames (filtering for negative ratings is only accessible when filtering for a time period)	no filter, only one listing	Filtering for pos/neutral/neg ratings and for received and given ratings	Filtering for pos/neutral/neg ratings.	Filtering for pos/neutral/neg ratings and listing of own ratings given by the user.
	What additional user information is available?	"Registered since", "commercial/ private", "my page", plus icon for verified users.	"Registered since", "my page", "ratings by this user", plus icon for verified users	None	"Registered since", but only accessible in detailed profile	"commercial/ private", "my page",
	Is there a user identity verification?	optional, using the Postident by Deutsche Post AG	no, only verification of email address	optional, using passport photograph	mandatory, by receiving a PIN number over the phone	mandatory, activation code received by post
	Is the profile always presented or only for sellers?	always	always	always	always	always

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### Decimal Hardware Multiplier

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