Measuring Human-Computer Trust

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Abstract

In this study a psychometric instrument specifically designed to measure human-computer trust (HCT) was developed and tested. A rigorous method similar to that described by Moore and Benbasat (1991) was adopted. It was found that both cognitive and affective components of trust could be measured and that, in this study, the affective components were the strongest indicators of trust. The reliability of the instrument, measured as Cronbach's alpha, was 0.94. This instrument is the first of its kind to be specifically designed to measure HCT and shown empirically to be valid and reliable.

Keywords

Human-Computer Trust, Instrument Development, Survey Research, Decision Support Systems, Expert Systems

INTRODUCTION

Trusting computer systems is an increasingly important issue for systems researchers, developers and users due to current market demands to provide and access information and business electronically and the trend toward automation through the use of intelligent systems. Intelligent decision systems are designed to assist the decision-maker to make better task decisions more efficiently (Muir 1987, Lee & Moray 1994, Sheridan 1988, Turban 1995). These systems are referred to here as intelligent decision aids (IDA).

There is one important question for users of IDA – "Do I trust this machine's advice?" An incorrect or inappropriate response to this question may have serious consequences for the user depending on the task they are performing (Muir 1987).

Trust, generally, is a complex concept that is related to, yet not completely analogous with, *confidence*. Human-computer trust is defined in this study to be,

> ***the extent to which a user is confident in, and willing to act on the basis of, the recommendations, actions, and decisions of an artificially intelligent decision aid.***

This definition, adapted from McAllister (1995, p.25), has been chosen as that which most clearly and fully states the concept of HCT as studied here. It encompasses both the user's *confidence* in the system and their *willingness* to act on the system's decisions and advice.

HCT is defined to be, in part, a level of *confidence* on the part of the user to act on, or accept, the advice and decisions generated by the IDA and, in such cases where it is applicable, to allow the IDA to take action without intervention (for example, process control systems). HCT is also defined to be a *willingness* on the part of the user to act on the advice of the system. The user's willingness to act may result from their level of confidence in the system when they have sufficient evidence to make a judgement about the trustworthiness of the system. However, when sufficient evidence does not exist something more than simple confidence is at work. Shaw (1997, p.21) explains this as follows,

> "Confidence (alone) arises as a result of specific knowledge, it is built on reason and fact. In contrast, trust is based, in part, on faith. We sometimes give our trust in spite of evidence that might suggest we should feel some caution, if not outright suspicion, about relying on another."

Thus, the definition of trust suggested above encompasses yet distinguishes between the user's *confidence* in the system and the user's *willingness* to use the machine to perform the decision task as intended. The duality of this definition corresponds well with the trust framework developed in this study from previous trust research results (Barber 1983, McAllister 1995, Misztal 1998, Rempel et al 1985) (see Table 1). *Confidence* may be seen to be the primary outcome from the cognition-based component of HCT and *willingness* (Yamagishi 1986) may be seen to be an outcome of both cognition-based and affect-based components of HCT. Cognition-based components of HCT (CBT) are based on the user's intellectual perceptions of the system's characteristics. Affect-based components (ABT) are those which are based on the user's emotional responses to the system. The overall affect-based component necessarily plays a greater role in situations where the user has insufficient knowledge upon which to base a cognitive decision.

Trust type Relationship Type	**Perceived**		**Manifest**
	Cognition Based	**Affect Based**	
Macro (general)	This society is lawful and we enjoy personal freedoms protected by these laws.	I like living in a free, orderly society.	I choose to continue to live in this society and I obey the laws that protect my personal freedom
Micro (dyadic, specific)	My partner has the same goals as I do.	I love my partner.	I allow my partner to make decisions that will effect my

Table 1: Trust Taxonomy and Framework

There has been little consistency to date in existing HCT research. Neither a robust definition of HCT, such as the one suggested above, nor a well-designed psychometric instrument for HCT could be found.

Initially, investigators of human-computer trust turned to the existing interpersonal trust models as a starting point for their studies. These researchers have attempted to describe and explain the user's development of trust in an IDA by using adaptations of interpersonal measurement instruments or simply creating their own scales (Lee & Moray 1994, Lerch et al. 1993, Muir 1987, 1994, Muir & Moray 1996, Will 1991, 1992). Confirmatory analysis of borrowed scales in human-computer trust studies could not be found and HCT researchers failed to provide evidence to support their selection of measurement instrument and creation of, or selection of scale items. Furthermore, with the exception of Lerch et al. (1993), previous investigators used small numbers of participants precluding any quantitative analysis of the results. Thus their results could not be generalized to other samples nor relied upon by other researchers. Finally, there had been no field work done in human-computer trust research. Existing HCT data was collected via experimental methods and was related to simulated or prototype systems rather than operational systems.

This study attempted to address some of these issues by following a rigourous development process and by testing the instrument in the field. This paper proceeds as follows. The following section describes the process of instrument development, field study test, and statistical analysis. The resutls are then discussed in terms of an underlying model of HCT. Finally, limitations and conclusion of the study are presented.

CONSTRUCTING THE HCT MEASUREMENT INSTRUMENT

Creating the Scales

Once HCT had been clearly defined, the next stage of the research involved the identification of the underlying dimensions of HCT and indicators for each dimension. The Nominal Group Technique (Delbecq et al 1975) was used with a group of four experienced computer users to identify factors believed to be correlated with HCT. This group identified 10 constructs which they believed would affect their level of trust in an IDA. The resultant constructs were compared to constructs from previous trust research (Barber 1983, Lerch et al 1993, Muir et al 1996, Rempel et al 1985, Sheridan 1988). Constructs which were similar in meaning were merged and constructs which were outside the scope of this study were eliminated. Nine constructs emerged as the basis for the new instrument (see Appendix 1). Items were then assigned to these constructs to comprise the initial set of sub-scales in the overall HCT instrument.

Refining the Scales

This set of constructs and items then underwent a series of refinements to eliminate items which were not representative of their constructs and constructs which were not easily discriminated. The method used for refinement was a modification of the Thurstone scaling technique (Moore & Benbasat 1991, Neuman 1994) with four rounds of sorting and four groups of judges. Judges were volunteers who may or may not have had IDA experience.

Inter-Rater Reliability Results

The inter-rater reliabilities for each round were calculated as Cohen's kappa (Moore and Benbasat 1991, Cohen 1960, Fleiss, Cohen and Everitt 1969). The initial instrument with 9 constructs and 74 items was introduced into the first sorting round. Two constructs and 31 items were deleted from the instrument in the first round. This process of sorting and refinement was repeated through the remaining three sorting rounds. The average inter-rater reliability of the scales improved from 0.40 in the initial round to 0.83 in the final round (Appendix 2 Figure 2). The instrument was finally reduced to a parsimonious 5 constructs and 25 items (Appendix 3).

Figure 1 shows expected relationships (E1-E7) between the five constructs, the two major components of HCT and overall HCT based on trust theory and the initial research findings.

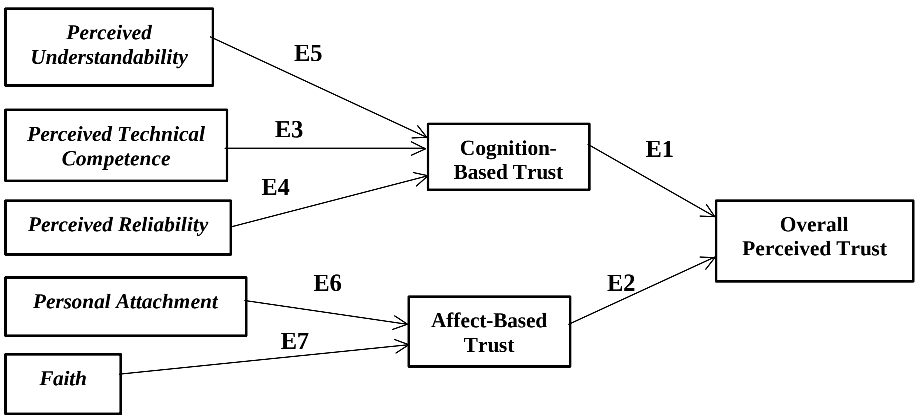

Figure 1: Model of Human-Computer Trust Components

VALIDATING THE INSTRUMENT

Finally, the instrument was tested for construct validity and scale reliability in a field study with users of operational Taxi Dispatch Systems. Four hundred surveys were distributed and 78 were returned completed. Of these, 75 passed through data screening. First the reliability of each of the sub-scales and the overall scale was determined as Cronbach's alpha as seen in Table 2 below. Then several principal components analyses (PCA) were performed on the data controlling for the number of factors produced. PCA was better suited to this study than path analysis techniques, which require that there be well defined relationships among the underlying variables in the model.

Scale	Standard a
Reliability	0.85
Understandability	0.84
Technical Competence	0.74
Faith	0.88
Personal Attachment	0.90
Overall HCT	**0.94**

Table 2: Scale Reliabilities reported as Cronbach's alpha (α)

Principal Components Analysis Results

Single Factor Model

The results of the single factor model (Appendix 4 Table 4a) clearly showed that there was one overarching factor, human-computer trust, to which all the variables were highly correlated.

Two Factor Model

The two factors proposed in the initial model for HCT were affect-based trust and cognitive-based trust. It can be seen clearly, from the rotated component matrix (Appendix 4 Table 4b) that two factors exist and that the items that were considered to be affect-based items load well on the first factor. This factor can thus be considered to be the affect-based trust latent variable. An unexpected result was that items belonging to perceived reliability, which were originally thought to be related to cognitive-based trust, can be seen here to load strongly on the affect-based component. The second factor, cognitive-based trust, is comprised of all the understandability and three of the perceived technical competence items. The result of a two factor model suggested that the affect-based constructs were more significant than the cognition-based constructs in this study.

The Five Factor Model

The decision to investigate the five factor model was based on the expected outcome of the analysis (Dunteman 1989). As such, it was a means of exploring the nature of the sub-constructs or latent variables, and the discriminant validities of the items, or manifest variables. Table 4 shows the five-factor model using a threshold value of 0.4. This value eliminates much of the noise while not eliminating any item completely. It should be noted that loadings of 0.6 and above are considered to be strong and reliable (Dunteman 1989). Therefore, 0.4 is still low enough to include less reliable correlations highlighting some of the problematic variables in this study.

It can be seen in Table 3, which has been ordered so that expected loadings fall along the diagonal, shaded cells, that the five expected scales do in fact appear with the personal attachment, faith, and understandability scales being comprised of all five of the items which were expected to load on these factors. These five factors account for 68.9% of the variance in this data set. Items such as R3 and T4, however, do not show good discriminant validity. The perceived reliability scale is particularly problematic with no items loading cleanly on this scale. Lastly, the results of a five factor model suggested that the underlying factors, faith, personal attachment, perceived reliability, perceived technical competence and perceived understandability, as initially proposed, existed, although not all items loaded on the factors expected.

	Component				
	1	**2**	**3**	**4**	**5**
P1	0.680				
P2	0.693				
P3	0.696				
P4	0.776				
P5	0.762				
F1		0.769			
F2		0.819			
F3		0.681			
F4	0.557	0.540			
F5		0.654			
U1			0.667		
U2			0.700		
U3			0.876		
U4			0.620		
U5			0.660	0.413	
T1	0.475				
T2				0.735	
T3		0.438			0.683
T4⌖	0.405		0.450		
T5				0.767	
R1		0.608			
R2	0.438				0.628
R3				0.512	
R4	0.546				0.533
R5	0.436			0.669	

⌖**T4** is the only item for which the scale reliability would have increased by its removal.

Expected Variable

1 - **P**ersonal Attachment
2 - **F**aith
3 - **U**nderstandability
4 - **T**echnical Competence
5 - **R**eliability

Table 3: Five Factors

DISCUSSION

The results of this study are discussed in terms of the underlying model for HCT depicted in Figure 1.

The Nature of HCT

The results of the principal components analysis strongly support the first two expected relationships, E1 and E2, which state that the overall perceived trust that a user has in an IDA is comprised of both cognitive and affective components.

Also supported are the expected relationships that *cognition-based trust* is comprised of both the *perceived understandability* of the system and the *perceived technical competence* of the system, E3 and E5 . The expected relationship, E4, that the *perceived reliability* of the system is a component of the *cognition-based trust* is not supported in these findings.

The expectation that *affect-based trust* is comprised of both *faith* and *personal attachment* is strongly supported by the findings from this analysis. An unexpected result, for which there is no expected relationship, is that the *perceived reliability* of the system was observed to be a component of *affect-based trust*.

Perceived technical competence appears to be related to both *affect-based* and *cognitive-based trust.* This finding supports E3 in part, but also introduces a possible new relationship between *perceived technical competence* and *affect-based trust*. What remains unclear is whether or not the *perceived technical competence* and *perceived reliability* variables are related to affect-based trust directly or whether they relate to *affect-based trust* through their relationships with the *personal attachment* variable. The relationships among these variables are likely to be far more complex than proposed initially in the current research. The detailed structure of human-computer trust is, as yet uncertain, and this model should not be seen as a final solution.

Scale Reliablities

The *perceived understandability*, *personal attachment* and *faith* scales demonstrated good reliabilities and their respective items were found to have both convergent and discriminant validities. These scales, therefore, are satisfactory as they stand and do not require further consideration at this time. The *perceived technical competence* and *perceived reliability* scales did not fare quite as well.

The *perceived reliability* scale demonstrated sound internal consistency, but its items did not show good convergent validity on their own construct. These items actually converged more consistently on the *personal attachment* construct.

While a user's perception of the reliability of the system and their personal attachment to the system appear to be quite distinct concepts these results would suggest that there may be a close relationship between them. If further studies show a strong positive relationship between these constructs then it may be sufficient to drop the reliability construct and to simply measure personal attachment because the reliability items could then be seen to be redundant.

At this point, however, it is believed that the *perceived reliability* items are important to the content validity of the overall scale and should, therefore, be retained. The conclusion about this scale, then, is to try to improve the convergent validity of its items by clarifying the wording of the items and to re-test the instrument.

The *perceived technical competence* scale had the lowest internal consistency of any other scale in this study, although at 0.74 (Table 2) it might still be considered adequate. These items did not converge well on their own construct nor did they converge well on any other construct. From the two factor model this construct appears to be related to both cognitive and affect-based trust. There were clearly some problems with the interpretation of items for this construct, T4 in particular could be seen to be the least discriminant of any of the items in this instrument. It is difficult from the limited amount of information available from one set of data to draw any hard conclusions about how to deal with this construct. The best suggestion that can be made at this point is that the items for this construct should be reworded and replaced and the instrument should be re-tested.

LIMITATIONS

This study deals specifically with intelligent systems which are designed to aid decision-making. These systems might be designed with various technologies but only those which either provide advice, or make decisions subject to the user’s discretion, are relevant to this investigation.

It is assumed that the user may not have knowledge of the underlying technology nor the specifics of how the system arrives at its output. It is also assumed that the users may or may not be experts in the task domain. Thus they will have more or less task knowledge depending on their level of experience. User experiences with the system being investigated may range from a few months to several years.

Since one objective of this study was to determine quantitatively the validity and reliability of the new measurement instrument it is necessary to consider what constitutes a sufficient sample size. In this case the measurement instrument, was analyzed using Principal Components Analysis (PCA). PCA is reasonably robust to sample size as long as the sampling adequacy can be shown to be relatively large. As a rule of thumb, it is prescribed that the researcher should have a ratio for the sample size to the number of items of at least five to one (Neuman 1994). The ratio in this study was three to one.

Finally, the results of this study may not be generalized too widely. The first caution against generalizing the results is that this study is context specific. The second caution is that this study involves only one sample group and only one method of measurement. Thus the representative reliability of the instrument was not tested nor was it possible to test the criterion validity of the instrument (Neuman 1994, p.131).

CONCLUSION

The approach taken to the development of the new HCT instrument in this study has proven to be one which resulted in a set of scales that show high internal consistency and construct validity. The results from stage one suggest that beginning scale development on the ground by soliciting the opinions of a representative sample of the target group, in this case users of IDA, provides a solid foundation from which to proceed. This ensures that the constructs chosen for investigation are indeed those which are relevant to HCT.

The new instrument has been shown to be both a reliable and valid measure of HCT and may now be used to more fully investigate the structure of HCT in the context of computer-aided decision-making and the dynamics of HCT development. For example, differences in HCT development among various user groups, particularly cultural differences could be investigated. In addition, the instrument and the development process used here provide a basis for the investigation of HCT in other contexts, such as electronic commerce.

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APPENDIX 1 - INITIAL NINE CONSTRUCTS RELATED TO HCT

1. ***Reliability*** of the system, in the usual sense of repeated, consistent functioning.
2. ***Robustness*** of the system, meaning demonstrated or promised ability to perform under a variety of circumstances.

3. ***Familiarity***, that is the system employs procedures, terms, and cultural norms which are familiar, friendly and natural to the trusting person.
4. ***Understandability*** in the sense that the human supervisor or observer can form a mental model and predict future system behavior.
5. ***Explication of intention***, meaning the system explicitly displays or says that it will act in a particular way (as contrasted to its future action having to be predicted from a model).
6. ***Technical Competence*** of the system meaning that the system is perceived to perform the tasks accurately and correctly based on the information that is input.
7. ***Integrity*** of the system in the sense that the system is able to recover from technical failures or user errors without loss of data.
8. ***Personal Attachment*** to the system comprised of: *liking* meaning that the user finds using the system agreeable and it suits their taste and *loving* meaning that the user has a strong preference for the system, is partial to using it and has an attachment to it.
9. ***Faith*** meaning that the user has faith in the future ability of the system to perform even in situations in which it is untried.

APPENDIX 2 - INTER-RATER RELIABILITIES

Inter-Rater Reliability Average k			
Round 1	**Round 2***	**Round 3***	**Round 4**
0.40	**0.32**	**0.44**	**0.83**

*Judges created their own constructs in these rounds

APPENDIX 3 - FINAL HCT INSTRUMENT

The five constructs and their corresponding items produced from the refinement stages of this research are listed below:

1. ***Perceived Reliability***
   R1 - The system always provides the advice I require to make my decision.
   R2 - The system performs reliably.
   R3 - The system responds the same way under the same conditions at different times.
   R4 - I can rely on the system to function properly.
   R5 - The system analyzes problems consistently.
2. ***Perceived Technical Competence***
   T1 - The system uses appropriate methods to reach decisions.
   T2 - The system has sound knowledge about this type of problem built into it.
   T3 - The advice the system produces is as good as that which a highly competent person could produce.
   T4 - The system correctly uses the information I enter.
   T5 - The system makes use of all the knowledge and information available to it to produce its solution to the problem.
3. ***Perceived Understandability***
   U1 - I know what will happen the next time I use the system because I understand how it behaves.
   U2 - I understand how the system will assist me with decisions I have to make.
   U3 - Although I may not know exactly how the system works, I know how to use it to make decisions about the problem.

U4 - It is easy to follow what the system does.
U5 - I recognize what I should do to get the advice I need from the system the next time I use it.

4. ***Faith***
F1 - I believe advice from the system even when I don't know for certain that it is correct.
F2 - When I am uncertain about a decision I believe the system rather than myself.
F3 - If I am not sure about a decision, I have faith that the system will provide the best solution.
F4 - When the system gives unusual advice I am confident that the advice is correct.
F5 - Even if I have no reason to expect the system will be able to solve a difficult problem, I still feel certain that it will.

5. ***Personal Attachment***
P1 - I would feel a sense of loss if the system was unavailable and I could no longer use it.
P2 - I feel a sense of attachment to using the system.
P3 - I find the system suitable to my style of decision making.
P4 - I like using the system for decision making.
P5 - I have a personal preference for making decisions with the system.

APPENDIX 4 - SINGLE AND TWO FACTOR MODELS OF HCT

Single Over-Arching Factor

F1	**0.614**
F2	**0.587**
F3	**0.687**
F4	**0.739**
F5	**0.741**
P1	**0.697**
P2	**0.717**
P3	**0.815**
P4	**0.796**
P5	**0.772**
R1	**0.642**
R2	**0.794**
R3	**0.673**
R4	**0.767**
R5	**0.648**
T1	**0.667**
T2	**0.609**
T3	**0.652**
T4	**0.432**
T5	**0.490**
U1	**0.452**
U2	**0.679**
U3	**0.361**
U4	**0.565**
U5	**0.453**

Two Factor Model

	Component	
	1	**2**
F1	**0.724**	
F2	**0.775**	
F3	**0.737**	
F4	**0.790**	
F5	**0.818**	
P1	**0.652**	
P2	**0.708**	
P3	**0.688**	**0.438**
P4	**0.649**	**0.465**
P5	**0.673**	**0.379**
R1	**0.63**	
R2	**0.681**	**0.408**
R3	**0.553**	**0.386**
R4	**0.716**	
R5	**0.629**	
T1	**0.659**	
T2	**0.403**	**0.508**
T3	**0.613**	
T4		**0.660**
T5		**0.585**
U1		**0.649**
U2	**0.347**	**0.735**
U3		**0.772**
U4		**0.757**
U5		**0.673**

Expected Variable
1 - Affect-based trust
2 - Cognition-based trust

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