Enabling User Involvement in Trust Decision Making for Inter-Enterprise Collaborations

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***Abstract*—Trust decisions on inter-enterprise collaborations involve a trustor's subjective evaluation of its willingness to participate in a specific collaboration, given the risks and incentives involved. We have built support for automating routine trust decisions based on a combination of risk, reputation and incentive information. To handle non-routine decisions, we must provide human users with a way to interface with this system and gain access to supporting information. Current collaboration management systems are missing the concepts, processes and interfaces for enabling user involvement. In this paper, we present two key contributions towards enabling user involvement in trust decision making for inter-enterprise collaborations: i) We have studied existing literature on human trust decision making perspectives, and produced a set of criteria for trust decisions. We analyze how three collaboration management systems support these criteria. ii) We provide a more detailed case study of enabling these features in our Pilarcos collaboration management system through implementing a trust decision expert tool prototype, and report the results of our user experiments on it.**

Keywords-trust decisions; inter-enterprise collaborations; collaboration management middleware; user interfaces

I. Introduction

Networked business is moving from closed strategic networks into open business ecosystems where inter-enterprise collaborations, i.e., business networks, are facilitated. In an inter-enterprise collaboration, services from independent organizations are brought together by interrelated business processes to achieve a shared goal for end users as a composed service. An online travel agency, for example, can compose travel packages for its customers by utilizing a set of services provided by its partners for payment handling, booking flights, hotel itinerary, car rental and other location-specific arrangements, where each partial service is provided by a separate autonomous enterprise [1].

We define a service as a network-accessible object with a published interface. It can consist entirely of software, or be a software interface to a physical system, such as a logistics service that can be reserved online. Inter-enterprise collaborations composed of these services involve multiple interdependent parties, extending beyond isolated provider and consumer interactions.

Inter-enterprise collaborations are particularly useful for small and medium-sized enterprises, which hold expertise in their own domain but have limited resources. By collaborating with other enterprises, they can attain a competitive edge in fields outside their individual scope, and also join forces to expand their business into fields dominated by large enterprises [2], [3]. Large enterprises can apply the same methods to organize their production life-cycles in-house, or to experiment on new service concepts together with external collaborators.

As the demand for easily set up collaborations between interoperable services grows in both the number and the scale of the collaborations themselves, ad hoc collaboration establishment and decision-making solutions are no longer cost effective.

The success of inter-enterprise collaborations relies on dynamically evolving open service ecosystems, supported by a flexible infrastructure that reduces the cost of setting up and managing the collaborations. This infrastructure ensures that individual enterprises do not need to solve issues of interoperability management, collaboration coordination, breach recovery and trust management using costly manual administration solutions.

The emergence of technology support, ranging from service-oriented architecture and Web Services to cloud infrastructures, are paving the way for semi-automated and low-cost setup and management of inter-enterprise collaborations. The Pilarcos open service ecosystem that we have proposed in earlier work [3] provides infrastructure services for finding potential partners and ensuring service interoperability, collaboration management and semi-automated trust decisions [2], for example; in this paper, we focus on the trust management support specifically.

The service provider enterprises operating in open service ecosystems are autonomous, and new service providers can join the ecosystem to offer new types of services by publishing service offers. The continuously evolving group of service providers and their independence makes trust management both important and challenging. Fine-grained routine decision-making and the monitoring to support the decisions should be automated to not form a bottleneck

in otherwise highly automated collaboration management, but the organizational and individual users' decision-making process and the conceptual basis required by them are not sufficiently supported by automation tools yet.

Automated trust decisions can only be relied on in routine cases: human intervention is required for making trust decisions in situations where the risk or incentives are particularly high, or the information available for supporting the decisions is insufficient. Current collaboration management systems are missing the concepts, processes and interfaces for enabling user involvement.

In earlier work, we have set the basis for how to identify points where human intervention is needed through metapolicy, including support for measuring the amount and quality of the input information [2], [4]. We have also analyzed different existing models for the trust building of individual [5] and organizational users.

In this paper, we present two key contributions towards enabling user involvement in trust decision making for inter-enterprise collaborations: i) We have studied existing literature on human trust decision making perspectives, and produced a set of criteria for trust decisions. We analyze how three collaboration management systems support these criteria. ii) We provide a more detailed case study of enabling these features in our Pilarcos collaboration management system through implementing a prototype of an expert tool for trust decisions, and report the results of our user experiments on it.

The rest of the paper is organized as follows: Section II provides an overview of the problem environment of making trust decisions on inter-enterprise collaborations. Section III presents our model of human decision-making criteria, based on existing literature on human perspectives on trust, and compares it to existing collaboration management systems to analyze how well the concepts are supported there. Section IV provides a detailed case study of enabling these features in Pilarcos: we have implemented an expert tool user interface prototype and present the results of user evaluations. Section V concludes the paper.

II. Trust in Inter-Enterprise Collaborations

Inter-enterprise collaboration depends on trust, as the autonomy of partners causes uncertainty and risk, which must be found acceptable for the collaboration to be established and for it to proceed. In this section, we discuss the basis of trust decisions on inter-enterprise collaborations and present three example trust management systems, which we will compare against our human trust decision-making criteria in Section III.

A. Trust Decisions on Inter-Enterprise Collaborations

For our context of inter-enterprise collaborations, we define trust as "the extent to which one party is willing to participate in a given action with a given partner in a given situation, considering the risks and incentives involved" [2]. Trust is crucial for the sustainability, existence and stability of any inter-enterprise collaboration, particularly when possibilities of direct interaction are limited [6], [7]. The stronger the willingness to depend on and cooperate with the other party is, the less need there is for explicit risk reduction, monitoring and other protective structures. In this sense, a strong trust relationship improves the performance and overall efficiency of the established inter-enterprise collaboration. On the other hand, the open service ecosystem will inevitably have untrustworthy actors as well, and each service provider must protect themselves against such risks. The goal of trust management is to identify the appropriate level of caution for different situations.

A trust decision compares the risks and incentives involved in a given decision context; at the basic level, the outcome is either positive (yes, collaborate) or negative (no, withdraw). A reduction in perceived risk or increase in incentives can be introduced to change the result through application of additional protection mechanisms or contract negotiations, for example.

Trust decisions are made during the establishment of inter-enterprise collaborations, and routinely during their operation, whenever new resources are committed. In the establishment phase, explicit trust decisions are needed because some of the actors in the ecosystem are previously unknown or little known: we argue that not fixing the set of possible collaborators beforehand to a well-weathered strategic network of enterprises provides competitive advantage [2]. The decision made in the establishment phase does not have complete information available on how the collaboration will span out. Instead, during the operation of a collaboration, committing more resources or observing significant behavioural deviations trigger the need for new trust decisions.

Trust decisions measure the subjective willingness of a trustor to perform a given action with a given trustee. In the context of our work, both the trustors and trustees are business services; this level of abstraction reflects the fact that two services even within the same enterprise may hold different information, have a different effect on assets, and be governed by different policies. When a trust decision is delegated to a human user, therefore, the interventions are made on behalf of a specific service, not the entire enterprise.

Some of the expected risks and gains can be estimated based on the trustee's past behaviour, represented by their reputation. The balancing incentives are created by the business importance of the activity itself, such as a need to fulfill existing contracts, or a desire to try out a new way of making business or a new set of partners.

A large body of existing work on reputation systems has focused on electronic markets, aiming to support either human or automated decisions specifically. Work in this environment involves one-on-one transactions to purchase

goods or services, and often focuses on a relatively narrow view of reputation information only [8].

A common approach focusing on the reputation management aspect in particular applies Bayesian modelling to estimating the trustee's likely future behaviour. In a nutshell, this branch of research focuses effort on mathematically credible calculation of the probability of different possible outcomes for the next event based on past information. The Beta reputation system [9] is a well-known example of this group. As its name implies, the system fits binary positive or negative experiences into a beta distribution [9]. Other work building on this approach proposes ways to extend this approach either from binary to discrete scales [10], [11] or to collecting binary data on more than one dimension, such as prompt delivery and overall approval of the product [12]. Aspects such as how to weigh experiences reported by other parties by their credibility are considered as well [11], [12].

From our point of view, research on Bayesian reputation and trust management systems focuses on a mathematically elegant transformation of reputation information into a risk evaluation. In other words, Bayesian trust and reputation systems seek to find a good pair of reputation update and trust decision policies, given a relatively simple baseline information model. We find that Bayesian policies can operate within our information model [13, ch. 4.3], although they only use a part of the provided input. Within this subfield, the search for well-performing policies has led to a need to fix the problem field reasonably early, and the information model assumptions warranted by this comparability requirement may prove to be too rigid for more general use [8]. On the other hand, for automation purposes the line must always be drawn somewhere. While we have chosen a tradeoff of increased information model complexity in exchange for capturing more aspects of trust decisions that we consider important, our model remains a simplification as well.

For a broader overview on related work on trust modelling, we refer to surveys on reputation systems [14], [15] and their robustness [8], [16]. Robustness in the face of attacks and other misbehaviour is one of the key issues that demand a holistic and high-complexity model of the operational environment to properly address. As trust management falls under the category of protective systems, robustness is an essential requirement; we discuss it more extensively in earlier work [13].

We have found that inter-enterprise collaborations, which involve multiple partners and a wide range of interdependent services, require a broader information model in order to capture the variety of risks and incentives as well as their dependence on the decision context [2]. While additional factors make the system more complex to understand, they vastly improve its configurability through policy and metapolicy [13].

In addition to Pilarcos, explicit risk information and the separation of risk calculation policy from reputation management has been proposed by the SECURE project [17] for ubiquitous computing either between private users or in client-to-business settings. As SECURE aimed to produce a personal general-purpose trust decision assistant to carry with the user, it also had to address the requirement for a flexible and configurable trust information model. For Bayesian systems, on the other hand, the chosen approach seems to reflect the target application area as well: in eBay [18], a typical electronic market where goods are bought and sold, a user's most visible reputation has long consisted of counters of the positive, neutral and negative feedback they have received [19].

In a recent paper, Marsh et al. specify a set of requirements for trust models from a usability perspective [20]: understandability by the actual users, support for monitoring and user intervention, actively prompting for input in uncertain situations, extensive configurability by the user delegating the decisions to the system, catering for different time frames for when the decision responses are needed, accepting the incompleteness of available information, and allowing the user to find out more about the decision context. This call for usability of trust models matches our goals well; we find that being able to understand and control the system is a requirement for users to trust the system to handle their trust decisions for them.

In terms of state of the art in information representation for nontrivial trust models, Ries has proposed and conducted user experiments on a two-dimensional graphical representation of positive outcome probability and the amount of available information in his thesis [21]. Research shows that the explicitly presented reputation information is not the only element affecting a trust decision: users may be influenced by unexpected user interface elements as well, such as decorative images [22], [23].

B. Trust Support in Inter-Enterprise Collaboration Management Systems

In preparation for comparison of the human and organizational decision-making perspectives in various trust management systems, we briefly introduce three inter-enterprise collaboration management systems that have suitably similar goals: i) TrustCoM, ii) ECOLEAD and iii) Pilarcos. The last of these will be further detailed to provide insight for the integration of the proposed interface.

TrustCoM is a large European Union project in the domain of inter-enterprise collaborations. The main contribution of TrustCoM has been the architectural and conceptual framework addressing trust, security and contractual issues from the perspective of inter-enterprise collaborations [24], [25]. The TrustCoM framework [24], [26] supports trust decisions during the joining and continuation of the collaboration. In TrustCoM, trust decisions are made when a new partner needs to be added or a previous partner

needs to be replaced. The trust decisions are made based on reputation information measuring trustee capabilities, integrity and benevolence, in addition to functional definitions of the role, requirements of quality of service, cost and security. The TrustCoM framework also involves an initial user interface in the form of an eLearning portal in a scenario demonstrator [26], helping users find the service best suited for them. In the general case, the design of trustworthy and secure user interfaces falls outside the scope of TrustCoM, although their importance is acknowledged.

ECOLEAD is also a European Union Integrated Project. It introduces a plug-and-play, pay-per-use, platform-independent and secure ICT infrastructure for the initiation and functioning of the inter-enterprise collaborations [6], [27]. The project addresses interoperability, trust, security, transparency, and affordability [27]. In ECOLEAD [6], [27], trust decisions are made at two points: base trust is established during the entry into the ecosystem, and specific trust is evaluated when each inter-enterprise collaboration is set up. For base trust, all enterprises entering the ecosystem answer a questionnaire on, e.g., organizational competences, prior successful collaborations, prior engagement in opportunistic behaviour, and adherence to technology standards and delivery dates [28]. Collaboration-specific trust is established in a hierarchical manner, starting from the specification of objectives in terms of measurable elements. The ICT infrastructure of ECOLEAD also provides support for portlets, pluggable user interface elements, for interaction with the users [27]. The trust prototype has a web and mobile portlet, providing a list of potential partners for collaboration, where the users can select those found most suitable for the task. Like TrustCoM, ECOLEAD does not focus on user interfaces for trust decision making specifically.

The Pilarcos open service ecosystem we have proposed in earlier work [3] aims to help service providers to find and collaborate with partners from the open service market. Collaborations are defined by a chosen business network model, which defines roles consisting of specific service types that the participanting services implement, and the shared business processes. Due to some of the potential partners being unknown or little known, trust management requires explicit support.

Pilarcos includes infrastructure services for finding and selecting potential partners and ensuring service interoperability, eContracting and collaboration management, local monitoring to collect evidence of trustworthiness, and semi-automated trust decisions [2]. The distributed infrastructure services in Pilarcos allow the enterprises to make local, private trust decisions on whether they want to join or continue in an inter-enterprise collaboration. Other decision policies are also needed to ensure that the automation tools act in accordance to the strategy and privacy requirements of the enterprise, for example [2].

While TrustCoM makes trust decisions when partners are added or changed in an operating collaboration, Pilarcos trust decisions are made both at the start of a collaboration and when new resources are committed, in which case the decision may trigger partner changes as well. The trust decisions in Pilarcos compare the subjective risks, calculated on the basis of the past behaviour of the trustee as encoded in its computational reputation, and incentives involved in the endeavour, such as the business importance of the collaboration [29]. The incentives are reflected on how much risk is tolerated. Routine decisions are automated, following local policies [2]; however, there are always situations that require human intervention. To allow for this, the decision policies define risk tolerance ranges for automatic acceptance, automatic rejection, and for requesting input from the human user [1]. Possible reasons for requiring human intervention include high risks combined with high incentives, or too little reputation information available on the trustee.

III. Decision-Making Perspectives

Designing a trust decision expert tool meant for humans requires understanding the process of human trust decision making in general. The reviewed research on human needs for decision-making has been conducted both in the context of electronic commerce and more general settings. The domain of inter-enterprise collaborations specifically has remained relatively unresearched, while the focus has been on business-to-consumer (B2C) settings. Considering the underlying problem, we believe that findings regarding human trust decision making in the B2C electronic commerce domain, for example, can be applied in the case of inter-enterprise collaborations with adaptations.

In this section, we present our model of human decision-making criteria, which is based on existing literature on human perspectives on trust. We then compare the three inter-enterprise collaboration management systems presented in the previous section in order to study how well the concepts we have extracted are supported in them.

We have studied the research literature from two perspectives: First, approaches to human trust development, and second, qualitative and quantitative criteria for trust decision making.

A. Human Preferences on Trust Decision Making

1) Approaches to Human Trust Development: The existing literature reveals two different approaches to modelling human trust development: cyclic and staged [30]. Table I summarizes the reviewed approaches.

The cyclic approach to trust development was introduced by Fung et al. [31]. It relies on the development of the trustor's confidence based on the satisfaction of prior behavioural outcome expectations. However, continuous distrust at any phase has a negative effect on the existing trust levels. Fung et al. [31] and Deelman et al. [32] have proposed two different models for cyclic trust development.

Table I A SUMMARY OF THE REVIEWED APPROACHES TO HUMAN TRUST DEVELOPMENT.

Author	Approach	Summary
Fung et al.	Cyclic	• Factors affecting initial trust establishment: information quality, interface design and reputation • Future trust is based on the satisfaction of prior expectations
Deelman et al.	Cyclic	• Factors affecting initial trust establishment: willingness to trust, estimation of trustworthiness of trustee, evaluation of past experiences, situation and risk inherent in current situation • Future trust is based on the satisfaction of prior expectations
Shapiro et al.	Three-stage	• Deterrence-based trust: relies on measures preventing occurrence of misbehaviour • Knowledge-based trust: relies on a knowledge gained as a result of direct interaction with trustee, and satisfaction of prior expectations • Identification-based trust: highest trust level, relies on the outcomes or experiences gained as a result of repeated interactions with trustee
Ba	Three-stage	• Calculus trust: relies on comparison of gains versus possible losses • Information-based trust: relies on information gained as a result of direct interaction with trustee and satisfaction of prior expectations • Transference-based trust: highest trust level, relies on the outcomes or experiences gained as a result of repeated interactions with trustee
Kim et al.	Two-stage	• Initial stage: marked by either no or low trust • Commitment stage: high-trust stage, where the trust relies on prior direct interactions with trustee
McKnight et al.	Two-stage	• Exploratory stage: marked by either no or low trust • Commitment stage: high-trust stage, where the trust relies on prior direct interactions with trustee

Fung et al. [31] present the basic model where information quality, interface design and reputation are the factors contributing to the initial trust development. Building on this, Deelman et al. [32] have further elaborated the original model by proposing additional factors: willingness to trust, estimation of the trustworthiness of the trustee, evaluation of past experiences, situation, and risk inherent in the current situation. The most notable point about the model of Deelman et al. is that it is applied to trust development in the domain of inter-enterprise e-commerce.

When we consider inter-enterprise collaborations in particular, the needs of trust modelling are slightly different. As regards to domain-specific needs, we would like to enhance the cyclic models proposed by Deelman et al. [32] and Fung et al. [31] in the following three ways: First, shared vision, contracts and legal conditions also play a significant role, especially during the initial stages of trust development; they should therefore also be considered as factors affecting trust development. Second, distrust development should be covered by the models as well, as services may change their behaviour and trust relationships may degrade or be broken off as a result. Third, while Deelman et al.'s model suggests that the given factors should be followed in sequential order, we find that the factors collectively affect trust development and their order completely depends on human preference.

Staged trust development models exist in different forms, with a different number of stages proposed for trust development. Shapiro et al. [33] and Ba [34] have both proposed a three-stage trust development model. The stages proposed by Shapiro et al. are deterrence-based, knowledge-based and identification-based trust. Ba instead proposes that the stages are calculus-based, information-based and transference-based. Kim et al. [35] and McKnight et al. [36] have suggested two-stage trust development models, which both call the final stage of trust development the commitment stage. Kim et al. refer to the first stage as initial trust development, while McKnight et al. call it the exploratory stage.

The staged trust development models cover different angles, but problems remain for applying them to the domain of inter-enterprise collaborations. The three-stage models do not consider the effect of opportunistic behaviour, such as degrading quality of service or contract violations due to changes in the priorities of an enterprise. Similarly, McKnight et al.'s model does not discuss the possibility of degrading or withdrawing from the existing trust relationship. As the financial situation and motivation of an enterprise can change at any time, its behaviour can notably change as well, and we believe that the trust development models should be able to capture this.

The three-stage trust development models are also limited in the sense of assuming that trust development proceeds in a sequential order. We noted a similar issue with the sequential order in Deelman et al.'s cyclic model; in this case we find that two stages of trust development could well be in use simultaneously. For example, Shapiro et al.'s knowledge-based and Ba's information-based trust are fixed as the second stage, which occurs after a series of direct interactions. We find that information from third-party reputation networks can be used also during the first stage,

before first-hand interactions have taken place. Apart from this, the model of Kim et al. does not propose a precise list of factors affecting trust development in the initial stage, and do not discuss the shift from initial to committed stage.

2) Criteria for Trust Decision Making: The second target of our literature research involves identifying different factors that affect trust decision making. The term 'criteria' refers to the various qualitative and quantitative factors that play a significant role in the process of human trust decision making [37], [38], [30]. Criteria for trust decision making in business-to-consumer (B2C) e-commerce can relate to institutional, environmental, website, trustor and trustee metrics, for example. The different criteria are applied in trust decision making to help analyze the situation that has called for a decision. They should be considered because they are necessary to complete the human trust decision making process.

The following section presents the different criteria we have selected for trust decision making in the domain of inter-enterprise collaborations within four categories: trustor, trustee, contextual and collaboration-specific criteria. The criteria have been gathered based on the process of human trust decision making, extended to suit the needs of inter-enterprise collaborations in particular.

Trustor Criteria: The trustor criteria are attributes of the trusting entity that affect the process of trust decision making. The personality and thinking of the trustor have a major influence on the final decision. The trustor criteria are propensity to trust, emotions and culture.

Propensity to trust is defined as a human behavioural trait, reflecting their inherent willingness or attitude towards trusting humanity, independent of any information regarding the entity to be trusted [35]. It makes the trustor risk-seeking, risk-averse or risk-neutral. The establishment of propensity to trust is based on prior experiences, starting from infancy. It can also be viewed as dispositional in nature, as human beings are taking their propensity to trust from one situation to another [38]. Propensity to trust plays a significant role during the initial stages of trust establishment in the case of previously unknown or little known entities [39].

Emotions can be defined as a cognitive approach to trust decision making [40], [41]. They are also independent of any kind of information regarding the target entity. Emotions bring in "temporal irrationality" in the process of trust decision making [41]. They might instigate a positive trust decision if the person is in a happy mood even in a situation that does not warrant trust at all otherwise, for example. Emotions acquire a dominant role in trust decision making by formulating a viewpoint regarding the available information and the current situation requiring the trust decision.

Culture is another personality trait of the trustor. It impacts the trustor's attitude, which plays a significant role in perceiving available information [41]. This way it also has an influence on the other two trustor criteria. For example, a small or medium-sized enterprise may be less willing to take a certain measure of risk as compared to large enterprises, owing to limited resources affecting their general tendency to trust. Shoorman et al. [41] state that the relationship versus task dimension of culture plays a major role in the process of trust decision making. This means that a task-oriented culture will be more risk-seeking, while a relationship-oriented culture invests particularly in building and maintaining long-lasting trust relationships.

We believe that all the aforementioned trustor criteria are a good fit with the domain of inter-enterprise collaborations. Their role becomes evident when we consider human trust decision making. However, they are also reflected in the automated trust decision making through the use of private, local or mutually decided and negotiated policies, contracts, rules and regulations. The mutual decision and negotiation is being carried out through either machine agents that are administered and configured by human users, or through the human users themselves.

Trustee Criteria: The trustee is the entity targeted by trust. As trust balances for risks that are inherent and not easily eliminated from the decision-making situation, the attributes of the trustee have a major role in the process of trust decision making as well. We consider trustee reputation to be the key trustee criterion.

Reputation information refers to the knowledge about the past and present behaviour of the trustee [6], [2], [37]. When coupled with an assumption of behavioural consistency, this historical information is used for making predictions about the trustee's future behaviour, and assessing the overall trustworthiness of the trustee. According to Mayer et al. [38], trustworthiness can be perceived in terms of ability, benevolence and integrity. Here, ability refers to the skill set and expertise of the trustee in some specific field. Benevolence refers to the extent to which the trustee will satisfy the behavioural expectations and avoid opportunistic behaviour. Finally, integrity pertains to the tendency of adhering to the agreed terms and conditions.

Reputation information can be collected from two different sources: direct interactions, and through third-party reputation networks. In the case of previously unknown entities, the third-party reputation networks are the primary source of reputation information. First-hand experiences, as they become available through direct interactions, are valuable as they can be relied on to be both truthful and apply well to the specific trustor's context. A combination of both sources can be used to reason about little-known entities. The assumption of behavioural consistency that any reputation-based predictions rely on can be broken by the trustee at any time; a key measure of the quality of reputation information is whether the actor is also known to behave consistently [4], while the reputation tracking itself also discourages misbehaviour [13].

Contextual Criteria: Contextual criteria comprise factors that vary from situation to situation. They might change even in the presence of the same trustor and trustee. We categorize the key contextual criteria as pertaining to system trust, user interface aiding decision making, and external environmental conditions.

The concept of system trust was introduced by McKnight et al. [39], [42], who proposed it to consist of two components: structural assurances and situational normality. Another component of facilitating factors was later added by Pavlou [43]. Structural assurances consist of legal and governmental impersonal structures, such as legal contracts, safety nets, legal regulations, guarantees and insurances [39], [30]. Structural assurances prove to be a reliable aid for the establishment of trustee trustworthiness during the trust decision making. They are especially useful for trust establishment in the initial stage of trust development, when collaborating with previously unknown or little known entities [30]. Situational normality reflects the trustor's belief that the situation requiring trust decision making is safe and positive for attaining the desired gains [39], [30]. Structural assurances and trustor criteria contribute to the formulation of the trustor's belief. Facilitating factors refer to non-governmental structures, such as shared standards, protocols, relationships, goals or beliefs, which lead to the formulation of a positive perception about the integrity and adherence of the trustee [43].

The user interface acts as an important tool for enabling human trust decision making, as it is responsible for presenting the required information to the users. Our research aims at providing user interfaces to support a range of trust-decision-related tasks, and towards this goal we have built an initial version of the trust decision expert tool that will be providing a user interface for semi-automated trust decisions in Pilarcos (see Figure 1). A literature review reveals the existence of interfaces for making human queries for the existing trust management systems of ECOLEAD [27] and TrustCoM [26] as well. During the initial stage, navigational ease, user-friendly interface, clarity, accuracy and reduced error rate have a positive impact on trust decision making [44], [45]. On the other hand, interactivity, usefulness, accurate transactions together with zero error rates are dominant during the committed stage [44], [46].

External environmental factors refer to the set of social, economic and technological aspects influencing trust decision making. For example, recession could be a major environmental factor affecting trust decisions. The external environmental factors are independent of the trustor, trustee or the contextual trust decision making criteria.

Collaboration-specific criteria: Collaboration-specific criteria refer to the individual objectives and perspectives of the collaborating enterprises that affect trust decision making [6]. The objectives of the enterprises refer to their pre-established intentions about what they wish to gain from the collaboration. These objectives target the perspective the adopts on the trust development. For example, if an enterprise aims at earning money from the collaboration, then it gives an economic perspective to trust development. The perspective reflects the trustor's viewpoint towards trust establishment [6].

We have identified seven different perspectives on trust establishment and decision making: service [47], [6], [2], [25] organizational [6], [2], [25], social [6], [2], economic [6], [2], psychological [24], [25], behavioural [6], [2], [24], [25] and technological [6], [2].

The service perspective refers to taking into consideration the details of service offers. Service offers are made by enterprises who are willing to collaborate [2], [24]. The organizational perspective is made out of enterprise characteristics such as its size and setup [6], [2]. The social perspective for trust decision making targets the outcomes of the interaction of the enterprise with its external environment. One example could be the activities and offerings made by the enterprise towards the surrounding society, through the proper consideration of mutually established contracts, security mechanisms and monitoring [24], [6]. The economic perspective to trust decision making comprises of the involvement of monetary risks or possibilities of making monetary incentives in addition to the financial situation of the enterprise [2], [6]. The psychological perspective refers to the intentions of the enterprise [24]. The behavioural perspective concerns the past and present behaviour of the enterprise [2], [24], [6]. Finally, the technological perspective to trust decision making covers the abilities and competencies of the enterprise [2], [6].

B. Comparison of Trust Management Systems

We will now compare the perspectives on human trust decision making discovered in the literature to the three inter-enterprise collaboration management systems presented in Section II-B. The comparison follows the structure of Section III-A. The key points of the comparison are summarized in Table II.

1) Approaches to Trust Development: TrutCoM follows a cyclic approach to trust establishment [24], [25]. The monitoring of the collaboration is performed during the operational phase. Any kind of misbehaviour is dealt with by activating the appropriate clauses in General Virtual Organisation Agreement (GVOA) and Service Level Agreement (SLA). For example, monetary compensation may be required due to service downtime. Furthermore, all the collaborating enterprises are informed about the observed bad behaviour. This immediate incorporation of any detected breach by taking required actions during the operational phase itself makes their approach to trust decision making cyclic in nature.

In ECOLEAD, trust establishment is carried out in a hierarchical manner [6], [28]. The establishment of specific

Table II SUMMARY OF THE COMPARISON BETWEEN TRUSTCOM, ECOLEAD AND PILARCOS [48].

Comparison Criteria			TrustCoM	ECOLEAD	Pilarcos
Trust Criteria	Trustor Criteria	Propensity to Trust	General Virtual Organization Agreements (GVOA) & Service Level Agreement (SLA)	Criterion governing specific trust	Policies and contracts
		Emotions	Not considered in automated functioning but present in user decision making process	Not considered in automated functioning but present in user decision making process	Trust decision expert tool
		Culture	Business Process Model (BPM) defining different roles & interactions between them	Depends in the administrator	Business Network Model (BNM) defining different roles & interactions between them
	Trustee Criteria	Reputation	• Through characteristics of the service mentioned in published service offer • Information about past behavior of the enterprises stored with the Enterprise Network (EN)	• Base trust established when enterprises enter the Virtual Breeding Environment (VBE) through a questionnaire • VBE storing past information about past behavior of enterprises in earlier collaboratios	Experiences gained from earlier collaborations, first hand information from monitors and shared through reputation networks. The reputation information is represented in the form of assets: monetary, reputation, satisfaction & control
	Contextual Criteria	System Trust	GVOA, SLA, communication standards, monitoring, contract negotiation possibilities & avoidance of information transmission	Hierarchical approach to specific trust, EN consists of enterprises certifying base trust & monitoring	Contract, possibility of contract negotiation, existence of interoperability measures & monitoring
		User Interface	Portlets for interaction with user	Portlets for interaction with user	User interface of trust decision expert tool
		Environmental Factors	Social context	Social perspectives	Contextual repository
	Collaboration specific criteria	Perspectives	Psychological, Social & Behavioral	Organizational, Economical, Social, Technological & Behavioral	Services, Economical, Technological, Behavioral & Risk analysis of threatened assets
		Objectives	Shared & Enterprise specific objectives	Shared & Enterprise specific objectives	Shared & Enterprise specific objectives

trust begins with specifying the underlying objectives which are further categorised into a number of perspectives. Each perspective consists of a set of requirements which are, in turn, divided into value measurement scales and constraints. The measurable elements act as the basis for monitoring. Result updating takes place during the termination phase, so that they can be used during the establishment of future inter-enterprise collaborations. The hierarchal nature of trust establishment and the use of monitoring results only in future collaborations indicate the ECOLEAD approach is staged.

The Pilarcos approach to trust establishment, management and decision making is hybrid, i.e., both cyclic and staged by nature [2], [29]. The Pilarcos middleware performs monitoring during the operational phase, using monitors local to each enterprise. As in the case of TrustCoM, the detection of any significant misbehaviour leads to compensation processes, possible partner reorganization and information dissemination among collaboration enterprises being done during the operational phase of the collaboration. In other words, the information from the current collaboration is being applied both within it and for future collaborations. The results of the monitoring constitute local reputation information, which is fed into third-party reputation systems during the collaboration termination phase [13]. The two kinds of trust decision points makes the Pilarcos approach staged as well. On one hand, trust decisions are made on entering into collaborations with enterprises that carry different levels of familiarity from before. Therefore, especially in the case of previously unknown or little known enterprises, this point is characterized by either no or very low trust, which is equivalent to the situation during the initial stage of trust development. On the other hand, decisions are also made when more resources need to be committed into the collaboration; here the decision can be made based on the experiences gained through the direct interaction with the collaborating enterprises.

2) Criteria for Trust Decision Making: As mentioned before, there is no direct involvement of *trustor criteria* in the automated trust decision making process of all three trust management systems. However, they are reflected in the involvement of human-configured machine agents and humans themselves during policy establishment and contract negotiations. The risk attitudes of the trustor have an effect, for example, as policies are configured for decision-making, and contract templates established for automatically negotiated contracts.

Propensity to trust: The mutually agreed contracts and policies among the collaborating enterprises during the negotiation phase reflect the propensity to trust in Pilarcos middleware [49], [50], [3]. The negotiated contract can be understood as an active and distributed agent containing all the meta-information that governs the working of the inter-enterprise collaboration [47]. The General Virtual Organization Agreement (GVOA) and Service Level Agreement (SLA) reflect the existence of propensity to trust in the case of TrustCoM [51], [24], [25]. Similarly, both GVOA and SLA comprise a set of policies that define the legal framework for the operation of the inter-enterprise collaboration as a whole, and specific to all the services provided by collaborating enterprises. For ECOLEAD, mutually negotiated contracts and criteria directing the trust establishment reflect the propensity to trust in the system [52]. In general, the trustor's propensity to trust is reflected in contracts particularly through any pre-established contract templates and negotiation policies. The specific clauses selected for a particular collaboration can be influenced by these criteria as well, for example through requiring an additional trusted third party to mediate transactions.

Emotions: The user interface of the trust decision expert tool that has been designed and implemented as a result of this research brings the direct involvement of emotions into the workings of the Pilarcos middleware. TrustCoM includes an eLearning portal demo, which has a user interface used for scenario demonstration to the users for finding suitable collaboration partners [26]. Similarly, ECOLEAD also has web and mobile portlets for handling human queries related to the search for potential partners [27]. The user interface is the main channel through which the user's emotional state can strongly affect a trust decision.

Culture: In the case of Pilarcos, the Business Network Model (BNM) constitutes the culture affecting the trust decision making process [49]. The BNM contains information regarding the organisation of the inter-enterprise collaboration. It specifies the policies based on the legal and regulatory systems of the strategic business domain under consideration, roles to be played by the different collaborating enterprises and interaction among them. Similarly, the Business Process Model (BPM) represents culture in the TrustCoM framework [24], [25]. The initiator enterprise willing to establish a collaboration defines the BPM, which contains information about business processes, roles to be fulfilled by the collaborating enterprises, and functional requirements of the collaboration. In the case of ECOLEAD's ICT infrastructure, culture is defined by the administrator through a process referred to as business opportunity characterisation [53]. As in the case of other trust management systems, the business opportunity characterisation process outlines the roles which will be played by the different collaborating enterprises.

The *trustee criterion* of reputation is to a degree supported in all three systems. The TrustCoM framework makes use of reputation information for trust establishment during the collaboration establishment and SLA generation in the negotiation phase. The reputation information exists as service quality, time, cost, integrity, consistency, capabilities, benevolence and past experiences. It is obtained from two different sources: service offers made by the enterprises willing to

collaborate, and the Enterprise Network (EN) gathering it through monitoring the collaboration during the operational phase of the collaboration. The ECOLEAD infrastructure also makes use of reputation information taken from two sources: a baseline trust questionnaire, and the Virtual Breeding Environment (VBE) [6]. The trust questionnaire is filled by all the enterprises willing to collaborate through the VBE, and it gathers information such as organisational size, setup, financial stability, reliability and experience of similar previous collaborations. The VBE contains reputation information gathered by monitoring the functioning of the collaboration. In Pilarcos, reputation information is gathered locally by monitors at each service provider during the operational phase, and from external reputation networks. The reputation information is used for making risk calculations regarding the inter-enterprise collaboration under establishment or in operation. Both local and external reputation information is transformed into a uniform format of number of experiences. Each experience is represented in terms of four assets, reflecting what kind of impact, positive or negative, major or minor, the collaboration in question has had on the assets. The asset types considered are monetary, the service's own reputation, its autonomy and security, and satisfaction of the contract and goals of the collaboration. We will return to the Pilarcos information model in the next section.

Contextual criteria are considered in various ways by the three reviewed systems. For system trust, the existence of monitoring, legally binding contracts and their negotiation possibilities act as its most notable forms. However, in addition to these elements all three trust management systems have certain individual factors contributing to this. In the case of Pilarcos, automated interoperability checking is an additional factor constituting system trust. The presence of communication standards and avoidance of information transformation are extra elements reflecting system trust in TrustCoM. Similarly, the systematic and hierarchical approach to trust establishment support system trust in ECOLEAD.

User Interface: The user interface and the information it provides influences the user's trust in the system itself, in addition to facilitating trust establishment and evaluation towards the trustee in a given collaboration situation. All three trust management systems provide user interfaces for trust management, in varied forms. For Pilarcos, we propose a trust decision expert tool whose user interface presents the users with information on risk, reputation, collaboration context and collaboration progress. The proposed trust decision expert tool targets non-routine cases that require human intervention for trust decision making. TrustCoM also supports information-providing user interfaces and realizes their importance [24], [25]. However, their design falls outside the scope of the TrustCoM project. ECOLEAD facilitates possibilities of user interaction via computer-supported collaborative tools such as mails, chat, calendar and notifications, in addition to the simulated partner search service provided by its test prototype [27].

The exact form of influence the interface has on the user is an interesting research problem in itself. Karvonen et al. have found cultural differences in how users experience the trustworthiness of an online service [54]. An earlier research collaboration in the Trustworthy Widget Sharing (WiSh) project studied how private people interact with the user interface when making decisions to download software for mobile phones provided by other users [55], [23], but more research is needed on the more complex user interfaces for trust management in inter-enterprise collaborations.

External Environmental Factors: We find that all three trust management systems indicate implicit or explicit support for external environmental factors. Pilarcos explicitly supports them through using context as one of the parameters for automated trust decision making. The sources providing the information for the context parameter reflect both internal and external environmental factors, encompassing the internal state of the service, the business state of the service provider enterprise, and the state of the collaboration the enterprise is involved in [29], [2]. On the other hand, TrustCoM and ECOLEAD implicitly support external environmental factors. TrustCoM has adopted the notion that "trust is always set within a social context" [24]. We believe that the social context is affected by different external social, technological and economic factors. Similarly, ECOLEAD also considers social factors as one of the perspectives for assessing trustworthiness of the target entity [6].

Collaboration-specific criteria are similar in terms of objectives, while varying in the selection of perspectives among the three systems.

Perspectives: All three trust management systems have their independent and overlapping perspectives to trust decision making. Pilarcos considers service, economical, technological and behavioural perspectives for trust establishment [49], [50], [29], [2]. Similarly, TrustCoM also considers trust decision making from four different perspectives: service, psychological, behavioural and social [24], [25]. ECOLEAD relies on five different perspectives: organisational, social, economical, technological and behavioural [6].

Objectives: As mentioned previously, there are either shared or individual objectives involved in any inter-enterprise collaboration. Therefore, the dimension of objectives applies equally to all three systems. In each of them, the inter-enterprise collaboration have some shared objectives, in addition to which collaborating enterprises have their own individual objectives behind their participation.

IV. Pilarcos Trust Decision Support

In this section, we present the design of the user interface for supporting human interventions on trust decisions. The

presented user interface extends the Pilarcos trust management system.

A. Pilarcos Trust Management System

In Pilarcos, local trust decisions are made by agents within the enterprise, on behalf of a single service provided by it. The decisions are based on a combination of local, private and shared information, and both the decision policies and policies for collecting and processing the relevant information are specific to a service. Decisions are triggered when a new collaboration is joined, or at points where significant new resources are committed in an ongoing collaboration. The goal of the decisions is to protect the enterprise's assets through evaluating whether the risks and benefits of the given collaboration are in balance.

The Pilarcos trust management system makes automated trust decisions based on seven different parameters: trustor, trustee, action, risk, reputation, importance and context [2]. As discussed previously, the trustor and trustee are business services operating within their respective enterprises. The action represents a collaboration task that needs to be performed, involving a commitment of the trustor's resources. The risk and reputation factors are closely connected: risk estimates present probabilities of different outcomes calculated based on reputation information, which in turn is stored as experience counters of different observed outcomes so far. These experiences are gathered both directly through local monitoring, and as shared information through reputation networks [2]. While shared reputation information may be erroneous and is therefore locally evaluated for credibility, it provides a valuable extension to the first-hand information particularly in the case of actors that are not previously known, and actors who have recently changed their behaviour.

The representation of the experience information determines how it can be used. The classical value imbalance problem [8], for example, stems from experiences only measuring the positive or negative outcome of an action: four small-value transactions weigh four times more than a single large-value transaction. In some cases the costs and benefits of a collaboration cannot easily be measured in monetary terms: a collaborator may pay an agreed-upon service fee, but then violate the contract terms or overload the service to make it fail for other users, causing lost business elsewhere.

In order to balance between better capturing complex outcomes and supporting automated real-time processing of the experience information, Pilarcos represents the effects of the collaboration outcomes on the enterprise, or the business service more specifically. We have applied the idea of asset-based risk analysis to form our model, and introduce four high-level asset classes: monetary, reputation, control and satisfaction [2]. The outcome effects are then represented on the scale of large negative effect, slight negative effect, no effect, slight positive effect and large positive effect that the action or collaboration task has been observed to have on that asset. This condensation of possible outcomes to a set of categories for affected assets improves the reusability and interoperability of reputation information across different enterprises; for example the monetary value of reputation gains is not universal, but highly subjective and even time-dependent.

The monetary asset denotes any resources that can be represented in monetary terms. The reputation asset reflects the trustor's own public relations, appearance in the media, and attitudes of their customers and partners towards them [2]; in contrast, the reputation information discussed above concerns the past behaviour of the trustee. The need for security, privacy and other aspects related to autonomy are represented by the control asset. This amalgam category aims to capture general threats that do not directly translate to monetary or reputation terms, such as threats towards the trust management system itself, service availability, or capacity to enter into new beneficial collaborations coming up during the given deal. Lastly, the degree of fulfillment of the trustor's expectations by the trustee is represented by the satisfaction asset: it is used to measure whether the trustee tends to respect its agreements [2]. While contract satisfaction by itself is not generally considered an asset in the sense of organizational risk analysis, it is such a central part of reputation information that most systems ignore all other dimensions of experience. An organization can decide whether it enters into a given contract with another organization, but it cannot control whether the counterparty follows the contract.

The reputation counters of observed outcomes are converted into a risk estimate by transforming the absolute numbers into ratios: essentially, 5 major positive experiences out of 10 total experiences translates into a probability of 50% of a major positive outcome for that asset. Relevant adjustments are made to accommodate low-stake actions that cannot have a large monetary effect, for example, and credibility-based weighting between local and shared reputation information.

The risk estimate is compared to risk tolerance formulae to determine the outcome of the decision. Risk tolerance checks may be adjusted automatically according to the strategic importance specified for the action; this essentially represents the known benefits of a positive decision, such as not having to compensate other collaborators due to withdrawal from the collaboration during its operation. In the automated trust decision making process, the different factors are also subject to change by the context parameter, which manifests as conditional filters, or modifiers, of the data to allow temporary situational adjustments in the system. One example of a context modifier is insurance, which can apply to all actions in one specific collaboration and either reduce or altogether eliminate the monetary risk involved. The information model and policy options are

discussed in more detail in earlier work [2], [13].

The information and process model for trust management forms the basis for automation as well as the information that can be shown to the user to support a human intervention in a situation where an automated decision cannot be made. Factors to consider in handling human intervention for semi-automated trust decisions include the phenomenon of human trust decision making and information requirements of the human users, which we have discussed in the previous sections. Further into the design phase, additional factors to consider include the appropriate way of presenting the information, and reducing the frequency of calls for human intervention in the future, to ensure that the efficiency of collaboration management is maintained. We discuss these factors in the next section.

B. User Interface

The user interface design of the proposed trust decision expert tool was gained from Nielsen's usability principles for designing user interfaces [44] and different cognitive strategies: Cognitive Fit Theory, Cognitive Load Theory, Unified Theory of Acceptance and Use of Technology and Technology Acceptance Model [56], [57], [58].

In accordance with the Pilarcos trust information model, the user interface presents information about risk, reputation, goals affecting the importance of the action, and context [48]. Within its main information views, it presents further details on the credibility of the information, behavioural changes that can affect the validity of the reputation information, assets endangered according to the risk tolerance comparison, and the progress status of the collaboration when trust decisions need to be made during the operational phase of the collaboration. The information is presented as a combination of textual and graphical formats. Figure 1 shows an example risk view of the user interface; the other major views of reputation, context and progress information are minimized in the screenshot.

On the top, the user interface presents the goals of the inter-enterprise collaboration, such as earning money, gaining experience or building reputation. The importance of the goals that the enterprise has set for the collaboration encourage a positive trust decision. In addition to the goals, the deadline for making the trust decision is prominently shown. Both these information elements and their placement promote transparency.

The risk view presented in the figure shows the produced risk estimate, represented in the form of probabilities of different outcomes. These outcomes for different assets follow the trust information model of Pilarcos, as described in the previous section. The four asset classes correspond to four graphs in the risk information view. The effects on different assets are independent of each other. In the figure, the probability of a slight negative effect on the monetary asset is 0.35, and the probability of a slight reputation gain is 0.4, for example, but it is entirely possible for the collaborator to both cost money and cause negative publicity. When forming a risk estimate, the total probability of 1 is divided between different outcomes towards a specific asset based on the experience information and context filters.

The risk information can be studied through two different views: collaborative and enterprise view. The collaborative view presents collective risk probabilities for the collaboration as a whole; it reflects the fact that even though a trust decision is generally made concerning a one-on-one interaction within a larger collaboration, other participants in the collaboration may have a strong influence on the eventual outcome of the action. A manager may consider placing an order to a generally reliable contractor, for example, yet decide against the plan due to not being able to trust its proposed subcontractors for this collaboration. In contrast, the enterprise view provides information about the risk posed by the single trustee individually. The current version of the trust decision expert tool presents the collaborative and enterprise view in the exact same format, as shown in Figure 1. As an item of future work, we study ways of visualizing an overview of multiple collaborators' reputation and risk information individually to avoid the information loss of automatically merging them into one, such as by weighted averages or selecting the worst case.

The reputation view provides background information to the risk estimate. Reputation information is presented as graphs, as shown in Figure 2. It consists of experiences, which reflect the past and present behaviour of the trustee on the same outcome scale as the risk information. The view also shows the estimated credibility of the shared reputation information, and presents whether the trustee's behaviour has been consistent or not, which may have an impact on the validity of the available reputation information.

Behavioral consistency is expressed through the number of times the system has detected a change in the actor's behaviour [4], and by showing both the overall experiences and the experiences based on the current period of consistent behaviour. Each period of internally consistent behaviour is referred to as a reputation epoch, and the number of epochs reflects the number of times an inconsistency has been observed. In this view, the total number of experiences observed on the trustee is 37, and they are divided into two reputation epochs. In other words, after the first 8 experiences, the trustee's behaviour pattern changed enough that a new reputation epoch was started. The current reputation epoch has lasted for the 29 most recent experiences, 17 (8+9) of which are negative, 7 (4+3) positive and 5 neutral.

The underlying system supports unknown outcomes in experiences as well, due to an implementation convention that each stored experience item contains an outcome value for all four assets. We do not show any unknown outcomes in this version of the user interface, however. Instead, the total number of experiences for, say, the control asset could

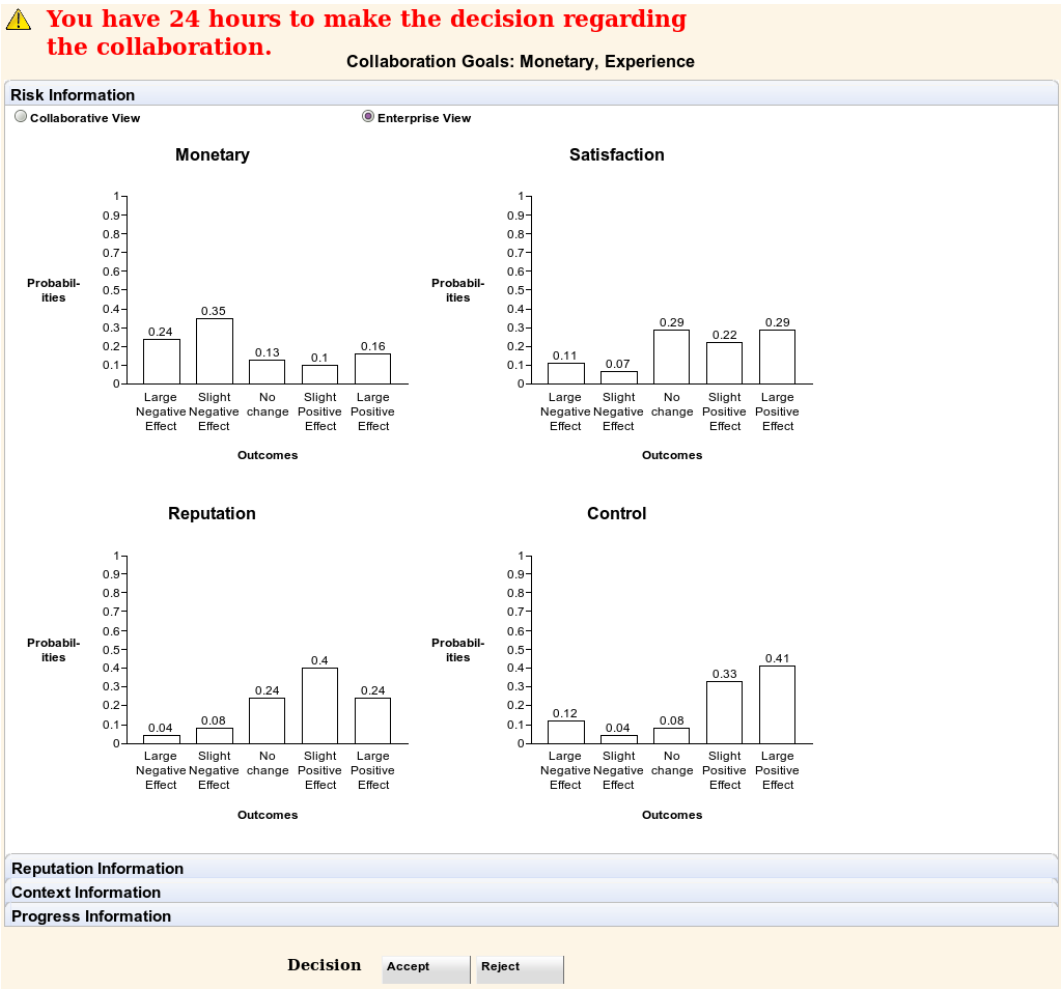

Figure 1. Risk information view of the trust decision expert tool [1].

be lower than the number of experiences for the monetary asset, if the outcome could not be measured in some cases or a reputation source only provided experiences from the monetary and satisfaction points of view, for example.

In Figure 2, the overall view credibility for reputation from the monetary point of view (0.9) is higher than that of the current reputation epoch (0.5), which implies that the recent experiences have come from lower-credibility sources, while the early experiences would be first-hand or from equally trustworthy sources. The exact calculation formula for derived factors such as the view credibility depends on the specific policies in use. To support the repeatability of the user experiments, we have manually configured a fixed output shown to all the users, so they do not directly reflect specific policies in the system.

Finally, the view uses colours to indicate the assets for which the risk estimate is not within the automatically acceptable risk tolerance bounds, as the actor's reputation information for these specific assets may be of particular interest. This information is communicated on the reputation view, where the user interface element doubles as a means to look at the reputation information of a specific asset. The red colour for monetary asset means that the high number of negative experiences gained on the actor, when measuring the monetary effects that collaborating with it has had, translates to a monetary risk estimate that is not considered acceptable for an automated decision. As with risk estimates, the collaborative view of reputation is identical in format to the enterprise view, which means that the reputations of the individual participants must be flattened into a single collection by weighted averages, for example. A way to visualize a collaboration-wide overview that retains relevant information better is an interesting item of future work.

In automated trust decisions in Pilarcos, risk estimates are compared against risk tolerance, which is in turn based on the strategic importance of the action at hand. While the importance is represented through the goals of the collaboration, and tolerance constraints are partially visible

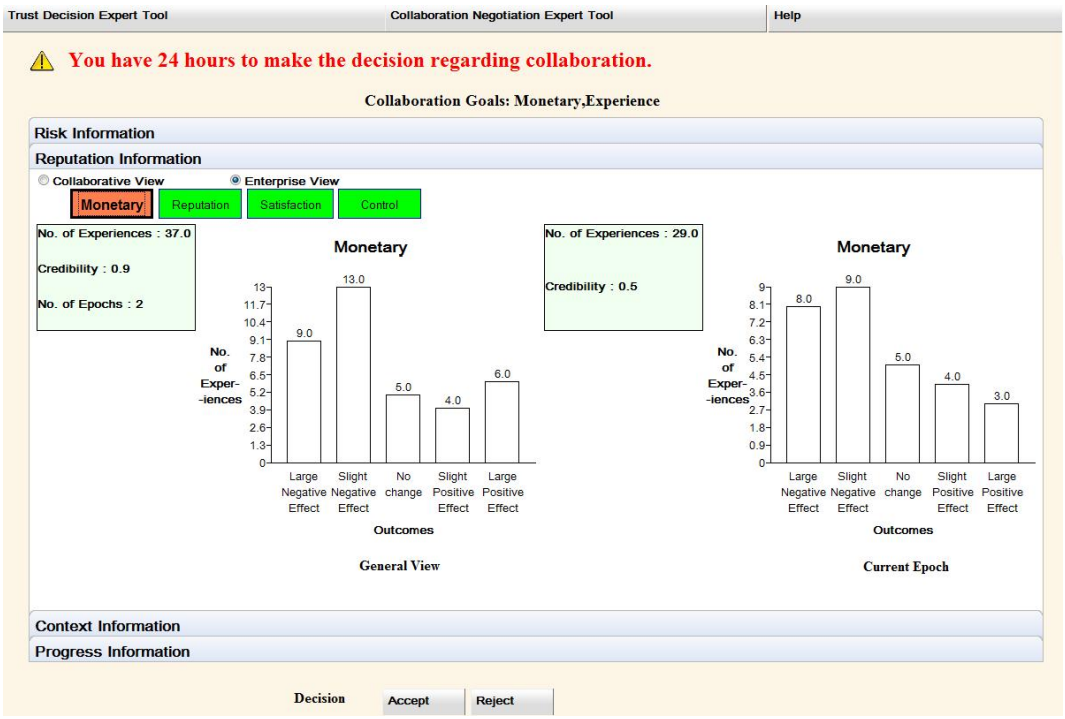

Figure 2. Reputation information view of the trust decision expert tool [48].

through the assets shown not to be within limits, in manual trust decisions the human user is responsible for analyzing and setting the actual risk tolerance limits for the decision.

In the expert tool, the context information view presents the currently active context items to the human users through simple textual phrases, such as “Enterprise A is an important strategic partner” or “The current collaboration is covered by insurance”. This information is collected from the descriptive metadata of any active context filters; we do not consider the formulas of the context filters themselves to be particularly informative to the user.

Finally, the progress information view of the expert tool supports trust decisions on ongoing collaborations. The view presents the progress of the collaboration in graphical format, visualizing the tasks completed by different partners. The views not shown in this paper can be found in the accompanying technical report [48].

The eventual user decision is either to accept and approve the action or reject it, which generally results in a withdrawal from the collaboration. In addition, the tool will ask the user to provide a scope for the trust decision: whether it applies for the remainder of the contract, or for a given time period, or for this specific decision only. This helps reduce the frequency of requests for human intervention, as further decisions needed within the set scope can be automated. The scope information is stored as a context filter, which overrides the risk tolerance formulae appropriately to automatic rejection or acceptance for future decisions within the given scope.

C. User Evaluation

The usability of the trust decision making tools is an important part of enabling user involvement in trust decision making for inter-enterprise collaborations. The tools will not be deployed if are too difficult to use, cannot reflect the user’s information needs, or are conceptually incompatible with human trust decision making processes. We have implemented the trust decision expert tool as a part of enabling user involvement in the Pilarcos collaboration management system, and present here the user study setup and initial results of the user evaluations of the expert tool [48].

We have evaluated the trust decision expert tool interface from four points of view: (i) sufficiency of the presented information, (ii) usability, (iii) user performance and (iv) quality. All five participants in the initial evaluation are researchers in the field of computer science, and one of them was somewhat familiar with the underlying Pilarcos trust management software specifically from before. The main objective behind recruiting technically savvy participants was to gather feedback from users who are representative of the actual target user base of the Pilarcos expert tool. The user study took around one hour per user.

The user studies were conducted in three phases: introduction, solving test tasks and debriefing. During the introduction phase, test participants were first explained the purpose of the study, study setup and details regarding task

performance. Following this, they were informed about the code of ethics and asked to sign the permission form. After the introduction by the moderator, the test participants were presented with the following test scenario:

"You are running an enterprise named 'Quick Service,' which provides online logistic services within Europe. Your enterprise is involved in collaborating online with other enterprises throughout the world. You are using the Pilarcos middleware for managing your online collaborations. Usually, Pilarcos middleware makes automated decisions regarding your enterprise's participation in the online collaborations, but now you have received an email, containing a link, asking you to make a decision regarding your continuation in an ongoing collaboration."

Based on the test scenario, the participants were asked to write down their expectations about information that they would like to have for making trust decisions in such a situation. After the introductory phase, the test participants were allowed to study the user interface to familiarize themselves with it. During the second phase of the user evaluation, the test participants were presented with a set of tasks they are asked to perform using the user interface, one by one. An example of a test task is as follows:

"After reading the email, you already started thinking about the assets that might be endangered by further participating in the collaboration. You figure out money is the most important asset for your enterprise. You decide to find out the risks that the collaboration poses economically to your enterprise."

Each task was further divided into three to four sub-tasks which involved finding required information from the user interface. The sub-tasks, handled one at a time, were provided on paper slips which consisted of a question statement and multiple choices where the participants could mark their answers using a pen or pencil. The decision on presenting the sub-tasks on pieces of paper was made in order to reduce moderator influence. Furthermore, they enabled concluding the test at any time when desired by the test participant, without making them feel uncomfortable for not completing the test.

The test participants were encouraged to think aloud while performing the test tasks. The "think aloud" methodology has been employed to gain insights into the problems and thought process of the participants while they are performing the test tasks [44]. The moderator noted the time taken by test participants to complete each sub-task and comments made while performing it. The completion of each task was followed by a short questionnaire capturing the real-time experience of the participants after each task.

Finally, during the debriefing phase, the test participants were asked to fill in a post-questionnaire aimed at gathering general experience and impressions about the user interface. The post-questionnaire consisted of objective type questions gathering feedback using a five-point Likert scale, ranging from "strongly agree" to "strongly disagree", in addition to open-ended questions. Example claims included: *"The trust decision expert tool is easy to use." "I think the trust decision expert tool presents all the information needed for decision making." "I think the trust decision expert tool presents the information in formats co-related with the task of decision making."* Example open ended questions included: *"In the trust decision expert tool I liked..."* and *"In the trust decision expert tool, I think the following information is missing..."*

The user evaluations have been made with five test participants, which has provided us with useful feedback on further developing the tool. In order to draw any broader conclusions about the usability of the trust decision expert tool, a larger user experiment is necessary. However, as the tool development work is ongoing, the smaller experiment supports particularly the discovery of any glaring issues that should be addressed in the next version of the prototype. We have planned and worked on related decision elements as separate projects that are yet to be bundled together to a coherent set of user interfaces; this bundled whole would then form a natural target for larger-scale testing in future work.

The first point of view evaluated the sufficiency of the information presented to the human users for trust decision making. As previously mentioned, the user interface presents risk, reputation, context, collaboration progress status, goals and credibility information for trust decision making. Table III shows the user rating of the user interface in terms of the sufficiency of the presented information. Based on the analysis of the debriefing phase and participant comments while performing the tasks, we believe the probable reason for disagreement might be the absence of some relevant information, such as the value of the contract in terms of possible monetary profits to the enterprise. Another suggestion for enhancing the available information concerned a more detailed representation of the collaboration progress, relating it to the underlying business process model instead of simple milestones.

The second point of view of usability evaluated how easy the user interface was to use, in terms of ease of finding the presented information, clarity and existence of correlation between the information presentation formats and tasks to be performed. Missing or unclear information were again a likely cause for critique here. For example, the test participants were unclear about the ontological meaning of the assets. Furthermore, some users suggested that a summarized and concise view of the information already presented should be added, including, for example, small textual sentences such as "you have 63% probability of gaining monetary benefits".

The third point of view of the user performance evaluated the user interface in terms of the success rate of task completion, number of errors committed while performing the tasks, and time taken for task performance. The evaluation results

Table III SUMMARY OF THE USERS' OVERALL EVALUATIONS.

Statement	Str. Agr.	Agree	Neutral	Disagree	Str. Dis.
Sufficiency of information	-	3	-	2	-
Ease of finding information	-	3	2	-	-
Clarity fo presentation	-	4	-	1	-
Correlation between information presentation and tasks	2	1	2	-	-
Ease of use	-	3	2	-	-
Confidence of using	-	3	2	-	-
Willingness to use in future	-	4	-	1	-
Feel safe to use	-	-	4	1	-

reveal that the task completion rate is 100% irrespective of accuracy. However, when considering the factor of accuracy, the successful task completion rate is 100% for only two of the participants. It is 93% for two other users, and 78% for one participant. In other words, the error rate is 7%. We suspect the lack of attentive focus while reading the tasks to be the main reason for the existing error rate, because we found the same participants giving correct answers to other similar tasks. Regarding task completion timing, we found that three of the test participants are able to perform 71% of the tasks within seconds, whereas the remaining participants perform respectively 79% and 93% of the tasks in seconds. The times taken here varied from less than 10 seconds seconds to almost a minute depending on the task presented. In contrast, the most laborous of the tasks required up to two and a half minutes (with a mean of 1:28) for the users to find the required information. The time taken is reasonably agreeable considering the novelty of the tool, as none of the participants have ever used any kind of trust decision expert tool before. It does reflect the difficulty of using an expert tool to make manual decisions in complex situations, however: as the available information becomes more intricate, the need to help the user through an intuitive user interface and controlled automation increases.

The fourth point of view of quality aims to evaluate the user satisfaction of using the user interface in terms of ease of use, confidence, willingness to use and perception about security. The evaluations are summarized on the last four lines of Table III. As mentioned previously, insufficient presented information seems to be a likely reason for disagreements or neutral opinions.

In general, we learned that the test participants found the information presentation formats to be easy to read and understand. They also stated they found the user interface to be intuitive, although obviously there is room for improvement.

The user evaluations also resulted in identifying some suggestions in terms of missing information for further improvement of the existing version of the trust decision expert tool. Table IV presents the suggestions or recommendations together with the participant concerns and their priority. The participant concern provides the justification for introducing the proposed change. Priority has been decided based on three factors: effect of the change on the workings of the trust decision expert tool, support provided by the Pilarcos trust management system, and number of participants supporting it. For example, presenting the summarised view of the presented information will affect trust decision making positively and can be supported by Pilarcos. Furthermore, a majority of the test participants expressed their desire of having this kind of information for trust decision making.

V. CONCLUSION AND FUTURE WORK

Inter-enterprise collaborations and social networking have become part of our normal life. To support dynamically evolving open service ecosystems, we need infrastructure to handle interoperability management, collaboration coordination, breach recovery and trust management. Organizational and individual users' decision-making processes and the conceptual basis required by them are not sufficiently supported by automation tools yet. Particularly, the concepts, processes and interfaces for enabling user involvement are missing in many current collaboration management systems. Furthermore, consumers of collaboratively provided services or networked services in general are not sufficiently aware of the trust related threats in this new environment. As a result, they act too trustingly or base their trust decisions on unreliable, or unsuited information. Both in the service provision environments and in the service consumption side it is still early days when it comes to understanding how the complex networks and partners cause threats in trust-requiring activities.

It is essential that research is done on trust management for inter-enterprise collaborations where there is no joint source for information on who to trust. We need to find out how the human or organizational decision-making processes work and what kind of information humans can perceive and judge situations with. We need to find out how trust decisions can be supported with automation, and how that automation or trust decision interfacing can be kept secure. Furthermore, trust decisions often take place side by side with strategical

Table IV SUGGESTIONS, PARTICIPANT CONCERN AND PRIORITY REGARDING RECOMMENDATIONS FOR TRUST DECISION EXPERT TOOL.

Suggestion	Participant Concern	Priority
Summary/Analysis of the presented information	Test participants are concerned about analyzing the presented information. The summary can give them more confidence and enhance clarity.	High
Information about other collaboration alternatives	Test participants are anxious to know other collaboration possibilities. In the case of Pilarcos, this need will be addressed by a collaboration negotiation expert tool in planning.	Low
Previous decision history	Test participants are concerned about the previous decisions made automatically or manually on behalf of the enterprise. This will enhance clarity and confidence in decision making.	Medium
Ontological explanation of presented factors	Test participants are particularly concerned about the exact meaning of the presented information. This will enhance confidence, clarity and perceptions about security.	High
Simulating effects of different policies	Test participants desire to analyze the effects of simulating different policies on presented value. Pilarcos supports only one simulation at the time, however. Availability will enhance confidence, clarity and perception about safety.	Medium
Proper business process representation	Test participants are concerned about current used format for presenting progress information. Good information formats will promote clarity, confidence and safety perception.	High

choices and privacy checks, as in the case of Pilarcos. Thus the larger problem is how to design a human-perceivable process to interact with all these facilities.

In this paper, we have analyzed some of the inter-enterprise collaboration management systems with their trust management approaches. Interfacing with human and organisational users on the collaboration and service aspects is not simply a technical user interface problem, but requires that the systems in their entirety have been built in a way that respects the human and organisational concepts, and the processes of perceiving and making decisions. In contrast to the other approaches, we are studying reputation systems based on contract fulfilment, as subjective experience reports based on pure opinion are problematic from the point of view of reputation system robustness. If there is no way to punish unfair experience reports, the incentives to misuse reputation systems threatens to leave them unusable in practice. Contractually regulated experience reporting improves the quality of the input information to the trust management system.

The contribution of this paper lies in the study and application of the human processes meeting the trust decision support systems. First, the literature study gave us insight on the human perspectives on decision making. Second, we focused on understanding the user interface role and criteria. The systems must approach users as autonomous decision-makers that need both automated support for routine tasks in routine situations, and intervention possibilities in less clear circumstances. Furthermore, an individual may be acting on behalf of an organisation, or at least bound by a hierarchy of regulations in his or her use case context. Third, we applied the gained knowledge to a first-cut user interface design. The small study on the usability of that indicates that our plans on a larger interface that captures decision aspects on privacy, business network model and enterprise strategies as well are justified, and the connectivity of those aspects is indeed expected by the users. The focal points to be presented include i) clear summaries that can be expanded into more detailed information as needed, ii) communication of the ontological meaning of presented decision factors, and iii) access to information about the proposed or existing collaboration as a whole, such as the progress of the collaborative business process. It is also particularly beneficial to represent and simulate the effects of configuring and reconfiguring a collaboration, such as partner changes and different business network model selection.

Our future work include research and development of interfacing processes and user interfaces for collaboration contracts, agents managing collaborations in organisations, and for ecosystems within which the inter-enterprise collaborations are governed. In addition, developing metrics for observing service behaviour would benefit both the reputation-based trust decisions and the re-engineering of collaborations and service portfolios of enterprises.

In larger scale, the future development should include education on trust issues for awareness rising in consumers to require proper management facilities for trust and privacy aspects of the networked services they use in daily life. In addition, standards for distributing trust and reputation related information should be developed with sufficiently wide scope of system models in mind, in order to cover not only client-to-system trust, or client-to-server trust, but true collaborative networks too.

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