A Survey in Multi-stakeholder Decision-Making based on Trust and Risk

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***Abstract*—Decision-making is expected to be encountered in many aspects of people's lives and is involved in fields such as economy, business, health care, and education. There are also different methods of making a decision, as well as various factors that affect making such decisions. Decision-making, therefore, depends on the context. It can be individual or group level. Group decisions are more challenging than individual decisions because of the existence of conflicting objectives among the participants or stakeholders. Group decisions may require negotiation, which involve the stakeholders' influences on each other. Such influences could be acquired from the trust among them. Therefore, trust is used as a criterion for making group decisions. Usually, the decisions come with consequences even if it is short term or long term; therefore, it is important to put those consequences into consideration before making any selections. Such consequences can be addressed by perceived risk. The main contribution of this paper is that it applies trust and risk as decision criteria in the field of multi-stakeholder decision-making. Additionally, we study multi-stakeholder decision-making processes and models based on our analysis of existing works. We found the consensus process and GDM1 model are mostly applied in the existing schemes.**

Keywords–Trust; Risk; Decision-Making; Multi-stakeholder.

I. INTRODUCTION

In real life, people encounter different situations, ranging from critical to noncritical, that entail making a selection among several options. Therefore, there have to be some techniques or methods that help people with the selection process. Trust and risk are criteria used for decision-making because of the uncertainty of consequences involved in these situations. Jøsang and et al. [1] stated that ”Risk and trust are two tools for making decisions in an uncertain environment.”

In multi-stakeholder decision-making, a group of people proposes an action or solution. From a psychological perspective, each individual in the group builds an impression toward others based on his or her selection or experience. As a result, we can imagine a network of participants who represent nodes and the links between them are the feelings they build for each other. This impression can be translated to trust. In this situation, each person proposes a solution that is feasible to him- or herself regardless of the effect it may have on others. Therefore, the multi-stakeholder decision-making model should help reach a solution that benefits everyone and prevents damage to the network of participants.

Numerous works on decision-making use different factors depending on the field and even the applications within the fields. Those factors can be used to model trust. Therefore, trust influences decision-making [2]. Moreover, every decision comes with consequences and, as a result, makes risk another important criterion in decision-making. The use and application of trust and risk as the two criteria in decision-making are beneficial.

Trust can be a result of the decision maker's expertise or experiences, as well as the interaction between the decision maker and other entities (e.g., humans and machines) [3]. Risk can be the result of estimating the potential damage or loss that may occur following the outcome of the decision [2]. Furthermore, when two entities interact with each other, such interactions, which can influence decision-making, can be risky [4]. It is necessary to survey multi-stakeholder decision-making schemes to determine how to use trust value and risk value when making decisions. Various trust systems have been proposed, such as [5]–[15], including our framework [16]–[26].

The main contributions in this paper are:

- Study the relationship between trust and risk.
- Study multi stakeholder decision-making process and models.
- Survey multi stakeholder decision-making schemes based on trust and risk.
- Analyze the challenges of existing multi stakeholder decision-making schemes.

There are several challenges associated with multi-stakeholder decision-making. For example, the participants may come from various backgrounds and have different expertise. Also, the participants may have partial views about the problem domain, as well as have conflicting objectives. Regarding the use of trust and risk in a decision, several challenges, such as risk quantification and, more specifically, rare events or those that have never occurred, arise as well. Another challenge can emerge from knowing how to apply trust and risk as decision criteria.

To the best of our knowledge, this is the first survey of multi-stakeholder decision-making using trust and risk. The outcomes of this survey include classifying the processes of multi-stakeholder decision-making and knowing the trust and risk models that were used for making decisions.

This paper is organized as follows: In Section II, we investigate different definitions of trust and risk, then we introduce the possible relationships between them by analyzing existing related works. Next, in Section III, we discuss trust and risk in multi-stakeholder decision-making by presenting existing multi-stakeholder decision-making schemes. In Section IV, we conclude the paper.

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II. Trust and Risk

In this section, we discuss trust and risk concepts by listing some definitions and the relationship between them.

A. Trust

There is no exact universal definition for it according to Daniel et al. [27]. Grandison and Sloman [28] indicated that many researchers use the definition of trust in a very specific form relating to topics, such as authentication, or the ability to pay for purchases. Townend and et al. [29] defined trust as the level of reliance placed on an entity based on experience of a particular context. Pereira and et al. [30] viewed the trust concept as the degree of confidence given to an entity. Neama et al. [31] considered trust as an assurance among participants while engaging in online auctions. Many researchers defined trust as a subjective probability that leads an individual to believe that another person will behave as expected [32] and as a particular level of subjective probability in which an agent assesses one or more agents to perform a specific action [33] [34].

B. Risk

Similar to trust, risk depends on the context as well. However, several works interpret risk as the probability of a negative event occurring. When taking risk into consideration, it is important to identify then evaluate it. The evaluation can be qualitative or quantitative. Flinn and et al. [35] defined risk as finding the balance between the likely cost and the possible reward. The cost is based on the likelihood of harm and its magnitude, which can be hard to asses. Jarvenpaa and et al. [36] defined risk perception as the ”trustor's belief about likelihoods of gains and losses.” Yet Dwaikat and Parisi-Presicce [37] defined risk as the probability of exploitation of vulnerabilities in terms of software. Liu and et al. [38] mentioned the ISO/IEC TR 133351 definition of risk, which is related to the likelihood of exploiting vulnerabilities. Risk was also defined as the likelihood of an unwanted event and its consequence according to some studies [29] [32].

C. Relationship Between Trust and Risk

It is necessary to understand the relationship between trust and risk to know how to use them for decision-making. According to our analysis of previous works, many types of relationships were identified.

1) Risk influences trust: In this relationship, risk may influence trust calculation [39],trust definition [1] and trust relationships [40].Also, some works [28] [36] [41] showed that trust is associated with lower perceived risk.

2) Trust influences risk: In this relationship, trust may influence risk calculation [4], risk assessment [42], risk mitigation [43], risk relationship [44], and risk management [45].

3) Complements to each other: Trust and risk can be viewed as complements to each other. Daniel and Ken [27] demonstrated that most systems consider trust and risk as complementary or ignore them. In our opinion, having such a relationship might lead to the use of one of them as a factor for decision-making because the other one is its complement.

4) No relationship: It is also possible that there is no connection between trust and risk. For example, trust can be considered as a property of principles but risk as a property of a process [27]. Kim and et al. [46] showed that it is common to treat trust and risk as different concepts. In our opinion, this is practical if we deal with trust as a property of an entity that can make decisions and uses risk as a property of the decision itself.

III. Using Trust and Risk in Multi-stakeholder Decision-Making

Decision-making is not limited only to an individual's decision. Some scenarios involve more than one person to make a decision. In these cases, it is called multi-stakeholders or Group Decision-Making (GDM) [47]. One member involved in a group no longer makes the final decision without the involvement of other members. In social settings, different approaches, such as taking the average of all the participant responses or taking the majority decision as final, have been proposed. Arrow's impossibility theorem is used in the field of GDM. According to Herrmann [48], ”When we consider the group decision-making problem (with more than two choices), it is clear that it would be nice to have a 'fair' procedure that combined the individuals' preferences about the alternatives (expressed as rankings) into a statement about the group's preferences about the alternatives while preserving the autonomy of each individual.”

A. Multi-stakeholder decision-making process

The involvement of multiple participants when making a decision makes it essential to construct a process that takes each individual selection into consideration to reach a final decision. There are different types of multi-stakeholder decision-making processes. However, based on our analysis of the existing works, we found that the three common processes are consensus, ranking, and voting(Table I).

Voting, for example, is considered a simple method because it involves making a decision based on the majority vote. However, its limitation comes from treating all participants equally even though they are different in terms of expertise. Also, the outcome of voting may be unsatisfactory for the members whose decisions received less votes [8]. Consensus, however, does have the advantage of reaching a solution that is agreed by everyone [7]. Thus, the decision makers need to negotiate several rounds, and in each round, they must modify their proposed solutions to be decided by other participants. However, this has its limitation as the participants cannot influence others, which could lead to an infinite number of rounds. The ranking process is used in several multi-stakeholder decision-making model by ranking the suggestions of each participant [9]. This has the advantage of knowing the degree of group convergence, which is useful in selecting the solution that receives the higher ranking. However, its limitation is the difficulty of ranking a large number of decisions. Also, it is possible that each participant will rank the solutions but will give his or her own the highest ranking.

In terms of using trust on those processes, it has been applied in a different way like obtaining the advices from the trusted individuals or weighting each alternative with the trust of the individual. Tundjungsari and et al. [5] used trust for the consensus process and showed that the consensus decision is

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TABLE I. LIST OF COMMON MULTI-STAKEHOLDER DECISION-MAKING PROCESS WITH THE ASSOCIATED CHALLENGES.

Process	*Description*	*Challenges*
Voting	Take the majority's opinion	The outcome is winning or not wining.Treat participants equally
Consensus	Consider the group decision instead of selecting one	The outcome is hard to reach if there is conflict
Ranking	Show the degree in which the group preferences converge	Difficulty to rank the large number of decisions

reached when decision makers adjust their preferences, such as the importance of the decision criteria, which can be obtained from the advice of other trusted participants. For the voting process, Rodriguez [8] aggregated single votes to a single collective decision and used trust to weight the influences of the decision makers in decision-making. Capuano and et al. [9] proposed a multi-stakeholder decision-making model to rank the preferences. However, in some cases, the decision makers may not have enough information about some alternatives to accurately rank them. Therefore, the decision maker's opinion about such alternatives is influenced by other experts he or she trusts.

B. Multi-stakeholder Decision-Making Models

According to French and et al. [49], there are five classes of GDM models. The first model, GDM1, assumes that the decision makers propose then aggregate their individual solutions, rank them based on their utilities, and finally select the highest ranked solution. In the second model, GDM2, the decision makers propose their individual solutions and use them as preferences when voting. In the third model, GDM3, there is a supra-decision maker that manages the decision-making process among the decision makers. The fourth model, GDM4, finds group utility to reach a consensus. In the fifth model, DGM5, the decision makers use the bargaining theory. There is no model better than the others because each model is useful in specific applications. For example, GDM1 is useful for applications that take individual preferences into account, GDM2 for applications that use voting as a decision-making process, GDM3 for applications where there is a hierarchy among participants, GDM4 for applications that take group preferences for the consensus process into account, and GDM5 for applications that deal with resource allocations.

C. Trust in Multi-stakeholder Decision-Making

Trust in multi-stakeholder decision-making is crucial [6] because it is a valuable group component and is essential in the collaboration process. It becomes, however, a further complicated or more dependent parameter when an expert may be uncertain, have incomplete information, or cannot access information. Experts have to use their domain expertise to arrive at a decision. An expert may give his or her subjective preferences, but they may not be agreed to by other team members. In such situations, experts have to collaborate, exchange information, and arrive at a consensus. Jian Wu and Francisco Chiclana [50] stated that the trust can indicate the actual reputation between experts Consequently, it should be taken into account as a credible source to be used in deriving aggregation weights for individual experts. As a matter of a fact, trust can be used in the decision-making process to weight the influence of different decision makers [8].

Several schemes for multi-stakeholder decision-making vary in terms of the trust model, as well as the GDM model and process. In addition, each of the schemes comes with limitations. For example, some schemes [5] [6] [10] [12]–[14] do not allow the stakeholder to modify the decision outcome because there is a fixed set of decisions to select from. Such fixed outcomes limit the stakeholder's ability to propose a new outcome. Some schemes [8] [9] apply preferences ordering. A large number of preferences is challenging to the stakeholder to order. In addition, each stakeholder might rank his or her own preference higher if he or she is the one proposing the decision outcome. Some schemes [7] [15] do not use historical interactions; they may lead to missing extra information that might help the stakeholder when proposing solutions and selecting the final decision. Some schemes [7] [11] limit trust to specific stakeholders, which leads to limited information in the problem domain (Figure 1).

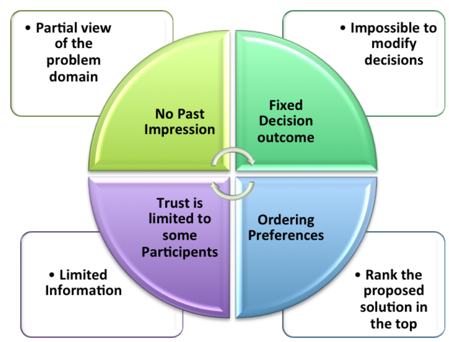

Figure 1. Limitations of Existing Multi-stakeholder Decision-making Schemes

Table II shows the existing multi-stakeholder decision-making schemes with the corresponding trust model, GDM process and model, limitations, and applications.

1) Tundjungsari, Istiyanto, et al.: Tundjungsari, Istiyanto, et al. [5] proposed a multistakeholder decision-making model for urban planning in rural areas by combining a trust model proposed by Abdul-rahman and Hailes [51] and the GDM3 model that assigns a supra-decision maker to manage the consensus process. This scheme is useful for applications that require assigning different roles to decision makers based on trust.

2) Indiramma and Anandakumar: The authors proposed a multistakeholder decision-making model for soil erosion applications [6]. In their scheme, they showed a multi-agent-based collaborative decision-making framework for distributed environments. Trust is strengthened by familiarity and similarity beliefs and evaluated during collaboration. The proposed decision model starts by collecting the decision maker's decisions and allows each agent to discuss any decisions, criteria, and conflicts. The trust values are then computed and aggregated, and each agent rates those trust values. The highest trusted decision is selected as the final decision.

3) Alonso, Perez, et al.: The authors proposed a multistakeholder decision-making model for applications that involve

TABLE II. MULTISTAKEHOLDER DECISION-MAKING SCHEMES WITH THE CORRESPONDING TRUST MODEL, GROUP DECISION-MAKING PROCESS, GROUP DECISION-MAKING MODEL, THE LIMITATION AND THE APPLICATION

Scheme	*Trust Model*	*GDM Process*	*GDM Model*	*Limitation*	*Application*
[5] Tundjungsari, Istiyanto, et al.	Direct interaction between participants	Consensus	GDM3	Fixed Decision outcomes	Urban planning
[6] Indiramma and Anandakumar	Direct experience/social interaction	Consensus	GDM1	Fixed Decision outcomes	Soil erosion
[7] Alonso, Perez, et al.	Opinions of all the experts involved in the process	Consensus	GDM2	No past impression and the trust is limited to some participants	Online and web systems
[8] Rodriguez	Similarity and expertise	Voting	GDM1 & 2	Ordering Preferences	Social decision support system
[9] Capuano, Chiclana, et al.	The history of past actions and behavior	Ranking	GDM1	Ordering Preferences	Incomplete information
[10] Lau, Singh and Tan Scheme	Agent tendency of accepting other agent to join	Voting	GDM2	Fixed Decision outcomes	Multi-agents system
[11] Sanchez-Anguix, Julian, et al.	Full knowledge about the information	Voting	GDM3	Trust is limited to some participants	Bilateral alternating protocol in electronic systems
[12] Wu, Chiclana, et al.	Social Network Analysis with incomplete linguistic information.	Consensus	GDM1	Fixed Decision outcomes	Incomplete Linguistic Information Context
[14] Wu, Chiclana, et al.	Social Network Analysis	Consensus	GDM1	Fixed Decision outcomes	Cloud service suppliers
[13] Liu, Liang, et al.	Opinions of the experts	Consensus	GDM1	Fixed Decision outcomes	Cloud services selection
[15] Park, Cho, et al.	Expertise for each criterion	Consensus	GDM1	Fixed Decision outcomes and no past impression	Supplier selection

large numbers of decision makers [7]. In their scheme, there are two groups: the selected expert and the nonselected expert groups. The nonselected expert group provides the utility toward the selected ones to establish the trust network.

4) Rodriguez: The author proposed a multistakeholder decision-making model for social decision support system applications [8]. In this scheme, the author proposed a process consisting of three serial stages; individual solution ranking,collective solution ranking and solution selection from collective solution ranking. Trust reflects the similarity and expertise of the individuals and is used to weight the influence of decision makers in the decision-making process.

5) Capuano, Chiclana, et al.: The authors proposed a multistakeholder decision-making model for applications that have incomplete information [9]. In their scheme, they proposed a model that adopts fuzzy rankings to collect experts' preferences on available alternatives and trust statements on other experts. Sometimes, experts cannot express an opinion on any of the available alternatives, leading to incomplete information. Therefore, to estimate the missing preferences, the Social Influence Network (SIN) addresses the experts' influences. Then, the aggregation process is applied, followed by selection of the best alternative.

6) Lau, Singh and Tan Scheme: The authors proposed a multistakeholder decision-making model for coalition formation applications in multiagent system environments [10]. In their scheme, they proposed a Weighted Voting Mechanism (WVM) that allows agents to join existing coalitions. There are two types of votes: agreement and disagreement. The trust element is the main criterion for deciding the weight in the voting session. The trust ration can be low, medium, or high.

7) Sanchez-Anguix, Julian, et al.: The authors proposed a multistakeholder decision-making model for a bilateral alternating protocol in electronic systems [11]. In their scheme, they proposed a mediated negotiation model for agent-based teams that negotiate with an opponent. This negotiation model defines the communication protocol with the opponent and the decisions of the negotiation team. Trust only applies to the group meditator because he manages the negotiation process and counts the votes from the team members.

8) Wu, Chiclana, et al.: The authors proposed a multistakeholder decision-making model for incomplete linguistic information contexts [12]. They proposed a trust propagation method to derive trust from incomplete connected trust networks. The decision-making model consists of computing trust degrees; estimating unknown preference values; determining the consensus index, consensus identification, recommendation, and feedback; and establishing a selection process. Similarly, they proposed a decision-making model [14] that is different from one [12] that employs dual trust (trust, distrust) and nonlinguistic assessments.

9) Liu, Liang et al.: The authors proposed a multistakeholder decision-making model for cloud service suppliers [13]. The proposed decision-making model consists of four stages: "(1) Constructing the interval-valued trust decision making space; (2) Determining the consensus degree at three levels; (3) Visual consensus identification, trust induced recommendation and rationality analysis; and (4) Selection Process.". This model has the advantage of having a fewer number of rounds by using the harmony degree in addition to the consensus degree.

10)Park, Cho, et al.: The authors proposed a multistakeholder decision-making model for supplier selection [15]. The proposed scheme uses the stakeholder trustworthiness as an influencing factor on the final decision. The decision-making process uses weighted scoring system, where the trustworthiness are used for the weights. Moreover, decision alternatives ranking is applied in this decision-making scheme.

D. Risk in Multi-stakeholder Decision Making

Due to the consequences that might occur following the decision, using such consequences as decision criteria could be practical to decision makers. Table III summarizes the existing GDM model with the corresponding risk model and process.

TABLE III. MULTI-STAKEHOLDER DECISION-MAKING SCHEME WITH THE ASSOCIATED RISK MODEL AND THE DECISION PROCESS

Scheme	Description	Risk Model	GDM Process
[52] Li, Kendall, et al.	Group decision making process that allow agents to express their utilities or evaluations over different alternatives	Based on evidence support logic and expected utility theory	Voting
[53] Pham,Tran, et al.	Dynamic group decision making which aggregates expert preferences and sensibilities, quantified by Self-Organizing Map (SOM) in order to select appropriate alternatives	Human Reasoning = fuzzy rules, quantitative knowledge and reasoning evidence	N/A
[54] Wibowo and Deng	Risk-oriented group decision making for modeling the inherent risk in the multi-criteria group decision making process	Subjective assessments	Ranking

IV. CONCLUSION AND FUTURE WORK

Decision-making is deeply interwoven in people's lives and is saturated in almost every field. It also incorporates various methods and factors that can affect the outcome of a decision. Collaborative decisions may involve negotiation, which requires creating some level of trust among the participants. Usually, decisions come with consequences. The main contribution of this paper is analyzing the existing schemes of multi-stakeholder decision-making based on trust and risk. This paper also explores the concepts of trust and risk and categorizes the relationship between them to investigate how to adopt them when designing a decision model. Moreover, we investigate some decision-making processes such as voting, consensus, ranking, and GDM models. We found the consensus process and GDM1 model are mostly applied in the existing schemes. For future work, we will build a multi-stakeholder decision-making framework that is applicable to every context and uses trust and risk as factors.

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