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Towards Consensus-based Group Decision Making for Co-owned Data Sharing in Online Social Networks

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ABSTRACT The use of online social networks has become a crucial activity for individuals in recent years. Users have started to share more data in online social networking platforms. The shared content sometimes includes more than one user's information. This type of data sharing has caused privacy issues as users are only informed after the sharing process is completed.
Although, many of the current studies have focused on applying group decision making in data sharing processes, this technique remains a challenge. In this study, we provide a framework in which a consensus-based group decision making process is used in order to take the best decision in co-owned data sharing processes in online social networking.

INDEX TERMS Consensus-reaching, co-owned data sharing, fuzzy decision making systems, group decision making, online social networks, users trust values

I. INTRODUCTION

In Group Decision Making (GDM), different alternatives are taken into account to reach the most appropriate decision. In GDM process, a group of experts, with different backgrounds and viewpoint, are presented with a problem. They provide their opinions to reach an aggregated solution in a given situation [1]. In general GDM, two main steps are followed i.e. aggregation and utilisation [2], to reach a solution by selecting the best option. Consensus Reaching Process (CRP) has been added to the GDM process to resolve the conflicts of decision makers' opinions.

Consensus reaching is a complex process in which the decision makers express their individual opinions, on a set of alternatives, in order to choose the best option. After that, consensus level is checked to ensure whether it is enough [3], [4]. Once enough consensus is reached, the selection process is required. There is a need of GDM and consensus reaching in collaborative systems, techniques and processes, etc.

Online Social Networks (OSNs) are considered as virtual collaborative systems which provide information sharing, interactive communication, and collaborative interactions [5] among users. However, making decision on data in OSNs has been a crucial issue, especially when data includes multiple users' information. OSNs' users usually ignore other users' (*i.e. stakeholders or co-owners*) opinions on data sharing process. In the best cases, users ask co-owners' opinions individually to make a decision. This satisfies their own benefits which means that the decision does not remain objective anymore, even though CRP in GDM is possible.

Consensus simply represents the agreement among decision makers [6]. In the past few years, consensus reaching in OSNs context has gained much attention [7], [8], [9], [10]. Many studies focused on using the trust relationships in group decision making process. In real life, the trust values between decision makers' play an important role in consensus reaching. In most cases, the importance of consensus reaching process, in online social network group decision making (OSNGDM), has been taken into consideration. However, the necessity of the usage of trust values among decision makers in OSNGDM is still a challenge [11].

Previous studies mostly ignored the decision makers' trust values in decision making processes. In Contrast, this study proposes a framework for OSNs to provide a view of OSNGDM on co-owned data sharing processes. This study also uses the trust values in the application of Extended Induced Ordered Weighted Averaging (EIOWA) technique in order to select the best alternative. As it mentioned above, most of the previous studies usually ignored the trust values. We use co-owners' (decision makers') trust values practically with the application of the ordered weighted average technique.

The main contributions of this paper are as follows:

1. A consensus-reached group decision making framework has been proposed for OSNs. The trust values between decision makers are associated with CRPs.
2. Three algorithms have been developed to reach consensus in OSNGDM co-owned data sharing processes.
3. In this research, reaching a consensus to make a decision on co-owned data has been proposed in order to maintain a balance in data sharing and intimacy protection.

The rest of the paper is organised as follows. Section II introduces the related literature with different techniques on GDM. The problem statement and preliminaries are given in Section III. After that, a proposed framework is introduced with a general view on its structure and details in Section IV. Section V presents the applicability of the proposed framework with details of experimental study. Finally, the concluding remarks of the paper are proposed in Section VII with some future work directions.

II. RELATED WORKS

We have separated the related works into two sections. This is because the paper is mainly related to two main areas in the literature.

A. PRIVACY PROTECTION IN OSNS

Collaborative Privacy Management is a challenge for OSNs since all users have different privacy requirements. Hence, it is possible to see conflicts on shared contexts in OSNs. Although privacy management mechanism has restrictions on users who want to access data, there is no restrictions on users who post the data. However, users who post data may violate other users' privacy. Recent works focus on conflicts among users' privacy policies. They first aimed to detect the conflicts, then generate an aggregation policy that resolves the conflicts. The aggregated policies are not the solution since there are still privacy loss issues in OSNs.

Researchers have worked on the problem of collective privacy management of co-owned data even though OSNs do not yet set restrictions on the co-owned data. This problem was addressed by Squicciarini et al. [12]. They proposed a solution for privacy management for photo sharing in OSNs, meaning that each co-owner can specify their own privacy preference for the shared content. They adopt Clarke-Tax mechanism to provide collective enforcement in shared content, they evaluate their work with Game Theory. The usability is an issue for this work, they do not take all stockholders' privacy preferences. Wishart et al. [13] provided a collaborative privacy policy authoring in the context of social networking. They allowed the originator of the data to specify policies for the content, however, their work does not consider co-owners' privacy policy specifications. Hu [14] proposed a collaborative management of shared data in OSNs, it is a simple but flexible mechanism. The mechanism provides conflict resolution that considers both the privacy risk and data sharing loss. Suvitha [15] formulated a multi-party access control and policies. He used voting mechanism for making decision on co-owned data. Collaborative privacy management issue might be described as the mother of the privacy conflicts. Therefore, it is an inevitable point to be involved while the co-privacy management of shared data is considered. Joseph [16] proposed a solution for privacy risk and sharing loss for collaborative data sharing in online social network. The work proposes an algorithm to identify conflict segments in accessor space.

A framework was developed for protecting and securing co-owned data for public OSN by Shaukat et al. [17]. They pointed that the privacy risk is seen not only from unauthorised users but also from the OSNs service providers. They used cartographic-based technique in their framework to overcome privacy concerns. Recently, a work has been proposed to address collaborative privacy management with an agent-model [18]. He has proposed to modify Clarke-Tax mechanism that was used in [12]. Du et al, proposed an evolutionary game model that analysis how a user's data privacy protection is affected by other users' privacy decisions [19].

B. FUZZY LOGIC-BASED DECISION AND GROUP DECISION MAKING

Group decision making is considered to be a significant and challenging process as it involves decision makers' problems, doubts and uncertainties [20]. Therefore, it is important to find the most appropriate ways to help decision makers. Thirumalai and Senthilkumar [21] propose a fuzzy model to resolve the group decision making problems in business areas. To make the group decisions, the proposed approach utilises membership and non-membership attributes. Fuzzy logic is an approach to tackle with uncertain situations, having the ability within binary logic, underlying on modern computer systems. It can be applied to take any decision because it helps to describe fuzziness. Therefore, it can easily be applied in decision making in the areas of education [22], health [23], Internet of Things [24], social networks [25]–[28]. Fuzzy logic is widely used in order to take decisions when alternative options are available. Because of its effectiveness, Fuzzy logic has also been applied for the resolution of problems related to group decision making processes. So, we use fuzzy logic decision making approaches to remove uncertainties in group decision making process for OSNs. In OSNs, Fuzzy systems have also been applied to resolve the group decision making issues [20].

Consensus process is considered as a recursive process in which a moderators (third party) give their advice, to create the alternative sets of decisions, which may help in changing the decisions taken by decision makers [3]. The moderator advice involves a feedback mechanism which helps in reducing the knowledge related inconsistencies, provided by decision makers [25]. In OSNs, consensus reaching approaches have been quite productive. A very first social network consensus reaching approach was proposed by *Alonso et al.* [29], which included a feedback mechanism and delegation mechanism for enhancing the consensus solution.

Li et al. [30] proposed a generalisation of the Deffuant-Weisbuch mode. It also studied opinion dynamics in a connected network in accordance to the hard-interaction model and the strategic interaction model. It showed how a required situation guarantees opinion aggregation in the hard interaction model and effect of individual incentives interaction on the opinion formation process. In the recent years, researchers have been attracted towards choosing the best parameter for the feedback mechanism [9], [31]. *Wu et al.* proposed a technique to reduce the changes on decision makers opinions and minimise the cost of feedback to reach the consensus for group decision making. It also expresses the trust values with linguistic terms. In order to avoid the inconsistency of the decision makers, the use of trust value has been considered as a resolution based on the importance addressed by [32], [26]. It was the first research in which trust value was applied to reach satisfied consensus-based decision in SNGDM. *Wu et al.* presented a new consensus approach that includes a trust based estimation method and an illustrative consensus aggregation model [8]. So, the proposed work uses a relative trust score to determine users' weights and to estimate the unknown evaluation values.

Above studies have proposed to improve CRPs by either developing of new models or with applications. Although consensus-reached group decision making processes models or application have commonly been improved. There is no approach to use consensus-reached group decision making in co-owned data sharing processes. Therefore, we propose a framework for consensus-reached group decision making processes for co-owned data sharing processes in OSNs. The proposed framework uses fuzzy decision making systems in order to reduce uncertainties in the decision making process. It also uses a feedback mechanism for taking the most appropriate decision (*i.e. consensus-reached decision*) in the sharing process.

III. PRELIMINARIES

In a general CRP, a group of Decision Makers (DMs), d_l, *{l=1,2,3,...,m}*, try to reach a consensus-reached decision by expressing their opinions (i.e preferences) on an alternative set $x_i = \{x_1, x_2, ..., x_n\}$. SNs are web platforms which allow the users to communicate with each others by sharing contents of data such as photos, messages, events, and videos. Decision makers negotiate their preferences over the Web 2.0 platforms, so SNs are the platforms to define the consensus-based GDM processes. Social networks are also known as OSNs [33]. They automatically bring the concern of GDM process into OSNs. In OSNs, sometimes the content of data includes more than one user's information (this type of data is called co-owned data since it is owned by multiple users). Such conditions demand consensus based decision making. In many of the current OSNs, users are notified by the system whether they are willing to share their personal ID or not. However, involved users still do not have rights to express their opinions on data sharing process. By taking this into consideration, a framework is proposed which involves two fuzzy systems to make a decision and choose the best alternative for sharing the content of co-owned data. Before going through the details of the proposed co-owned data sharing process, a general structure of co-owned data sharing process for OSNs is given in Figure 1.

The figure basically presents a co-owned data sharing process, which includes a group of people taking a group decision. In this process, the data owner uploads a content of data, either from a storage or can produce a content of data with any IoT devices [34]. The owner decides who is going to access the content (*i.e. targeted group*), and informs the decision makers (*i.e. co-owners*), who are related to the data. The group makes a group decision and returns their decision to the owner. In the end, owner take the last decision.

Specifically, the user specifies what information is to be shared and with whom it is to be shared. Decision makers give their opinions to make a group decision and choose an alternative from given alternative set for sharing data. The importance of the DMs' choices depends upon the trust values which shows the user's trust in each member of DMs group. In order to compute the best alternative in the EIOWA technique, trust values are used instead of weights. In the proposed framework, time restriction mechanism is used. User is given an option to share the data when the given time is expired. Decision makers are expected to reach a convenient decision during the given time. If they can not reach a consensus-based decision, the data owner decides to share data with his/her own decision. At the end of the sharing process, the change in trust value is based on the owner's behaviour in co-owned data sharing process, therefore users' trust is not a dynamic value.

IV. PROPOSED FRAMEWORK

In this section, the structure of the proposed CRP framework in OSNs is given. In the framework, the moderator is the data owner to start the process. The process starts with providing the data, deciding the targeted group for data, and the set of alternatives. Decision makers give their individual opinions on the alternatives and their choices on the Confidentiality, Integrity, Availability, Privacy and Possession (CIAPP) features. The selection of CIAPP features are given in [35]. With the data sensitivity value and confidence value in targeted group, the decision on the data is made with Fuzzy Decision System. While the CIAPP features are chosen, the preferences on the alternatives are given by decision makers in Fuzzy Alternative System. After getting the decision and the aggregated choice on given alternative set, the Fuzzy Decision System's decision is fused with the Fuzzy Alternative System's output in the DEI-DEO (Decision In-Decision Out) box. The framework has two outputs based on the output of the DEI-DEO. The system either gives recommendations to the decision makers or notifies the owner with the best

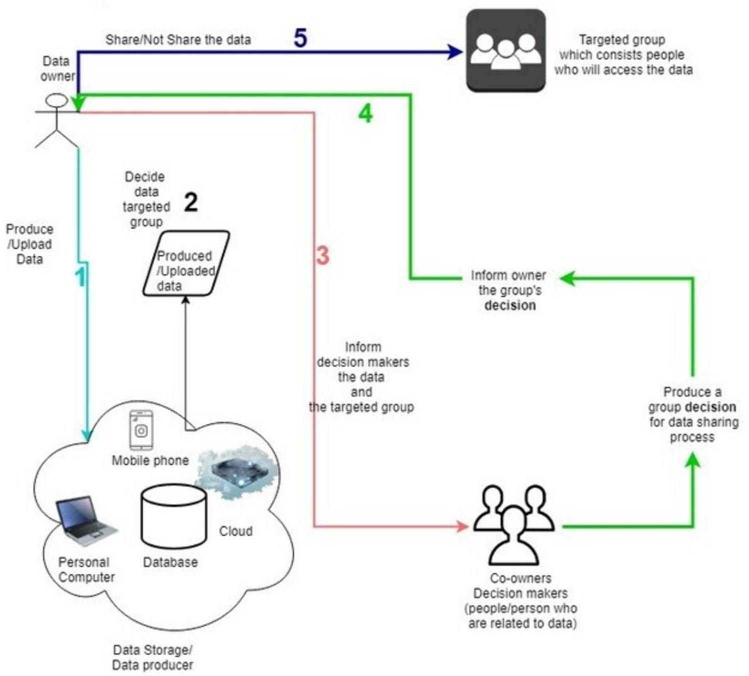

FIGURE 1. General Process for Data-sharing in OSNs with the proposed group decision making

alternative.

Figure 2 represents the structure of the proposed CRP in OSNs. Explanation of the steps in Figure 2 is as follows;

- Notify DMs with the data, targeted group and the set of alternatives.
- DMs provide their choices on CIAPP features and provide their preferences on the alternatives.
- DMs' choices are used to compute the decision in the Fuzzy Decision System and the x_i is chosen with the *EIOWA* aggregation technique in Fuzzy Alternative System.
- The Fuzzy Decision System's output (*yes, maybe or no*) is fused with the Alternative System's output(x_i).
- If the fused decision is meshed conveniently with eachother, then the x_i is recommended to the data owner and the process is stopped. Otherwise, a feedback mechanism is applied, the owner can prepare some guidance and advice for decision makers to reach the consensus easily.
- Finally, an advise is given to the decision makers and the first round is completed.

A. FUZZY DECISION SYSTEM

In the real life, when people decide to share their information with others, they determine some criteria to make a decision. The information sensitivity is one of the important criteria to decide with whom the information is to be shared. Also, in order to decide whether the information is to be shared or not, the confidence in the other person is another important factor to be considered.

In OSNs, people communicate with other people through data. Therefore, the data sharing process in OSNs needs to be considered in the same way as the real life data sharing process. It requires that users should be able to express their opinions on the data sensitivity [35]. Also, the confidence on the data targeted person or group should have a crucial impact on the data sharing process. The confidence value in targeted group is computed only with the relation values [11], [36]. However, relation values and the data sensitivity value are used to compute the confidence value [35], which shows the intensity of decision makers' confidence on targeted group in order to share the data. The models of *R and* C_f are given in our previous work [35].

An adjacent matrix *R*= $(R_{DM}$-$R_{Ui})_{mxm}$ is also used to identify the *R* value, where

$$R_{DM-Ui} - R_{Ui-DM} = \begin{cases} 1, & \text{if } (D_M, U_i) \in E \\ 0, & (D_M, U_i) \notin E \end{cases} \quad (1)$$

thus R_{DM}-R_{Ui}=1 denotes decision makers have relationship with U_i in targeted group. The following adjacency matrix indicates the values of R_{DM-Ui}.

$$\begin{pmatrix} & U_1 & U_2 & U_3 & ... & U_n \\ DM_1 & 1 & 1 & 0 & ... & 1 \\ DM_2 & 1 & 1 & 0 & ... & 0 \\ . & . & . & . & ... & . \\ . & . & . & . & ... & . \\ DM_n & 0 & 0 & 0 & ... & 0 \end{pmatrix}$$

In order to fulfil the mentioned requirements, a fuzzy logic-based decision making process is provided in which the

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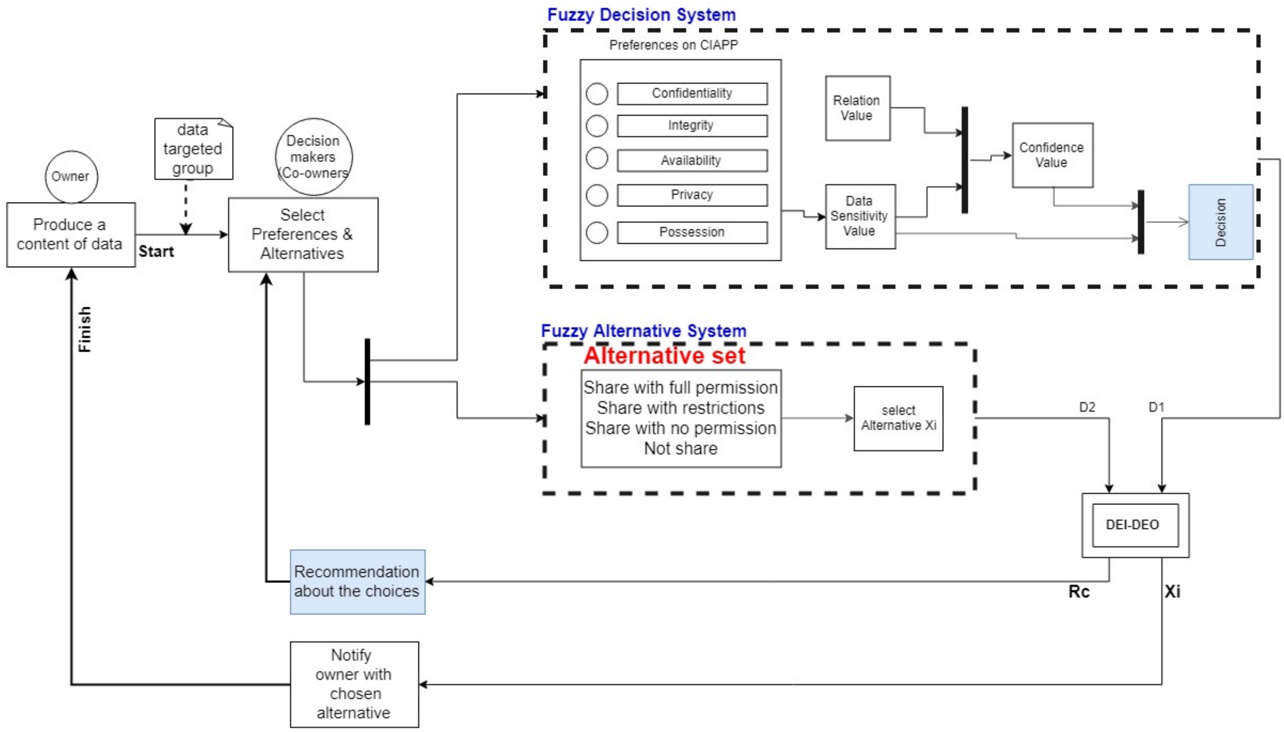

FIGURE 2. Main steps of sharing co-owned data with the proposed framework

data sensitivity and the *confidence value on targeted group* are used to take the fuzzy logic-based decision. Following equations are used to calculate the input variables' values for the *Fuzzy Decision System*.

Equation 2 shows the developed model for co-owned data sensitivity calculation in OSNs [35]. S_d represents the data sensitivity ranging from 0 to 1. The numerator gives the summation of the data CIAPP probabilities in which P_i indicates the probability of CIAPP concerns that is selected by co-owners and w_i is the weight of the properties. The denominator indicates the total number of features.

$$S_d = \frac{\sum_{i=1}^{m}(P_i * (w_i))}{\sum_{j=1}^{m}(f_j)} \tag{2}$$

The model 3 indicates the relation value between the owner and people who are in the targeted group for the data. In the model, *n* indicates the size of the group. It shows the number of people in the targeted group. τ represents the trust values that appears between owner and the users in the targeted group.

$$R_{o-u} : f(r_{o-u1}, r_{o-u2}, ..., r_{o-un}) = \frac{\sum_{j=1}^{n}(r_{oj}) * \tau_{o-uj}}{n} \tag{3}$$

The model below indicates the relation between co-owners (i.e. stakeholders) and the members of the data targeted group. In the model, $f(r_{co1-u1}, ..., r_{co1-uj}, ..., r_{con-uj})$ is the function which takes the relationship values between each co-owner and user in targeted group. τ_{co-uj} is the illustration of the trust value between each co-owner and each user in the targeted group.

$$R_{coi-u} : f(r_{co1-u1}, ..., r_{co1-uj}, ..., r_{con-uj}) = \frac{\sum_{j=1}^{n}(r_{coj-uj}) * \tau_{co-uj}}{n} \tag{4}$$

Model 5 is the combination of the model 3 and model 4. This model gives the final relation value for the fuzzy-logic decision system's fuzzification.

$$R = R_o * \prod_{l=1}^{c} R_{ci} \tag{5}$$

Confidence in targeted group is defined as a trust value to believe someone [37]. The connection between trust and sharing private information or sensitive data is defined as confidence value. Therefore, the data sensitivity value and the relation value are important to develop confidence model. Model 6 indicates the confidence value in targeted group, it ranges between 0 and 1 [35].

$$C_f = 1 - S_d * (1 - R) \tag{6}$$

Algorithm 1 is the process that shows the steps for decision making on Fuzzy system 1 in Figure 2.

input : Preferences *CIAPP* features
output: Fuzzy Decision Linguistic Term
Yes, No, Maybe

Evaluate Fuzzy decision dec;
for $k \leftarrow 1$ **to** m **do**
the round for decision makers;
for $l \leftarrow 1$ **to** 5 **do**
$w_i = 1$: **the weights of the CIAPP features**
Confidentiality← $Pc[Pc, w_i]$;
Integrity← $Pi[Pi, w_i]$;
Availability← $Pa[Pa, w_i]$;
Possession← $Pp[Pp, w_i]$;
Privacy← $Pp[Pp, w_i]$;
end
Sum=Pc+Pi+Pa+Pp+Pp
S_d=sum/5
end
Evaluate S_d;
Evaluate Relation R;
Evaluate Confidence C_f;
Evaluate Fuzzy decision dec;

Algorithm 1: Algorithm for Fuzzy Decision System

B. FUZZY ALTERNATIVE SYSTEM

In the Fuzzy Alternative System, the group evaluates the given alternatives in order to make the most convenient decision for sharing the data. The main criteria is that the group's decision needs to be concurrent decision with the Fuzzy Decision System's output.

The set of alternatives and the linguistic variables are given to the DMs (*in this work DMs are called co-owners* (C_o)). In co-owned data sharing process, the number of the DMs is the number of users who are notified by the data owner for making a consensus-reached group decision.
DM_l=*l=1,2,...,n* ⇔ Co_l=*l=1,2,...,n*.

The structural details of consensus group decision making model is given in Figure 3. The alternative set is the main part of any group decision making. It is provided to the group members for giving them a chance to make choices on the given set. The options in the alternative sets are general enough to cover all the situations in any co-owned data sharing processes. However, if the options need to be specified with more details, it does not create an issue with the proposed work. EIOWA method is used in which linguistic variables are utilised to make choices. However, it is important to highlight that the linguistic variables make the process easy for the group decision makers, which is explained in the following section with its details.

In the Fuzzy Alternative System (see Figure 3), the group evaluates the given alternatives in order to make the most convenient decision for sharing co-owned data. The main criteria is that the group's decision needs to be a concurrent decision with the fuzzy logic-based decision system's output. The group members' make their choices on the CIAPP features and the confidence in the targeted group is used. The set of alternatives with the linguistic variables are given to the co-owners.

In Figure 3, the relationship between the owner and the co-owners can be evaluated as follows;

$$R_{o-co} : f(r_{o-co1}, r_{o-co2}, ..., r_{o-com}) = \frac{\sum_{j=1}^{m}(r_{ocoj}) * \tau_{o-coj}}{m} \quad (7)$$

In the above model, R_{o-co} presents the values of the relationship between the owner and co-owners. It takes the owner's relationship with each co-owner as a function $f(r_{o-co1}, r_{o-co2}, ..., r_{o-com})$ and gives the calculated relation value.

In GDM processes, weighting group decision makers' opinions is considered to be an important step. In OSNs, the major challenge is to apply the group decision making and weighting decision makers' opinions. The challenge of weighting decision makers' opinions in SNs has been addressed in [7]. In addition to this, the difficulties of the trust usage in group decision making across social networks has also been discussed. In order to overcome the usage of the trust values in social networks, we developed trust model for social networks. As it is aforementioned, trust τ plays a key role in co-owned data decision making process. For any users $user_i$ and $user_j$, if they are directly connected (i.e. be friends) where $R_{useri-userj}$=1, we use $\tau_{useri-userj} \in$ [0,1]. The more $user_i$ trusts $user_j$, the higher the τ_{useri}-τ_{userj} is. In this work, we have two types of users in a co-owned data sharing process namely the owner and co-owners. Model 9 is the representation of trust values between owner and co-owners. These trust values between those pairs are updated, based on the owner's final decision in the sharing process. For example, if the owner respects the decision makers' group decision, then the owner gains trust in co-owners. On the contrary, the owner loses trust in co-owners. Equation 9 is used to update the trust values between the owner and the co-owners.

Equation 8 presents the privacy loss for each co-owner in a co-owned data sharing process. This equation illustrates that if the owner posts the data without respecting a co-owner's opinion in the co-owned sharing process, especially when a co-owner has concerns on the *CIAPP* data security features, then the co-owner will suffer a privacy loss because of the sharing process. In the equation, $R_{(co_{si})}$ indicates the relation value which exists between each co-owner and targeted group of people. In order to calculate $R_{(co_{si})}$ value, the existing relationship (*i.e. friendship in OSNs*) is checked. $R_{(o_{si})}$ shows the relation value between the owner and

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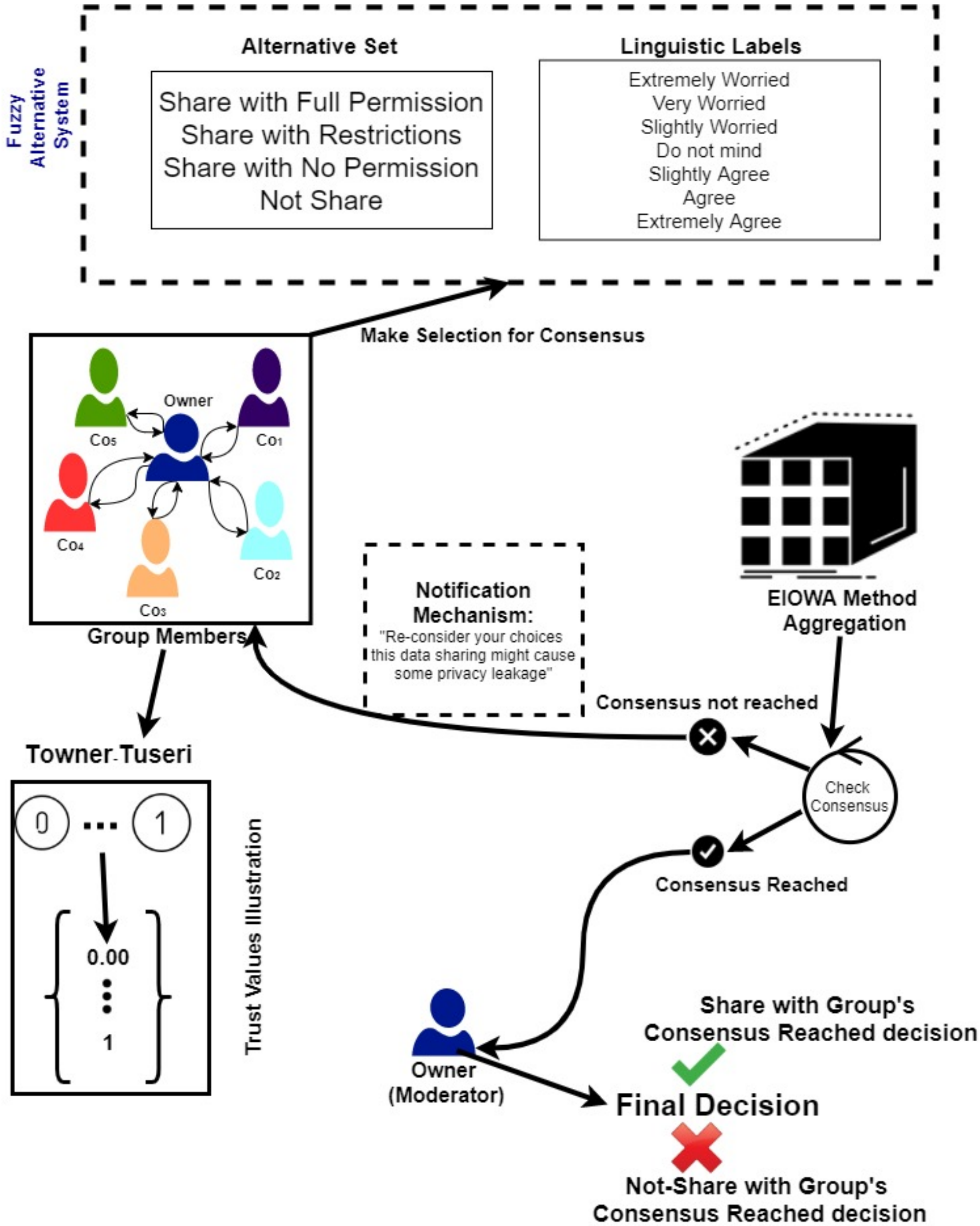

FIGURE 3. General Trust values usage and EIOWA technique usage for consensus model in co-owned data sharing

people in the targeted group.

$$P_l(c_{owner}) = S_d * |\frac{R_(co_{si})}{R_(o_{si})}| \quad \boxed{\begin{array}{r} where \\ |\frac{R_{co_i}'}{R_{ci}}| : common friends \\ S_d : data - sensitivity \end{array}} \tag{8}$$

$$
\begin{aligned}
\tau_{ui-uj} &\in [0,...,1] \\
(\tau_o) - (\tau_{coi}) &: Owner - trust - in - Co - owner_i \\
(\tau_{coi}) - (\tau_o) &: Co - owner_i - trust - in - Owner \\
\tau_l(user_i) : \tau_l(pl) &= \frac{1-e^{(pl)}}{1+e^{(pl)}} \\
\tau_g(user_i) : \tau_{g(\tau ui)} &= (\tau_{ui})^n \quad (9)
\end{aligned}
$$

$$
\boxed{\begin{aligned} &where \\ n_{mood} &= (0 \leq n \leq 1 \\ \tau_l(user_i) &: Trustloss \\ \tau_g(user_i) &: Trustgain \end{aligned}}
$$

We now introduce the usage of the trust values in the extended induced weighted average (EIOWA) technique. In this work, we give the steps of the EIOWA technique not in detail. Therefore, for more details of the techniques, we refer readers to [38].

- **Step (1)** Utilise the EIOWA operator (see Equation 10) $\hat{r}_{ij} = EIOWAw(r_{ij}^{(1)}, r_{ij}^{(2)}, ..., r_{ij}^{(l)})$

  i,j=1,2,3,4,...,n are associated to the trust values (τ) between the data owner and the co-owners (DMs).

$$
\begin{aligned}
EIOWA\tau(s_{\alpha 1}, s_{\alpha 2}, ..., s_{\alpha n}) = \tau_1 s_{\beta 1} \otimes \\
\tau_2 s_{\beta 2} \otimes ... \otimes \tau_n s_{\beta n} \quad (10) \\
= s_{\bar{\beta}}
\end{aligned}
$$

  where $\bar{\beta} = \sum_{j=1}^{n} \tau_j \beta_j$
  $s_{\beta j}$ is the *j* th largest value of the $s_{\alpha i}$.
- **Step (2)** Collect all additive linguistic preference relations $R^{(m)}$*(m=1,2,...,l)* into an aggregated linguistic preference relation $\hat{R}$=$(\hat{r}_{ij})_{nxn}$
- **Step (3)** In order to aggregate the preference information $(\hat{r}_{ij})$ in the *ith* alternative over all the other alternatives utilise, the following operator;

$$
z_i = (\hat{r}_{ij}) = \frac{1}{m}(\hat{r}_{ij}^{(1)} \oplus \hat{r}_{ij}^{(2)} \oplus \cdots \oplus \hat{r}_{ij}^{(n)}) \quad (11)
$$

- **Step (4)** Rank all the alternatives and select the highest valued option from the value of z_i*(1,2,...,n).*

In Algorithm 2, the steps of the EIOWA techniques is given with the usage of users' trust values (τ). It takes the alternative choices as input values and gives the aggregated matrix as an output. τ is weighting values for decision makers' opinions in the process. τ is the owner trust value for each co-owner where τ ranges in [0,1]. The most trusted co-owner's opinion has more effect in the decision making. When the aggregated decision is taken, the decision consistency on outcome of both the fuzzy decision system and the fuzzy alternative system is controlled.

```
input : x_i: set of alternatives (i=1,2,...,n)
        decision makers, DM_l, l ≥ 1
output: Aggregated Matrix
Preference Process;
for k ← 1 to l do
    the round for decision makers;
    for i ← 1 to n do
        the value of the alternative x_i ;
        for j ← 1 to n do
            s_a (−q ≤ a ≤ q): x_j th x_i value;
        end
    end
end
Aggregation Process;
τ_{o−dl}: τ_1, τ_2, ..., τ_l;
for k ← 1 to l do
    the round for decision makers;
    for i ← 1 to n do
        s_{a/−a}: the value of the alternative x_i;
        for j ← 1 to n do
            EIOWAτ(s_α1, s_α2, ..., s_αn)=τ_1 s_β1 ⊗
             τ_2 s_β2 ⊗ ... ⊗ τ_n s_βn =s_β̄
        end
    end
end
```

Algorithm 2: Algorithm 2: Aggregation on x_i

C. BEST ALTERNATIVE SELECTION: DEI-DEO

Decision in-Decision Out (DEI-DEO) is a fusion technique in which input decisions are fused to obtain either a better or a new decision [39]. The DEI-DEO in Figure 2 represents the implementation of decision in-decision out technique. The function to implement the technique is given in Equation 12, which takes two decisions values from the *Fuzzy Decision System* and the *Fuzzy Alternative System* and provides fused decision D_o. Table 1 represents the cases for obtaining the fused decision.

TABLE 1. Decision In-Decision Out Rules

IF (D_1 is YES & D_2 is x_1) THEN D_o is o_1
IF (D_1 is YES & D_2 is x_2) THEN D_o is o_2
IF (D_1 is YES & D_2 is x_3) THEN D_o is o_3
IF (D_1 is YES & D_2 is x_4) THEN D_o is o_5
IF (D_1 is MAYBE & D_2 is x_1) THEN D_o is o_5
IF (D_1 is MAYBE & D_2 is x_2) THEN D_o is o_2
IF (D_1 is MAYBE & D_2 is x_3) THEN D_o is o_3
IF (D_1 is MAYBE & D_2 is x_4) THEN D_o is o_5
IF (D_1 is NO & D_2 is x_1) THEN D_o is o_5
IF (D_1 is NO & D_2 is x_2) THEN D_o is o_5
IF (D_1 is NO & D_2 is x_3) THEN D_o is o_5
IF (D_1 is NO & D_2 is x_4) THEN D_o is o_4

Table 2 shows the values of the D_o. If the D_o is equal to o_5, then the case is defined as a conflict. For instance, if the D_1 is *NO*, which simply shows that the decision makers are worried about their data security features (*CIAPP*), and the D_2 is x_1, then the conflict happens. In order to resolve the conflicts, a model is defined which is given in Equation 12. This model is a representation of decision fusion technique.

Equation 12 is a function having two input variables, which are D_1 and D_2, and one output variable D_o.

TABLE 2. The values of Decision Output

D_o	Value	Definition
o_1	x_1	Share with full permissions
o_2	x_2	Share with restrictions
o_3	x_3	Share with no permissions
o_4	x_4	Do not share
o_5	R_c	Reconsider on Choices

The proposed framework has a time restriction. Decision makers are supposed to make a consensus reached decision in time *t*. The reason being OSNs users may not be patient to wait for others' decision to share data. If the time is over and the group has not reached an appropriate decision, then the framework notifies the owner with the last decision that is made in *t*.

Equation 12 checks the consistency between two fuzzy systems' outcome decisions. The function f_t takes two input values, D_1 and D_2 gives one output value defined in Table 2. If the last output value of DEI-DEO is o_5 in time *t*, then it is a special case. If the owner is notified with the o_5, then a decision is taken because consensus decision is not achieved in the group.

$$f_t(D_1, D_2) = D_{oi} \qquad where, 1 \leq i \leq 5 \qquad (12)$$

Algorithm 3 compares the output of both *the fuzzy decision system* and *the fuzzy alternative system* in Figure 2. In the algorithm, the input values are those two systems' outputs namely D_1 and D_2. After taking the two systems' outputs, the consistency of those two decisions is checked in the algorithm. For instance, if *the fuzzy decision system* output is *NO* and the *fuzzy alternative system* output is *Share with Full Permission*, in such a case, the developed framework gives a recommendation to co-owners with *"Re-consider your choices: this data sharing might cause some privacy issues for others"*. The inconsistency case is D_{o5} in the algorithm and in Table 2.

V. PUTTING IT ALL TOGETHER: THE PROPOSED WORK'S ILLUSTRATION

In this section, demonstration of the proposed work is given with detailed implementation. This illustrates how a consensus-reached group decision can be taken in co-owned data sharing processes in OSNs. It also applies the trust values with the importance of users' trust in GDM process.

Let us assume that *user A* uploads a photo (*photo id=photo A*) and wants to share that with his friends, which has eight hundred users in. The owner also tags five users on *photo A*, therefore, the photo involves five other users' ids on it. Those five users are called co-owners and at the same time, they are decision makers. Now, the group is supposed to choose the best option to share or not share to the *photo A*. As it is aforementioned in Section IV, the group is notified

```
Selection Process;
input  : D_1, D_2
output: D_o, o ∈ 1,2,3,4,5
Time t:
for i = 1 to n do
    D_o ← f_T1(D_1, D_2) if o_1 then
        x_1 :best alternative;
    else if o_2 then
        x_2 :best alternative ;
    else if o_3 then
        x_3 :best alternative ;
    else if o_4 then
        x_4 :best alternative ;
    else
        Recommend: D_o5 Reconsideration on choices;
    end
    return: D_oi alternative
end
return: Consensus Not reached
```

Algorithm 3: Algorithm 3: DEI-DEO Functions

with the targeted group and the data id (*photo A*). After the notification, each member of the group gives their choices on the CIAPP data security features in *Fuzzy Decision System* and on the set of alternatives in *Fuzzy Alternative System*. Although, the *Fuzzy Decision System* and the *Fuzzy Alternative System* are carried out in a parallel flow. Those two systems have been explained separately for the intention of clear explanation.

A. THE FUZZY DECISION SYSTEM APPLICATION AND RESULTS

The decision makers' give their choices on the CIAPP features, which helps the system to compute the confidence value in targeted group. The choices of decision makers can either be 0 or 1 (see Table 3), where 0 indicates that the decision maker/co-owner does not have any concern on the data security feature and 1 indicates that the decision maker/co-owner has concern on the data security feature.

TABLE 3. Decision makers choices on CIAPP

DM_l/ $Co-owner_l$	C	I	A	P	P
DM_1/co_owner_1	1	1	1	1	1
DM_2/co_owner_2	1	1	1	1	1
DM_3/co_owner_3	1	1	0	1	1
DM_4/co_owner_4	1	1	0	1	1
DM_5/co_owner_5	1	1	1	1	1

The *Fuzzy Decision System* calculates the data sensitivity value and confidence value for taking D_1.

Table 3 show that decision makers/co-owners are worried if the *photo A* is shared by the owner. Then, they chose most of the *CIAPP* data security features. Equation 2 is used to calculate the data sensitivity value and it becomes *0.99*.

The confidence value is needed to be calculated for the *Fuzzy Decision System*. To do so, we need to know how many

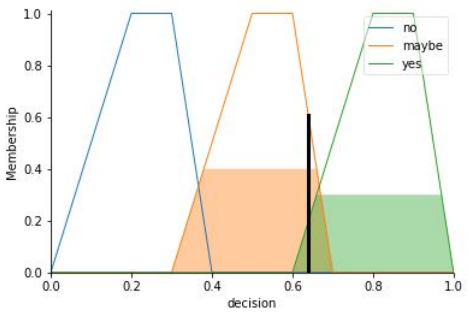

FIGURE 4. Fuzzy Decision System's Output Graph representation

people are known by co-owners/ decision makers. Table 4 gives the number of people which are known by each co-owner. In the targeted group (the number of people in the owner's friend's group).

TABLE 4. People who are connected to each co-owner

$DM_l/ Co-owner_l$	The number of people known by co-owner
DM_1/co_owner_1	110
DM_2/co_owner_2	105
DM_3/co_owner_3	115
DM_4/co_owner_4	100
DM_5/co_owner_5	100

The confidence value in the targeted group is calculated with the relation values between co-owners and people which are part of the targeted group. With Table 4 and with Equation 5, the confidence value becomes *0.66*. As a result, the *Fuzzy Decision System* output with data sensitivity and confidence in targeted group is *maybe*. Figure 4 shows the result of the Fuzzy Decision System in a graph with the value of the output membership's degree.

see Table 5

TABLE 5. Fuzzy Decision System Output

S_d	C_f	D_1
0.9	0.66	$Maybe_{0.63}$

B. FUZZY ALTERNATIVE SYSTEM APPLICATION AND RESULTS

The set of choices X is as follows;

X=

$$\left\{ \begin{array}{c} x_1\textit{=Share with full permission} \\ x_2\textit{=Share with restrictions} \\ x_3\textit{=Share with no permission} \\ x_4\textit{=Do not share} \end{array} \right\}$$

and the linguistic labels are given as follows:

S=

$$\left\{ \begin{array}{cc} s_{-4} & \text{extremely worried} \implies \text{EW} \\ s_{-3}: & \text{very worried} \implies \text{VW} \\ s_{-2} & \text{worried} \implies \text{W} \\ s_{-1} & \text{slightly worried} \implies \text{SW} \\ s_0 & \text{do not mind} \implies \text{DNM} \\ s_1 & \text{slightly agree} \implies \text{SA} \\ s_2 & \text{agree} \implies \text{A} \\ s_3 & \text{fully agree} \implies \text{FA} \\ s_4 & \text{extremely agree} \implies \text{EA} \end{array} \right\}$$

Let us assume that the decision makers give their choices on the alternative set. Table 6, Table 7, Table 8, Table 9, and Table 10 show the assumed choices for each co-owner (*i.e. decision makers*).

TABLE 6. Linguistic Preference Relation R^1

	x_1 Share with full permission	x_2 share with restrictions	x_3 share with no permission	x_4 do not share
x_1	$s_0 \implies$ DNM	$s_{-3} \implies$ VW	$s_{-4} \implies$ EW	$s_{-4} \implies$ EW
x_2	$s_3 \implies$ A	$s_0 \implies$ DNM	$s_2 \implies$ A	$s_{-2} \implies$ W
x_3	$s_4 \implies$ EA	$s_{-2} \implies$ W	$s_0 \implies$ DNM	$s_3 \implies$ FA
x_4	$s_4 \implies$ EA	$s_2 \implies$ A	$s_{-3} \implies$ VW	$s_0 \implies$ DNM

TABLE 7. Linguistic Preference Relation R^2

	x_1 Share with full permission	x_2 share with restrictions	x_3 share with no permission	x_4 do not share
x_1	$s_0 \implies$ DNM	$s_1 \implies$ SA	$s_{-2} \implies$ W	$s_{-4} \implies$ EW
x_2	$s_{-1} \implies$ SW	$s_0 \implies$ DNM	$s_1 \implies$ SA	$s_{-2} \implies$ W
x_3	$s_2 \implies$ A	$s_{-1} \implies$ SW	$s_0 \implies$ DNM	$s_4 \implies$ EA
x_4	$s_4 \implies$ EA	$s_2 \implies$ A	$s_{-4} \implies$ EW	$s_0 \implies$ DNM

TABLE 8. Linguistic Preference Relation R^3

	x_1 Share with full permission	x_2 share with restrictions	x_3 share with no permission	x_4 do not share
x_1	$s_0 \implies$ DNM	$s_3 \implies$ FA	$s_3 \implies$ FA	$s_4 \implies$ EA
x_2	$s_{-3} \implies$ VW	$s_0 \implies$ DNM	$s_{-3} \implies$ VW	$s_{-1} \implies$ SW
x_3	$s_{-3} \implies$ W	$s_3 \implies$ FA	$s_0 \implies$ DNM	$s_2 \implies$ A
x_4	$s_{-4} \implies$ EW	$s_1 \implies$ SA	$s_{-2} \implies$ W	$s_0 \implies$ DNM

TABLE 9. Linguistic Preference Relation R^4

	x_1 Share with full permission	x_2 share with restrictions	x_3 share with no permission	x_4 do not share
x_1	$s_0 \implies$ DNM	$s_2 \implies$ A	$s_{-3} \implies$ VW	$s_4 \implies$ EA
x_2	$s_{-2} \implies$ W	$s_0 \implies$ DNM	$s_2 \implies$ A	$s_{-2} \implies$ W
x_3	$s_3 \implies$ FA	$s_{-2} \implies$ W	$s_0 \implies$ DNM	$s_3 \implies$ FA
x_4	$s_{-4} \implies$ EW	$s_2 \implies$ A	$s_{-3} \implies$ VW	$s_0 \implies$ DNM

The trust values between the data owner and decision makers are used to weight the decision makers' opinions, see Table 11. Utilising the *EIOWA* operator $\hat{r}_{ij}=EIOWAw\ ({r_{ij}}^{(1)},{r_{ij}}^{(2)},...,{r_{ij}}^{(m)})$, here we use the

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TABLE 10. Linguistic Preference Relation R^5

	x_1 Share with full permission	x_2 share with restrictions	x_3 share with no permission	x_4 do not share
x_1	$s_0 \implies$ DNM	$s_1 \implies$ SA	$s_{-2} \implies$ W	$s_{-4} \implies$ EW
x_2	$s_{-2} \implies$ W	$s_0 \implies$ DNM	$s_1 \implies$ SA	$s_{-2} \implies$ W
x_3	$s_2 \implies$ A	$s_{-1} \implies$ SW	$s_0 \implies$ DNM	$s_{-4} \implies$ EW
x_4	$s_4 \implies$ EA	$s_2 \implies$ A	$s_4 \implies$ EA	$s_0 \implies$ DNM

TABLE 11. Owner's trust in decision makers (λ_{o-DMl})

DM_l	The trust value τ_{o-DM_l}
DM_1	0.01
DM_2	0.01
DM_3	0.03
DM_4	0.03
DM_5	0.02

τ (i.e. trust values). τ represents the trust values that exist between decision makers and data owner, $\tau = T_o - {}_{co}$. We take the parameter values *a*=0.5, *b*=0.5 and the values of the weights become *w=0.5,0.5*.
τ_1=0.01 and τ_2=0.01, τ_3=0.03,τ_4=0.03,τ_5=0.02 .

TABLE 12. Calculation for the aggregation matrix

Details of Calculation for Each Value on The Aggregation Matrix
$\hat{r}_{11}$=τ_1x$R^1{}_{11} \otimes \tau_2xR^2{}_{11} \otimes \tau_3xR^3{}_{11} \otimes \tau_4xR^4{}_{11} \otimes \tau_5xR^5{}_{11}$
$\hat{r}_{12}$=τ_1 $R^1{}_{12} \otimes \tau_2$ x$R^2{}_{12} \otimes \tau_3xR^3{}_{12} \otimes \tau_4xR^4{}_{12} \otimes \tau_5xR^5{}_{12}$
$\hat{r}_{13}$=τ_1x$R^1{}_{13} \otimes \tau_2xR^2{}_{13} \otimes \tau_3xR^3{}_{13} \otimes \tau_4xR^4{}_{13} \otimes \tau_5xR^5{}_{13}$
$\hat{r}_{14}$=τ_1x$R^1{}_{14} \otimes \tau_2xR^2{}_{14} \otimes \tau_3xR^3{}_{14} \otimes \tau_4xR^4{}_{14} \otimes \tau_5xR^5{}_{13}$
$\hat{r}_{21}$=τ_1x$R^1{}_{21} \otimes \tau_2xR^2{}_{21} \otimes \tau_3xR^3{}_{21} \otimes \tau_4xR^4{}_{21} \otimes \tau_5xR^5{}_{21}$
$\hat{r}_{22}$=τ_1x$R^1{}_{22} \otimes \tau_2xR^2{}_{22} \otimes \tau_3xR^3{}_{22} \otimes \tau_4xR^4{}_{22} \otimes \tau_5xR^5{}_{22}$
$\hat{r}_{23}$=τ_1x$R^1{}_{23} \otimes \tau_2xR^2{}_{23} \otimes \tau_3xR^3{}_{23} \otimes \tau_4xR^4{}_{23} \otimes \tau_5xR^5{}_{23}$
$\hat{r}_{24}$=τ_1x$R^1{}_{24} \otimes \tau_2xR^2{}_{24} \otimes \tau_3xR^3{}_{24} \otimes \tau_4xR^4{}_{24} \otimes \tau_5xR^5{}_{24}$
$\hat{r}_{31}$=τ_1x$R^1{}_{31} \otimes \tau_2xR^2{}_{31} \otimes \tau_3xR^3{}_{31} \otimes \tau_4xR^4{}_{31} \otimes \tau_5xR^5{}_{31}$
$\hat{r}_{32}$=τ_1x$R^1{}_{32} \otimes \tau_2xR^2{}_{32} \otimes \tau_3xR^3{}_{32} \otimes \tau_4xR^4{}_{32} \otimes \tau_5xR^5{}_{32}$
$\hat{r}_{33}$=τ_1x$R^1{}_{33} \otimes \tau_2xR^2{}_{33} \otimes \tau_3xR^3{}_{33} \otimes \tau_4xR^4{}_{33} \otimes \tau_5xR^5{}_{33}$
$\hat{r}_{34}$=τ_1x$R^1{}_{34} \otimes \tau_2xR^2{}_{34} \otimes \tau_3xR^3{}_{34} \otimes \tau_4xR^4{}_{34} \otimes \tau_5xR^5{}_{34}$
$\hat{r}_{41}$=τ_1x$R^1{}_{41} \otimes \tau_2xR^2{}_{41} \otimes \tau_3xR^4{}_{41} \otimes \tau_4xR^4{}_{41} \otimes \tau_5xR^5{}_{41}$
$\hat{r}_{42}$=τ_1x$R^1{}_{42} \otimes \tau_2xR^2{}_{42} \otimes \tau_3xR^4{}_{42} \otimes \tau_4xR^4{}_{42} \otimes \tau_5xR^5{}_{42}$
$\hat{r}_{43}$=τ_1x$R^1{}_{43} \otimes \tau_2xR^2{}_{43} \otimes \tau_3xR^4{}_{43} \otimes \tau_4xR^4{}_{43} \otimes \tau_5xR^5{}_{43}$
$\hat{r}_{44}$=τ_1x$R^1{}_{44} \otimes \tau_2xR^2{}_{44} \otimes \tau_3xR^4{}_{44} \otimes \tau_4xR^4{}_{44} \otimes \tau_5xR^5{}_{44}$

We use the EIOWA operator to get the best alternative for *Fuzzy Alternative System* in the proposed framework (*see* 2).

After aggregating the preference relation, we need to compute the degree of the global preference see Table 15.

Once the preference degrees are averaged, all the alternatives are ranked in accordance to the values of r_i *(i=1,2,3,4).*

When the ranking process is finished, the Fuzzy Alternative System's decision is transferred to the DEI-DEO functions, to check whether Fuzzy System's and Fuzzy Alternative System's decisions' are convenient.

C. BEST ALTERNATIVE SELECTION: DEI-DEO

After taking the fuzzy decision system output and fuzzy alternative system output, the developed framework checks the consistency between two outputs based on the conditions in Table 1 and with Equation 12. Either of the following cases is expected to happen.

- **Case Conflict:** This case happens when the Fuzzy System's Decision (D_1) is in conflict with the Fuzzy Alternative System (D_2). In such cases, DEI-DEO control point's output is o_5, which shows the conflict and gives a recommendation to the decision makers in order to resolve inconsistency.
  For instance, if the D_1 is *NO*, which simply shows that the decision makers are worried about their data security features (*CIAPP*), and the D_2 is x_1, then the conflict happens.

  In order to resolve the conflicts, we define the model that is given in Equation 12. The model is a representation of decision fusion technique. Equation 12 is a function that has two input variables, which are D_1 and D_2, and one output variable D_o.
- **Case Convenient:** This case happens when the Fuzzy System's Decision (D_1) and the Fuzzy Alternative System (D_2) are consistent. In such cases, DEI-DEO control point's output is either o_1, o_2, o_3, or o_4.

The proposed framework has time restrictions. Decision makers are supposed to make a consensus reached decision in time *t*. If the time is over and the group has not reached an appropriate decision, then the system notifies the owner with the last decision that is made in *t*. If the last output value of DEI-DEO is o_5 in time *t*, then it is a special case. If the owner is notified with the o_5, then they can make the decision because of unattainable consensus decision in the group.

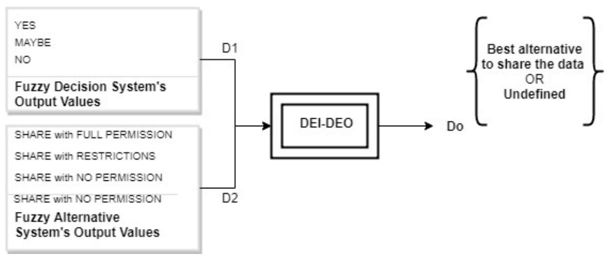

FIGURE 5. Selection of the best alternative

VI. IMPLEMENTATION OF THE PROPOSED WORK: *TRUSTY*

In this section, we give the implementation of the developed models with an online social network. We developed *Trusty* (visit http://www.trusty.gen.tr/) online social network in order to show the usability of the proposed work in real life applications. *Trusty* enables users to get accounts, interact with other users, express opinion for making group decisions on a co-owned data sharing process, and make consensus-based group decision. It is worth noting that *Trusty* is restricted to text/ comments and photo sharing. *searching* and *tagging* methods are used to identify users.

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TABLE 13. Each value of calculation for the aggregation matrix

Details of the Calculation	Result Value
$\hat{r}_{11}$=0.01x$s_0 \otimes$ 0.01x$s_0 \otimes$ 0.03x$s_0 \otimes$ 0.03x$s_0 \otimes$ 0.02xs_0	$\hat{r}_{11}$ =0
$\hat{r}_{12}$=0.01x$s_{-3} \otimes$ 0.01x$s_1 \otimes$ 0.03x$s_3 \otimes$ 0.03x$s_2 \otimes$ 0.02xs_1	$\hat{r}_{12}$ =0.15
$\hat{r}_{13}$=0.01x$s_{-4} \otimes$ 0.01x$s_{-2} \otimes$ 0.03x$s_3 \otimes$ 0.03x$s_{-3} \otimes$ 0.02xs_{-2}	$\hat{r}_{13}$ =-0.1
$\hat{r}_{14}$=0.01x$s_{-4} \otimes$ 0.01x$s_{-4} \otimes$ 0.03x$s_4 \otimes$ 0.03x$s_4 \otimes$ 0.02xs_{-4}	$\hat{r}_{14}$ =0.08
$\hat{r}_{21}$=0.01x$s_3 \otimes$ 0.01x$s_{-1} \otimes$ 0.03x$s_{-3} \otimes$ 0.03x$s_{-2} \otimes$ 0.02xs_{-2}	$\hat{r}_{21}$ =-0.17
$\hat{r}_{22}$=0.01x$s_0 \otimes$ 0.01x$s_0 \otimes$ 0.03x$s_0 \otimes$ 0.03x$s_0 \otimes$ 0.02xs_0	$\hat{r}_{22}$ =0
$\hat{r}_{23}$=0.01x$s_2 \otimes$ 0.01x$s_1 \otimes$ 0.03x$s_{-3} \otimes$ 0.03x$s_2 \otimes$ 0.02xs_2	$\hat{r}_{23}$ =0.04
$\hat{r}_{24}$=0.01x$s_{-2} \otimes$ 0.01x$s_{-2} \otimes$ 0.03x$s_{-1} \otimes$ 0.03x$s_{-2} \otimes$ 0.02xs_{-2}	$\hat{r}_{24}$ =-0.17
$\hat{r}_{31}$=0.01x$s_4 \otimes$ 0.01x$s_2 \otimes$ 0.03x$s_{-3} \otimes$ 0.03x$s_3 \otimes$ 0.02xs_2	$\hat{r}_{31}$ =0.1
$\hat{r}_{32}$=0.01x$s_{-2} \otimes$ 0.01x$s_{-1} \otimes$ 0.03x$s_3 \otimes$ 0.03x$s_{-2} \otimes$ 0.02xs_{-1}	$\hat{r}_{32}$ =-0.02
$\hat{r}_{33}$=0.01x$s_0 \otimes$ 0.01x$s_0 \otimes$ 0.03x$s_0 \otimes$ 0.03x$s_0 \otimes$ 0.02xs_0	$\hat{r}_{33}$ =0
$\hat{r}_{34}$=0.01x$s_3 \otimes$ 0.01x$s_4 \otimes$ 0.03x$s_2 \otimes$ 0.03x$s_3 \otimes$ 0.02xs_{-4}	$\hat{r}_{34}$ =0.14
$\hat{r}_{41}$=0.01x$s_4 \otimes$ 0.01x$s_4 \otimes$ 0.03x$s_{-4} \otimes$ 0.03x$s_{-4} \otimes$ 0.02xs_4	$\hat{r}_{41}$ =-0.08
$\hat{r}_{42}$=0.01x$s_2 \otimes$ 0.01x$s_2 \otimes$ 0.03x$s_1 \otimes$ 0.03x$s_2 \otimes$ 0.02xs_2	$\hat{r}_{42}$ =0.17
$\hat{r}_{43}$=0.01x$s_{-3} \otimes$ 0.01x$s_{-4} \otimes$ 0.03x$s_{-}2 \otimes$ 0.03x$s_{-3} \otimes$ 0.02xs_4	$\hat{r}_{43}$ =-0.14
$\hat{r}_{44}$=0.01x$s_0 \otimes$ 0.01x$s_0 \otimes$ 0.03x$s_0 \otimes$ 0.03x$s_0 \otimes$ 0.02xs_0	$\hat{r}_{44}$ =0

TABLE 14. Aggregated preference relation *R*

	x_1	x_2	x_3	x_4
x_1	s_0	$s_{-0.14}$	$s_{-0.11}$	$s_{-0.08}$
x_2	$s_{0.14}$	s_0	$s_{0.08}$	$s_{-0.05}$
x_3	$s_{0.11}$	$s_{-0.08}$	s_0	$s_{0.01}$
x_4	$s_{0.08}$	$s_{0.05}$	$s_{-0.1}$	s_0

TABLE 15. The averaged preference degree

$\frac{\sum_{n=1}^{4} x_{1n}}{4}$	-0.082
$\frac{\sum_{n=1}^{4} x_{2n}}{4}$	0.042
$\frac{\sum_{n=1}^{4} x_{3n}}{4}$	0.01
$\frac{\sum_{n=1}^{4} x_{4n}}{4}$	0.007

TABLE 16. Ranked alternatives

$z_2 > z_3 > z_4 > z_1$
$x_2 > x_3 > x_4 > x_1$

Table 17 presents various information about the *Trusty* including its web address, its source code location, the number of users on it, and the number of friends on it.

TABLE 17. *Trusty*'s Information

The Trusty Address	http://www.trusty.gen.tr/
PHP Source Code	https://github.com/gulsumakkuzu
The number of nodes	4200
The number of edges	1000

Figure 6 shows a screenshot from Trusty database which includes details of shared co-owned data contents. The most useful and related information from the figure are as follows; number of co-owners, the group's decision, the number of the rounds which were taken to make a consensus-reached group decision, the sensitivity value, and the confidence in the targeted group.

A. EVALUATION

We evaluate *Trusty* for group decision making by comparing it with existing OSNs' platforms, such as Facebook, with respect to a co-owned data sharing process. Consider the example demonstrated in Section V, where a user wants to share co-owned *photo A*, that involves 5 more users information on it. In Facebook, user uploads the photo, tags other users, and share the photo without asking those five users' opinions. After the photo is shared, tagged users remove their ids from the photo if they do not want their ids being seen on the shared photo. If they feel the shared photo is sensitive and leaks their privacy, they may not only remove their tags but also be unfriend with the user, worse they quit from Facebook. However, in the proposed work, users are tagged and notifies before the photo is shared and they are given right to make a consensus-reached group decision in the sharing process, where it is aimed to satisfy all co-owners. Photo can not be shared until the group makes a decision, if co-owners are satisfied/ not satisfied with the owner's final decision, then the proposed work increases/decreases their trust in the owner based on the choices they make.

Table 18 gives the main differences between Facebook and Trusty with the main steps in a co-owned data sharing process. As it is mentioned above, Facebook allows users/co-owners removing their tags after data is shared. Users/co-owners do not know on which data their ids will be seen until the data is shared. However, in our approach users/co-owners are notified before the data is shared. They are given right to express their opinions, and make a group decision with other users/co-owners whose ids are included on the data. Other difference is that users/co-owners might choose being unfriend or quit from Facebook if the owner leaks their privacy while in Trusty trust values are used for keeping users online and keep the friendship.

In order to measure the practicality and usability of *Trusty*,

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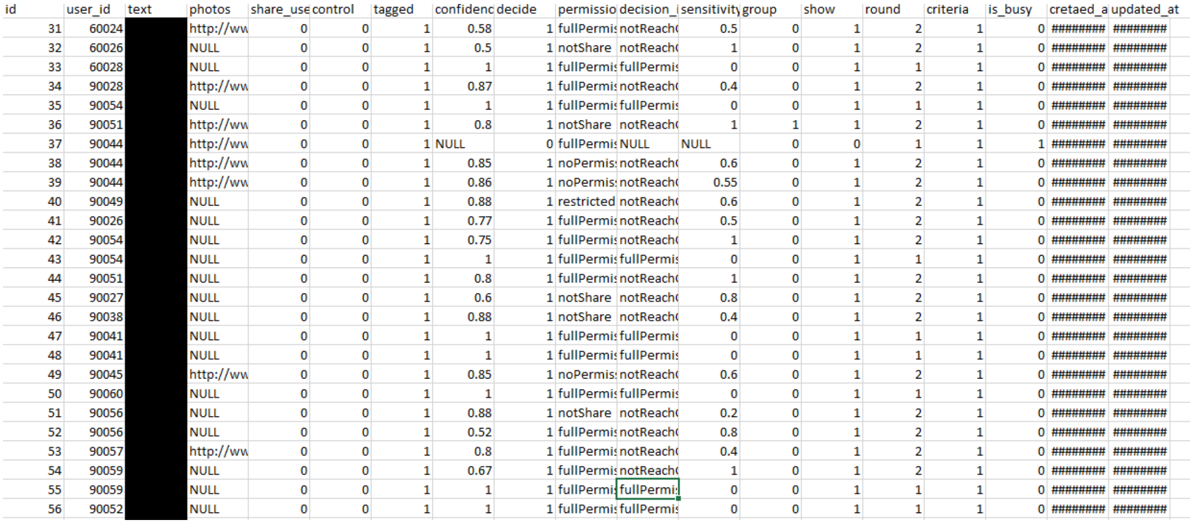

id	user_id	text	photos	share_use	control	tagged	confidenc	decide	permissio	decision_i	sensitivity	group	show	round	criteria	is_busy	cretaed_a	updated_at
31	60024	[redacted]	http://ww	0	0	1	0.58	1	fullPermis	notReach(	0.5	0	1	2	1	0	#########	#########
32	60026	[redacted]	NULL	0	0	1	0.5	1	notShare	notReach(	1	0	1	2	1	0	#########	#########
33	60028	[redacted]	NULL	0	0	1	1	1	fullPermis	fullPermis	0	0	1	1	1	0	#########	#########
34	90028	[redacted]	http://ww	0	0	1	0.87	1	fullPermis	notReach(	0.4	0	1	2	1	0	#########	#########
35	90054	[redacted]	NULL	0	0	1	1	1	fullPermis	fullPermis	0	0	1	1	1	0	#########	#########
36	90051	[redacted]	http://ww	0	0	1	0.8	1	notShare	notReach(	1	1	1	2	1	0	#########	#########
37	90044	[redacted]	http://ww	0	0	1	NULL	0	fullPermis	NULL	NULL	0	0	1	1	1	#########	#########
38	90044	[redacted]	http://ww	0	0	1	0.85	1	noPermis	notReach(	0.6	0	1	2	1	0	#########	#########
39	90044	[redacted]	http://ww	0	0	1	0.86	1	noPermis	notReach(	0.55	0	1	2	1	0	#########	#########
40	90049	[redacted]	NULL	0	0	1	0.88	1	restricted	notReach(	0.6	0	1	2	1	0	#########	#########
41	90026	[redacted]	NULL	0	0	1	0.77	1	fullPermis	notReach(	0.5	0	1	2	1	0	#########	#########
42	90054	[redacted]	NULL	0	0	1	0.75	1	fullPermis	notReach(	1	0	1	2	1	0	#########	#########
43	90054	[redacted]	NULL	0	0	1	1	1	fullPermis	fullPermis	0	0	1	1	1	0	#########	#########
44	90051	[redacted]	NULL	0	0	1	0.8	1	fullPermis	notReach(	1	0	1	2	1	0	#########	#########
45	90027	[redacted]	NULL	0	0	1	0.6	1	notShare	notReach(	0.8	0	1	2	1	0	#########	#########
46	90038	[redacted]	NULL	0	0	1	0.88	1	notShare	notReach(	0.4	0	1	2	1	0	#########	#########
47	90041	[redacted]	NULL	0	0	1	1	1	fullPermis	fullPermis	0	0	1	1	1	0	#########	#########
48	90041	[redacted]	NULL	0	0	1	1	1	fullPermis	fullPermis	0	0	1	1	1	0	#########	#########
49	90045	[redacted]	http://ww	0	0	1	0.85	1	noPermis	notReach(	0.6	0	1	2	1	0	#########	#########
50	90060	[redacted]	NULL	0	0	1	1	1	fullPermis	fullPermis	0	0	1	1	1	0	#########	#########
51	90056	[redacted]	NULL	0	0	1	0.88	1	notShare	notReach(	0.2	0	1	2	1	0	#########	#########
52	90056	[redacted]	NULL	0	0	1	0.52	1	fullPermis	notReach(	0.8	0	1	2	1	0	#########	#########
53	90057	[redacted]	http://ww	0	0	1	0.8	1	fullPermis	notReach(	0.4	0	1	2	1	0	#########	#########
54	90059	[redacted]	NULL	0	0	1	0.67	1	fullPermis	notReach(	1	0	1	2	1	0	#########	#########
55	90059	[redacted]	NULL	0	0	1	1	1	fullPermis	fullPermis	0	0	1	1	1	0	#########	#########
56	90052	[redacted]	NULL	0	0	1	1	1	fullPermis	fullPermis	0	0	1	1	1	0	#########	#########

FIGURE 6. Co-owned data sharing details in Trusty database

TABLE 18. Comparison of main co-owned data sharing steps in Trusty and Facebook

Facebook [40]		**Trusty**	
Owner	**Co-owners**	**Owner**	**Co-owners**
Uploads/creates data		Uploads/creates data	
Tag co-owners		Tag co-owners	
Shares data	Notified	Notifies	Notified
	Remove tag	Waits	Make a group decision
	Be unfriend	Share/ Not Share	
	Quit from Facebook		Lose/gain trust in owner

we conducted two questionnaires. One for users who take the role owner and the other for users who take role co-owners, in a co-owned data sharing process. These questionnaires are placed at the end of each co-owned data sharing process on *Trusty* social network, so that only users who experienced co-owned data sharing process are participated in the questionnaires.

Figure 7, Figure 8, and Figure 9 provide the outcomes obtained from the analysis of the first question on the questionnaire which was completed by owners. From the outcomes in the figure, it is apparent that *knowing co-owners' group decision* was found very useful by the majority of owners in their co-owned data sharing process. Owners were asked to rate *how useful did they find knowing data sensitivity value in data sharing process*, Figure 8 indicates the results of respondents on the question. There was a significant number of owners who found it useful to know the data sensitivity value. However, it is important to mention that there were people who did not know the data sensitivity value in the sharing process. The implementation of the developed models has been done with *Trusty* online social network. Therefore, it is important to have a question which can be used to evaluate the network. Respondents were asked to evaluate *Trusty* with question *"How useful did you find the Trusty?"*. Of the 316 respondents, who completed the questionnaire, just 30 percent of them rated the *Trusty* with *Good* option.

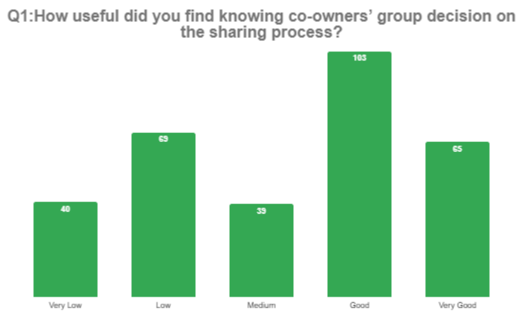

FIGURE 7. Usefulness of knowing group's decision in the sharing process

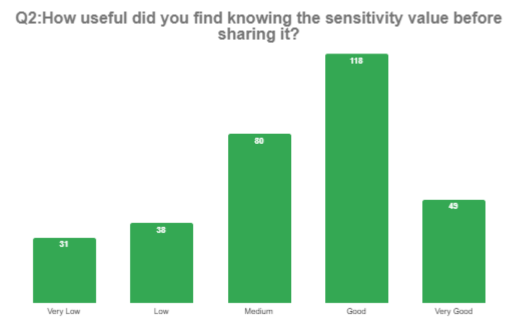

FIGURE 8. Usefulness of knowing the co-owned data sensitivity value

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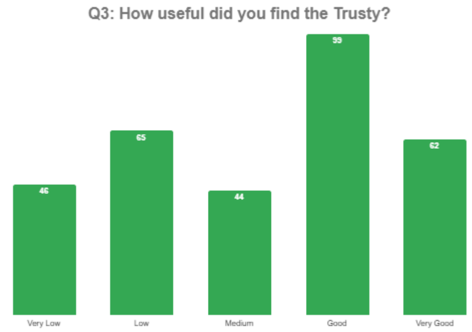

FIGURE 9. Usefulness of *Trusty*

As it is aforementioned, two questionnaires were conducted. One was filled by the data owners and the other one was filled by data co-owners. Figure 10, Figure 11, and Figure 12 represent the results obtained from data co-owners' on the questionnaire.

Figure 10, Figure 11, and Figure 12 represent the results on the question "How useful did you find giving your opinion on the sharing process". This question was developed to understand the applicability of group decision making in online social networks. Of the data, co-owners giving their opinions in the sharing process, 50% rated either good or very good. Co-owners are given chance to give their concerns on co-owned data security features in order to decide the data sensitivity value of their co-owned data. Figure 11 represents the results on the question ted to data security features, the figure shows that the majority of co-owners chose the option *Good*. The next question was related to having reputation values in online social network platforms. This question and the next question were same on data owners' questionnaire. The last question on the questionnaire was about rating *Trusty* network. From the chart, it can be seen that by far the greatest choice is for *Good* option. The result shows that the *Trusty* social network is quite useful.

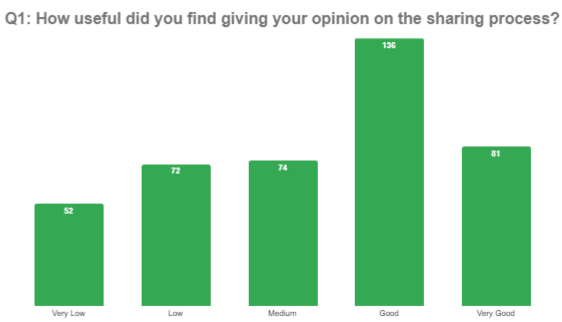

FIGURE 10. Analysis on the question 1 on co-owners' questionnaire

VII. CONCLUSION

In this work, we present a novel approach on the privacy protection caused by co-owned data sharing in OSNs. In order to make a balance between co-owned data sharing and preserving co-owners privacy, we propose a consensus-reached group decision making structure. In the proposed work, when a user wants to post a co-owned data, the user first asks co-owner's group decision in the sharing process, and then makes the final decision by either respecting the group's decision or dis-respecting co-owners' group decision. We use users trust values for weighting co-owners' opinions in the sharing process where users trust values are dynamic values. If co-owners are worried about the co-owned data security features and do not want the data to be shared but the owner shares the data, then the proposed work decreases the co-owner's trust in the owner otherwise it is increased. We also create an online social network platform in order to show the applicability of the proposed work. With the created social network, we ask users' opinions about the proposed work by conducting questionnaires. The result shows that the consensus-reached group decision is found very useful by the respondents.

In the future work, we aim to use users' reputation values in order to punish or award the owner, based on his final decision.

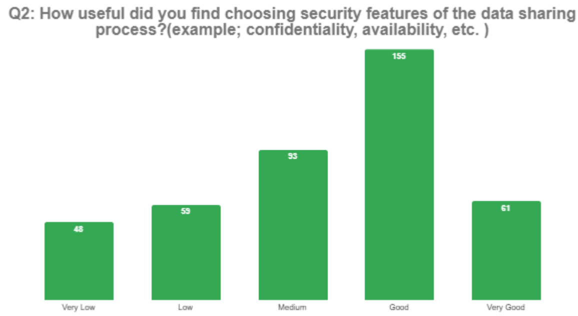

FIGURE 11. Analysis on the question 2 on co-owners' questionnaire

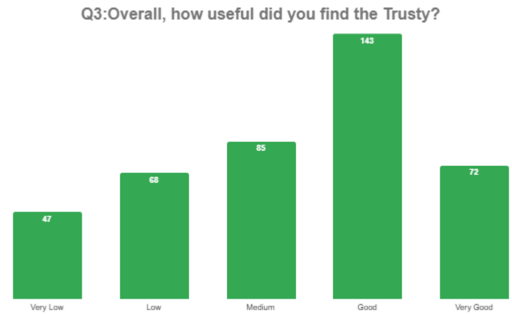

FIGURE 12. Analysis on the question 3 on co-owners' questionnaire

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