Team Situation Awareness Measurement Using Group Aggregation and Implication Operators

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Abstract

Situation Awareness (SA) has been received much attention from human factors and ergonomics community during the past two decades. Team working plays a vital role in complex dynamic situations, increasing requirements for sharing perceptions and comprehension of a situation among team members and improving team situation awareness have been merged. This paper presents a team SA measurement (TSAM) method taking both qualitative and quantitative information into consideration. The TSAM method uses a hierarchy to depict team's shared mental model, applies linguistic terms to represent individual SA and adopts a group aggregation strategy to integrate individual SA through indicator-specified implication operators. Example has shown its effective.

1. Introduction

Situation Awareness (SA) is "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future[5]". It is widely used in aircraft operator training. During the past two decades, it has been extended to complex dynamic systems where human factors are involved such as nuclear power plants [3], air traffic control [24, 12], and emergency response [2, 21]. Since team working plays an important role in organizational decision making in a dynamic situation, team situation awareness has drawn remarkable attentions of industrial and military communities recently.

Improving team SA becomes a crucial issue in complex dynamic systems, which is required to meet three main demands in those fields[6, 7, 20, 22, 13]. First, the increasing complexity of dynamic systems provides a great challenge

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to decision makers or operators to recognize external environment timely and conduct ongoing analysis. Second, correct awareness about external environment is a basis for appropriate decision making. Particularly, team members often work simultaneously at different geographical locations. Research shows that team working can efficient reduce decision errors by individuals. Moreover, requirement for real world applications, such as developing friendly user interface for complex control systems and training operators in a complex dynamic environment, needs to be fulfilled. To improve team SA, an accurate measurement of team SA is important.

Since team SA is development with SA which focuses mainly on human factors analysis, traditional study of team SA is conducted through qualitative analysis methods. Qualitative techniques cannot be satisfactory to the aim of quantitative measurements for team SA. Thus quantitative techniques based on statistical models[19, 14, 23] and inference models[22] have been merged. However, these quantitative techniques have a common drawback, i.e., they completely replace qualitative information by numeric values. Accurate numeric values are easy to implement designed models at the cost of lacking meaningful qualitative information.

It is noticed that SA is information processing with a great amount of uncertainty. In the processing course, one applies background knowledge (forms the mental model of a situation) and uncertainty reasoning to handle perceptions with uncertainty (refers as situation models in [4]). An alternative technique for team SA measurement should combine qualitative and quantitative models. Research on linguistic decision making indicates that linguistic term is an efficient form to describe uncertain qualitative information[9, 8, 25, 27, 16, 18, 17, 11, 10]. Hence, in the light of research on linguistic information decisions, this paper presents a team SA measurement (TSAM) method by combining qualitative information process and quantitative computation. In the TSAM method, linguistic terms are used to describe individual and team SA. Moreover, the

TSAM method applies group aggregation and implication operators to implement uncertain reasoning. The rest of the paper is organized as follows. In Section 2, an overview of the TSAM method is provided. Concrete steps of it are illustrated in Section 3. A case study on nuclear safeguards information management is discussed in Section 4 to illustrate the TSAM method. Finally, conclusions and future work are discussed in Section 5.

2. Overview

Developing team SA is an evolutionary process. First, team members generate individual SA based on personal mental models (i.e. relevant knowledge and experience) and individual situation models (i.e., perceptions of the external environment). Team members then share their individual SAs in the team through communication and cooperation. Next, the team forms a common awareness, which is treated as the team SA in this paper, about the situation. Finally, team's SA then is applied to reactions to the external environment to verify and modify. This is a repetitive course in a complex dynamic environment.

In order to measure team SA, two main factors are concerned in the TSAM method, i.e., the shared mental model of the team and the measurement of team members' awareness.

The shared mental model of a team is treated as the common accepted knowledge and experience about a given situation. In the TSAM method, the shared mental model is assumed to be a hierarchy with a set of identified indicators. Each node of the hierarchy is an identified indicator. An indicator at a lower level is called support an indicator at a higher level if there is a connection between them. An indicator is called an ***independent indicator*** if it is not supported by any indicator. Accordingly, an indicator is called a ***dependent indicator*** if it is supported by at least one indicator. Therefore, indicators in the mental model are divided into two groups.

A team member's individual SA is described as a covering on the identified indicators in the TSAM method. The covered indicator may be an independent one or a dependent one.

The shared mental model and individual SA are established based on the following consideration. Seen from viewpoint of uncertain information processing, the shared mental model plays the role of rule bases. The triggers of those rules are team member's perceptions of the external environment. That means team members' perception acts as the antecedent of uncertain reasoning. In general, one perception may trigger several rules. The TSAM method uses the triggered indicators of a perception to represent a perception. Moreover, team SA can be seen as the consequence of a series of uncertain reasoning. The TSAM

method uses a hierarchy to describe the cause-and-effect between indicators. Therefore, a perception spreading from its covered indicators and stopping at the indicator to team SA implements the uncertainty reasoning. The team SA is thus formed.

Based on the division of indicators, the TSAM method includes two stages. At stage one, team SA on independent indicators is measured. At the second stage, team SA on dependent indicators are measured. A brief illustration of the TSAM is shown below.

Stage 1: team SA measurement for independent indicators.
  input: team members' perceptions
  output: team SA on each independent indicator

Stage 2: team SA measurement for dependent indicators.
  input: team SA on depended indicators
    Step 1: generating team SA by uncertain reasoning
      from each depended indicator
    Step 2: generating team SA by group aggregation
    (repeating Step 1 and Step 2 if needed)
    Step 3: generating team SA
  output: team SA on situation

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3. Team SA Measurement

Suppose a team $T = \{g_1, g_2, \cdots, g_m\}$ is working in a given environment to complete an assigned task. For each member $g_i \in T$, let $w_i(\in LW)$ be a linguistic weight attached to g_i based on his/her professional background, experience, etc. Suppose a set IND of indicators for the team's mental model are identified and organized in a hierarchy. Let $\text{ind}_{ij} \in$ IND be the j-th indicator at level i to which a linguistic strength, denoted by s_{ij}, is assigned to it and $s_{ij} \in S$. Assume IND^i is the indicators covered by a perception of member g_i, $i = 1, 2, \ldots, m$.

3.1. Team SA measurement for independent indicators

The team SA measurement for independent indicators is implemented through aggregating individual SAs. In the following, let SA_i be the individual SA of team member g_i.

For an independent indicator ind, let G be the set of team members whose tasks cover indicator ind. Then team SA on indicator ind is obtained by

$$\text{tSA} = \text{Agg}_{g \in G}(w_g, SA_g), \tag{1}$$

where Agg is a selected aggregation operator[1, 26, 27]. Although G may not include all team members in T, the result tSA can still be taken as the team SA under the assumption that team members completely trust others in the team because this is a fundamental basis for team collaboration.

3.2. Team SA measurement for dependent indicators

The main work at the second stage is to obtain team SA on dependent indicators through integrating team SA on the indicators it depends on.

Suppose ind is a dependent indicator which depends on indicators ind_1, ind_2, ..., ind_n. Assume that tSA_i is the team SA on indicator ind_i. Then, team SA on indicator ind is obtained by the following steps.

Step 1: generate team SA on ind through each depended indicator ind_i.

Dependent relationship between ind and ind_i describes the internal cause-and-effect relationship which can be formally illustrated by

$$P(\text{ind}_i) \to P(\text{ind}), \quad (2)$$

that is to say, when some fact about indicator ind_i occurs, a certain fact about indicator ind occurs then. Furthermore, this relationship can also be formalized by

$$P(\text{ind}) = P(\text{ind}_i) \circ (P(\text{ind}_i) \to P(\text{ind})), \quad (3)$$

where $\circ$ depicts the logical connective "AND". To determine the operators "$\circ$" and "$\to$", we first select an implication operator as "$\to$", and then determine the "AND" for "$\circ$". For example, if the used implication operator is the Łukasiewicz implication operator $a \to b = \min\{1, 1 - a + b\}$ where $a, b \in [0, 1]$, then the operator $\circ$ is defined by

$$a \circ b = \min\{a, b\}, \quad a, b \in [0, 1]. \quad (4)$$

However, in real situation, we need not directly use the implication operator because $P(\text{ind}_i) \to P(\text{ind})$ and $P(\text{ind}_i)$ can be replaced by the strength s_i and the tSA_i, respectively. The thing only needs to do is determining the "AND" by the implication operator and the smallest truth-value in a non-classical logic for uncertainty reasoning where the implication operator is applied.

Therefore, team SA on indicator ind from indicator ind_i is generated by under an implication operator "$\to$"

$$\overline{\text{tSA}}_i = \text{tSA}_i \circ s_i. \quad (5)$$

Step 2: generate team SA on indicator ind by group aggregation for indicator groups.

Group aggregation is a strategy discussed by Liu et al. [15] for nuclear safeguards information management. The basic idea of it is dividing indicators into several groups according to their strengths and selecting strength specific aggregation operators for different groups. The TSAM method applies the group aggregation. Suppose indicators ind_1, ind_2, ..., ind_n are divided into p groups $IND^{(k)}$,

$k = 1, 2, \ldots, p$. For group $IND^{(k)}$, let $\text{Agg}^{(k)}$ be a selected aggregation operator, then the team SA on $IND^{(k)}$ is generated by

$$\text{tSA}^{(k)} = \text{Agg}^{(k)}(s^{(k)}; \{\overline{\text{tSA}}_j | \text{ind}_j \in IND^{(k)}\}), \quad (6)$$

where $s^{(k)}$ is the strength of indicators in that group. The $\text{tSA}^{(k)}$ is thus the team awareness on ind through $IND^{(k)}$.

Step 3: generate team SA on indicator ind by aggregating group team SA $\text{tSA}^{(k)}$.

Suppose the obtained team SA for p groups are $\text{tSA}^{(k)}$, $k = 1, 2, \ldots, p$ and Agg is a selected aggregation operator for indicator ind, then the team SA on ind is generated by

$$\text{tSA}_{ind} = \text{Agg}((\text{tSA}^{(1)}, s^{(1)}), \cdots, (\text{tSA}^{(p)}, s^{(p)})). \quad (7)$$

By above three steps, team SA on a dependent indicator ind is generated. Repeating the process in Stage 2, the team SA about the given situation is measured.

4. Case Study

4.1. Case illustration and settings

In this section, we apply the TSAM method to an example[15].

Suppose a team of four members, E_1, E_2, E_3, E_4, is assigned a task to inspect whether an organization is conducting a kind of nuclear activity. The team's mental model about the nuclear activity is shown in Figure 1. Team members report their observations about the organization's nuclear activity independently. Table 1 is the report of their observations where the observations are labels for terms taken from a linguistic term set $S = \{s_0 = $ impossible, $s_1 = $ almost impossible, $s_2 = $ slightly possible, $s_3 = $ quite possible, $s_4 = $ possible, $s_5 = $ high possible, $s_6 = $ absolutely possible$\}$. Let weight of each member be $E_1 = r_3$, $E_2 = r_5$, $E_3 = r_4$, and $E_4 = r_2$, where r_i in $W = \{r_0 = $ none, $r_1 = $ very low, $r_2 = $ low, $r_3 = $ medium, $r_4 = $ high, $r_5 = $ very high, $r_6 = $ perfect$\}$.

For convenience, we use the fuzzy numbers in Figure 2 and Figure 3 to describe these linguistic terms. Notice that "weak" is near s_1, "medium" is near s_2, "strong" is near s_6 by the distance defined in [28], we also use s_1, s_2 and s_6 to replace them respectively.

4.2. Case solution

Based on the above assumptions, we apply the TSAM method as follows.

First, the team SA measurement is obtained for independent indicators. Taking indicator "gaseous diffusion barriers (id 266)" for instance, members E_2, E_3, and E_4 has
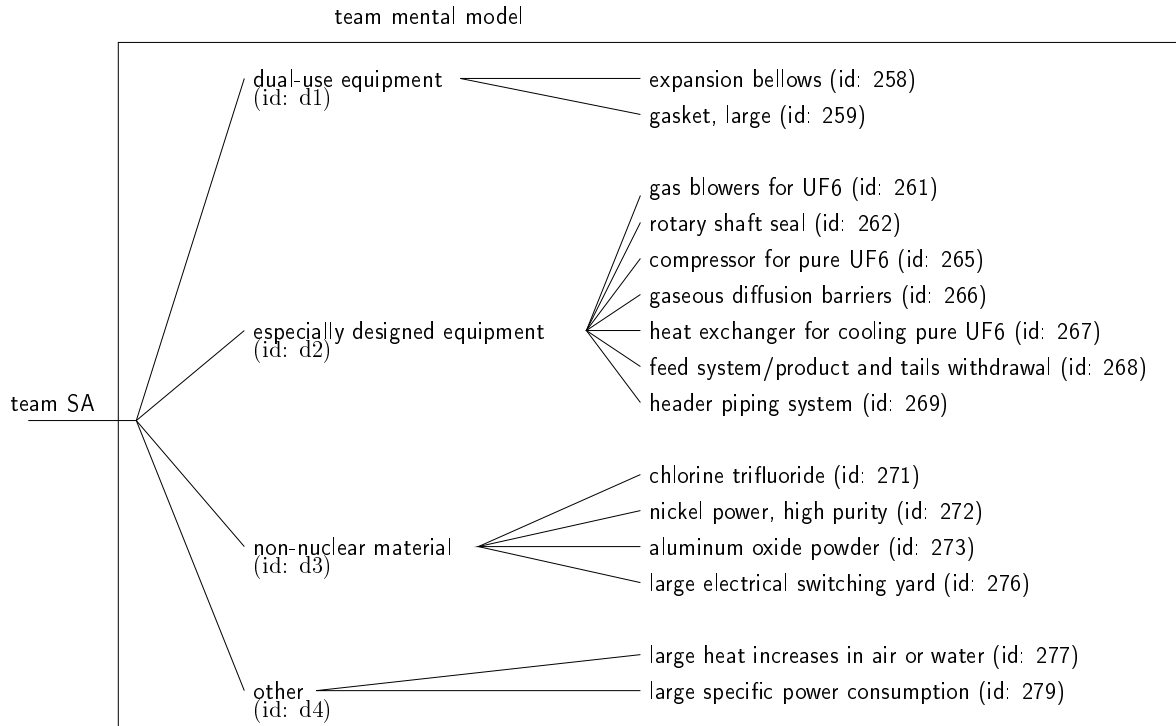
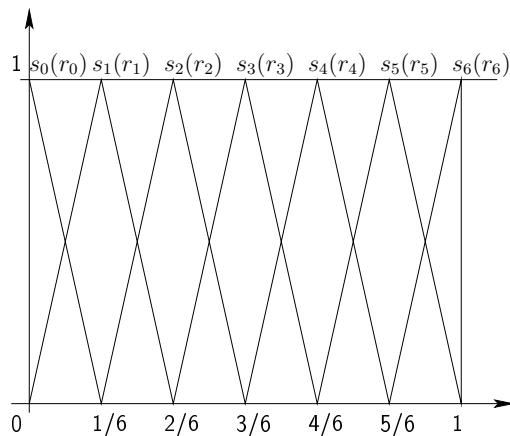**Figure 1. Team's mental model about a kind of nuclear activity.**

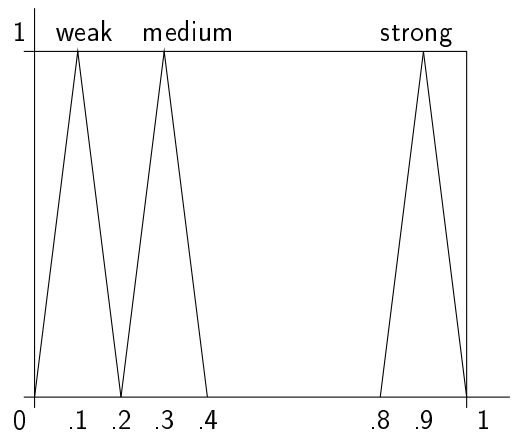**Figure 2. Fuzzy numbers used for linguistic terms.**

Figure 3. Fuzzy numbers used for indicator strengths.

reported observations for this indicator. Hence, these observations are aggregated. Here, we apply the fuzzy method in [28] to the aggregation, i.e.

$$tSA_{266} = s_5 \otimes r_5 \oplus s_4 \otimes r_4 \oplus s_6 \otimes r_2 \approx s_4. \quad (8)$$

Thus s_4 is taken as the awareness of the team on this indicator. Similarly for other independent indicators, the team's SA are calculated and list in Table 2.

Secondly, the team SA is obtained for dependent indicators. Taking indicator "especially designed equipment" (ind with id 2) for example, this indicator depends on seven indicators. Hence contribution to team SA on ind from each independent indicator is first calculated. For example, to obtain the contribution from indicator "gas blowers for UF6," the TSAM method selects the min operator Eq. (5). Then

Table 1. Reported observations.[15]

| \multicolumn{4}{c|}{Observations} | Indicator IDs | Strength |
E_1	E_2	E_3	E_4		
6	6	6	5	258	weak
2	-	5	-	259	weak
-	2	3	6	261	medium
4	3	-	-	262	medium
4	-	4	-	265	strong
-	5	4	6	266	strong
5	3	6	-	267	strong
1	-	2	4	268	weak
5	-	6	4	269	weak
3	2	-	4	271	medium
-	2	3	-	272	medium
-	2	2	3	273	weak
3	-	5	5	276	weak
6	3	-	-	277	weak
-	3	5	6	279	weak

Table 2. Team's SA for independent indicators.

Ind ID	258	259	261	262	265	266	267	268
tSA	5	3	3	4	3	4	4	2
Ind ID	269	271	272	273	276	277	279	
tSA	4	2	2	2	3	3	3	

$\overline{\mathrm{tSA}}_{261}$ is

$$\overline{\mathrm{tSA}}_{261} = \min\{s_3, w_{medium}\} \approx s_2. \tag{9}$$

Similarly, the contributions of other independent indicators are obtained as below.

Ind ID	261	262	265	266	267	268	269
$\overline{\mathrm{tSA}}$	2	2	3	4	4	1	1

Following above step, the TSAM method applies group aggregation to these seven indicators. As indicator 261 and 262 have same strength, they are aggregated by

$$\mathrm{tSA}_{261,262} = \min\{s_2, s_2\} = s_2. \tag{10}$$

Similarly, the TSAM method applies the $\max$ operator to indicator $265 - -267$ because their strength is strong and obtains

$$\mathrm{tSA}_{265-267} = \max\{s_3, s_4, s_4\} = s_4. \tag{11}$$

For indicators 268 and 269, the TSAM method uses the $\min$ operator and gets

$$\mathrm{tSA}_{268,269} = s_2. \tag{12}$$

Finishing the group aggregation, the TSAM method applies the technique in [28] to get team SA on "gas blowers for UF6" as

$$\mathrm{tSA}_{\mathrm{ind}} = s_2 \otimes s_2 \oplus s_4 \otimes s_6 \oplus s_1 \otimes s_1 \approx= s_3. \tag{13}$$

Hence the team SA is "slightly possible."

Similarly for other dependent indicators, the team SAs are obtained:

$$\mathrm{tSA}_1 = s_1 \qquad \mathrm{tSA}_3 = s_2 \qquad \mathrm{tSA}_4 = s_1.$$

Finally, based on the team SA on indicators d1, d2, d3, and d4, an overall team awareness on the situation can be obtained. Suppose strengths for indicators d1, d2, d3, and d4 are s_2, s_6, s_2, and s_1, then the overall team SA is near s_2. This indicates that the organization has slight possibility to conduct the very kind of nuclear activity.

5. Conclusions and Future Works

Efficiently measuring a team's awareness for a situation is a vital issue in complex dynamic management. This paper proposed a TSAM method to measure team SA which takes both qualitative information reasoning and quantitative information computation into consideration and uses indicator-specified implication operators and aggregation operators to generate team SA from individual SA. The TSAM method has been implemented in decision software. More presentation and discussion of this software will be in our following papers.

Because the core feature of developing team SA is the communication and collaboration among members, a detailed analysis of the specific nature of team communication and cooperation may contribute to establish an effective approach for developing team SA and supporting appropriate decision, which is exactly our future work.

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