Team Situation Awareness: A Review of Definitions and Conceptual Models

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Abstract. Situation awareness (SA) has been a hot topic in the area of human factors and ergonomics. The SA in collaborative socio-technical systems, which is called team situation awareness (TSA), also draws increasing attentions. TSA is considered as a critical influencing factor in task performance. Like SA and many other psychological constructs, TSA receives numerous controversies in its definitions, conceptual models, theoretical underpinnings, etc. Based on a careful review of literature, this paper provides a summary and comparison of different TSA definitions, conceptual models and theoretical underpinnings. Several relevant but confusing terms are distinguished. The major controversies on TSA, including the critiques and responses, are also reviewed. The review is expected to help readers to have a comprehensive and up-to-date understanding of TSA.

Keywords: Team · Situation awareness · Definition · Conceptual model · Controversy

1 Introduction

Situation awareness (SA) has been a hot topic in research areas since the late 1980s [1–3]. Most of the relevant studies are carried out from the perspective of individuals. In complex systems, however, a team of operators often performs tasks collaboratively to achieve an ultimate goal. The SA in collaborative environments, the so-called team situation awareness (TSA), is receiving more concerns [4]. TSA is considered as a critical factor in team decision-making [5–7]. Maintaining TSA helps the team members to know when to work individually and when to work together thus enables fluent shifts in the mixed-focus collaboration [8, 9]. TSA simplifies the verbal communications among team members and improves the collaboration efficiencies [9, 10]. In emergency situations, maintaining a high level of TSA aids the team members to react quickly to abnormalities and avoid unexpected consequences [1]. Due to the potential problems (such as information overload, attention narrowing and over-reliance) caused by system digitalization and automation, TSA becomes more pronounced in collaborative system design, assessment and training [11]. As is the case with SA, TSA receives both attentions and controversies [4]. There have been contentions in its theoretical underpinnings and valid measures [3, 12]. In this paper, we first make clear the concept of SA, because many TSA theories are the extensions of the SA ones.

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The TSA definitions, conceptual models, and their theoretical underpinnings, are then reviewed from literature. Several relevant but confusing terms, including shared situation awareness (shared SA), mutual awareness, task-work situation awareness (task-work SA), teamwork situation awareness (teamwork SA), distributed situation awareness (DSA), compatible situation awareness (compatible SA) and transactive situation awareness (transactive SA) are distinguished. The major controversies on TSA, including the critiques and responses, are also reviewed.

2 Situation Awareness (SA)

As one of the mostly studied and debated topics in human factors and ergonomics, so far SA has not received a universally accepted definition [2, 3]. In simple words, SA can be described as what is going on [5]. Among the attempts to define SA, Endsley's work is mostly cited. Based on the information processing theory and the pattern matching theory, Endsley proposes a three-level SA model [5, p. 35] and defines SA as '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' [13]. Consisting of three levels (i.e., perception, comprehension and projection), SA is regarded as a part of the information processing [3]. According to the model, the data in the environment is the basis for acquiring SA. Maintaining SA is the premise of decisions and actions. The environmental data perceived is matched to the mental models held in the individual's mind and the individual forms the understanding of the current situation [5]. The task goals, the mental models and the feedback of actions all direct individual's attention to certain features in the environment [12]. Roughly this model follows an input-process-output-feedback loop. Using the similar theoretical basis, Fracker [14, 15], Sarter and Woods [16], and Dominquez [17] raised their own definitions. Fracker highlights the importance of attention allocation and regards SA as 'the knowledge that results when attention is allocated to a zone of interest at a level of abstraction' [14]. The integration of environmental information with existing knowledge (i.e., mental model, which stores in long-term memory) happens in the working memory [15]. Sarter and Woods consider SA as the temporal product of continuous situation assessment and argue SA is 'the accessibility of a comprehensive and coherent situation representation which is continuously being updated in accordance with the results of situation assessment' [16]. Dominquez emphasizes on the cyclical and dynamic nature of SA and refers to it as 'the continuous extraction of environmental information, the integration of this information with previous knowledge to form a coherent mental picture, and the use of that picture in direction future perception and anticipating future events' [17].

Taylor [18] holds the view that SA has three components: the attentional demand, the attentional supply and the understanding of the situation. According to Taylor, the SA is 'the knowledge, cognition and anticipation of events, factors and variables affecting the safe, expedient and effective conduct of a mission' [18]. Based on this view, he raised a simple subjective SA rating technique called SART [18, 19].

Adams et al. [20] and Smith and Hancock [21] base SA on Niesser's perceptual cycle theory [22]. That is, the environment provides the available information to the individual and modifies his or her knowledge. The knowledge possessed by the individual directs him or her to take certain actions. Being acted on, the environment is sampled or altered. The changes in the environment then modify the knowledge in the individual. In this way, the environment, knowledge and action form a circulation [21]. Adams et al. believe that SA can be 'the state of the active schema' or 'the state of the perceptual cycle at any given moment' [20]. Smith and Hancock [21] distinguish SA from competence and performance to clarify what SA is. They argue that competence resides in the individual and is independent of the situation, while performance resides in the world and changes with the situation. SA is the mediation of the two and resides in the interaction between the individual and the world. Smith and Hancock view SA as 'the adaptive, externally directed consciousness'. The 'consciousness' in the definition indicates the environment-directed knowledge creation behavior [21].

Based on the perceptual cycle theory and schema theory, Stanton and his colleagues [23] suggest that the individual's inner held schema (i.e., genotype schema) drives the continuous circulation of perception and action. On the other hand, the tasks and external environments activate and update the schema. This view of perceptual cycle and schema makes no big difference from other researches. What really makes a difference is their view of distributed cognition. Stanton et al. advocate a system thinking of SA and propose that SA is distributed amongst the humans and nonhuman artifacts in the socio-technical system [3, 4, 24]. In their view, SA no longer exists solely in the individuals, but is an emergent property of the system [3]. The possession, usage and exchange of SA-related knowledge depend on the goals and sub-goals, the tasks to be performed and the specific roles of the agents (both human and nonhuman). Thus they define SA as 'the activated knowledge for a specific task, at a specific time within the system' [25].

3 Team Situation Awareness (TSA)

In many organizational environments, especially complicated ones, a team of individuals takes charge of the operational tasks [26]. Team is not a merely summation of individuals, but a 'distinguishable set of two or more people who interact dynamically, interdependently and adaptively toward a common valued goal/object/mission, who have each been assigned specific roles or functions to perform and who have a limited life span of membership' [27, 28]. Within a team, the workloads are distributed and the required knowledge is complemented. Facing unexpected events or emergencies, teams are more robust than individuals [29]. Effective teams engage in both task-work and teamwork [30]. Task-work refers to the performance of tasks undertaken by individual team members with their specific roles [28]. Teamwork refers to the episodic, dynamic and interactive process that shares the attitudes, thoughts and behaviors [30]. Task-work is necessary for the execution of individual goals and teamwork is critical for the coordination to achieve team goals [28, 30]. Generally the team is composed of humans, while from the perspective of system thinking, the team's scope is expanded to both humans and nonhuman artifacts.

3.1 Definitions

The traditional and dominant view emphasizes TSA on a shared understanding of the situation, that is, the team members ought to have a common picture [3]. This is how the concept of "shared SA" is raised. Shared SA is the 'the degree to which every team member have the same SA on shared SA requirements' [29]. Team members do not need to share all the environmental elements but those "common SA requirements" with each other. Endsley and Robertson [31] argue that the effective team performance relies on a high level of individual SA and the same SA for the common environmental elements that are required. Team SA, as defined by Endsley, is 'the degree to which every team member possess the SA needed for his or her job' [5]. Wellens [32] suggests that to maximize the TSA (in his research TSA is called group SA), the environmental elements monitored by each team member should have enough overlaps. Wellens defines TSA as 'the sharing of a common perspective between two or more individual regarding current environmental events, their meaning and projected future status' [32]. Salas et al. [28] figure out the importance of communication and information exchange in successful team performance. They conclude that individual SA and team process constitute TSA, in which the team process is 'the teamwork behaviors and cognitive processes that facilitate team performance'. This way, Salas et al. point out 'TSA is at least in part the shared understanding of a situation among team members at one point in time' [28]. Shu and Furuta [26] extend Bratman's [33] shared cooperative activity theory (SCA), in which mutual responsiveness, commitment support, and joint activity are identified as key features of SCA. The cooperative activity is simplified to individual activities and mutual beliefs. They believe that TSA is partly shared and partly distributed among team members [26]. Shu and Furuta then define TSA as 'two or more individuals share the common environment, up-to-the-moment understanding of situation of the environment, and another person's interaction with the cooperative task' [26]. This definition implies that TSA consists of individual SA and mutual awareness. Shu and Furuta do not provide a clear definition of mutual awareness. Schmidt subsequently defines mutual awareness as 'the mutual understanding of each other's intentions, beliefs and activities' [34].

Although the above definitions emphasize on different aspects of TSA, the authors all conceive that TSA resides in people's mind and TSA involves the interactions among team members. To summarize the above definitions, TSA is a multidimensional construct and contains the SA related to the individual's own roles, the SA of other team members, and the SA of the overall team. The SA of other team members is called task-work SA and the SA of the overall team is named teamwork SA [4].

Several researchers argue that TSA is a characteristic of the socio-technical system, rather than a psychological construct of the individual [3, 4, 24, 25, 35]. Artman and Garbis [35] hold the view that TSA is distributed across the human agents and non-human artifacts in the system. They give the definition of TSA as 'the active construction of a model of a situation partly shred and partly distributed between two or more agents, from which one can anticipate important future states in the near future' [35]. The "agents" in this definition can be both human and artifacts. After that, Stanton and his colleagues propose the concept of distributed situation awareness (DSA) [25]. Please note that this is not the first time that DSA is raised. Endsley and Jones [29] used to define DSA as 'the SA in teams which member are separated by distance, time and/or obstacles'. Stanton et al. endow TSA a new meaning. According to [3, 4, 25], SA is not shared, but distributed amongst the whole system. The agents (both human and artifacts) possess unique awareness based on their goals and tasks. Their views can be different even on the same environmental elements. If the different views serve to the overall goal of the system, these views are regarded as compatible. This is what compatible SA means. An agent's deficiency in SA can be enhanced or modified through the transaction with other agents. The transaction implies the interaction among agents, such as the verbal and nonverbal communications in the system. This is where transactive SA comes from. Endsley endorses that the information exists throughout the system containing both human and artifacts. What she finds hard to understand is why the inanimate artifacts have the awareness. In her view, those objects (e.g. displays, technologies, documents) are just repositories of information [12].

3.2 Conceptual Models

In the early years of TSA studies, Endsley raise a TSA model, in which a set of circles overlaps with each other [5, p. 39]. Each circle represents a team member's SA elements related to his or her specific role. The overlaps of the circles represent shared SA and the union of the circles represents TSA.

Salas et al. [28] argue that TSA includes individual SA and team processes. The individual's existing knowledge (mental model) and expectations affects the perception of elements in the environments. The limitation of one's mental model can be complemented and updated through the information exchange with other team members. Team processes, such as planning and assertiveness, facilitate the information exchange among team members. The model raised by Salas et al. describes the cyclical and dynamic nature of TSA [28, p. 130]. In their model, the team members' preexisting knowledge, the team members' characteristics and the team processes interacts with each other. As the product of the team situation assessment, SA also affects the above components in the model.

Incorporating the team processes into the depiction of TSA, Endsley and Jones extend the early TSA model (refer to [5, p. 39]) to reveal the key factors influencing the quality of TSA [12, p. 24, 36, pp. 49–57]. The four factors are TSA requirements, TSA devices, TSA mechanisms and TSA processes. TSA requirements include the elements in thee levels that need to be shared among team members and how well these elements are maintained affects the quality of teamwork. TSA devices include physical ones (e.g. shared displays), nonphysical ones (e.g. verbal and nonverbal communications), and the shared environment. The devices help team members to form shared understanding of the situation. TSA mechanisms refer to the degree to which team members adopt the mechanism (e.g. shared mental models) to understand and project the situation in the same way. Shared mental models benefit the communications [37] and enable the individual to predict other members' behaviors [38]. TSA processes, such as self-checking, coordination, prioritization and questioning, facilitate the ongoing of information exchange [28].

Based on the above TSA models, Salmon et al. provide a summary model in which TSA includes the individual SA, the task-work SA and the teamwork SA [4, p. 318]. However, Salmon et al. argue that this summary model applies only in simple, small-size collaborative systems. As the system becomes more complicated and numerous individuals are distributed far from one another, the DSA model demonstrates its advantages [4].

In reviewing the definitions of SA and TSA raised by Stanton and his colleagues, the DSA theory has been introduced in details. To summarize the key points of the DSA model [3], the perception cycle theory, the schema theory, and the distributed cognition theory together underpin it. From the perspective of system thinking, TSA is distributed across the people and the artifacts in the system. The schema held in the agent drives the perception of elements and directs the action in the world. In turn, the world modifies the schema. This schema-driven process is a continuous circulation. Towards the same external elements, different agents may have different views. These views are exchanged through transactions and are compatible towards the ultimate goal. The compatible SA and transactive SA are crucial for an efficient team performance.

3.3 Controversies

- Whether the three-level model is linear?

Some researchers criticize Endsley's three-level model (perception, comprehension and projection) is linear [39, 40]. According to the model, Level 1 (perception) seems to be necessary to achieve Level 2 (comprehension); Level 1 and Level 2 seem to be inevitable for Level 3 (projection) [41]. This bottom-up, data-driven behavior does exist in real situation. However, a large portion of behaviors follows the top-down, goal-driven pattern [42]. The goal-driven behaviors refer that the task goals, the understanding, and prediction of the situation direct individual's attention to certain elements in the environment. Without the rich information or the detailed model, people may still judge the situation well [3]. Endsley agrees that both data-driven and goal-driven processes of maintaining SA exist [12]. Her view that the comprehension of the situation drives the attention resources to new data in the environment proves this [43]. Endsley denies that the three-level model is a simple 1-2-3 linear one, arguing that the 1-2-3 levels represent the ascending stages of SA [12].

- Is SA a process or product?

There have been debates on whether SA is a product or the process to acquire it. Sarter and Woods regard SA as the comprehensive situation representation as the result of situation assessment [16]. Salmon el al. regards SA as both a product (the mapping of the external information with inner schema) and the process (the continuous perception-action processing) [4]. Endsley used to distinguish SA from situation assessment. The SA in her definition is often regarded as a product [4], which Endsley does not agree with [12]. Ensley argues that the three-level SA model fully describes the process of maintaining SA, such as the matching of mental models on external information and the direction of SA to certain elements in the environment [5].

- Does TSA reside in the mind, in the world or in the interaction of the two?

Whether TSA resides in the mind, in the world, or in the interaction of the two depends on the unit of analysis [24]. Endsley [5, 13], Wellens [32], Salas [28], etc. regard the individual as the unit of analysis and define TSA from the perspective of cognitive psychology. Thus they believe TSA resides in the individual's mind. Ackerman [44], Jenkins [45], etc. regard the objects and artifacts that people interact with as the unit of analysis and define TSA from the engineering perspective. Thus they believe TSA resides in the world. Stanton et al. [3, 25] regard the whole socio-technical system as the unit of analysis and define TSA from the perspective of systems ergonomics. Thus they believe TSA resides in the interaction of human-with-human, human-with-artifact and artifact-with-artifact.

- Whether the TSA is shared or exchanged among team agents?

The researchers who conceive TSA is shared insist that team members ought to have the same understanding on the same information requirements [28, 29, 32]. The common picture facilitates the teamwork [3]. On the contrast, those who conceive TSA is exchanged believe that team agents (both human and artifacts) possess different views on the same information [3, 4, 24, 25]. These different views are exchanged among team agents to form a compatible awareness of the ultimate situation [25]. Stanton et al. [3] hold the view that the shared SA only applies for simple scenarios in small-scale teams, and the DSA is applicable for real complicated situations. Even so, Stanton approves that there are cases in which a common picture (shared awareness) is needed for effective team performance [3].

- What are the cause of Air France 447 crash and many other accidents? Loss of individual SA or loss of DSA?

Many accidents are caused by the loss of SA [11, 12]. Take Air France 447 crash in 2009 for example: the psychological view of TSA [12] attributes the accident to the individual's failure in detecting key information (airspeed) and in accurately judging the situation in time. Attentional narrowing and over-reliance on automation are likely to cause such failures. In the system view of TSA, however, the aircraft crash is not solely due to the failure of individuals. System-view supporters [3] argue that the information is always there; the accident is due to the disconnection between artifacts (the icing tubes that cannot measure the airspeed) and individuals. That is, the information is not transacted successfully within the system. Though the agents possess their own SA, these SAs are not compatible towards the ultimate system goal.

- What TSA model is applicable for what situation?

So far there are no empirical studies on this issue. Stanton et al. [3] propose a three-dimension model to infer what SA approaches are applicable for what situation. The three dimensions in the model are individual/system, stable/dynamic, and normative/formative. Stanton et al. suggest that the individual SA approaches are more suitable for normative, stable and less systemic situations; the team SA approach (e.g. Endsley [29], Salas et al. [28]) for formative, stable and less systemic situations; the systems SA approaches (e.g. DSA model [25]) for formative, dynamic and more systemic situations. Besides the above three dimensions, the dimensions of team size (small-scale/large-scale), the complexity of the environment (low/high), the degree of coupling (loosely-coupled/tightly-coupled), the character of the task (skill-based/rule-based/knowledge-based) might have an impact on TSA model selection. This issue is worth studying in the future.

4 Conclusion

This paper reviews the literature on team situation awareness (TSA) and compares various theories in terms of definitions, conceptual models and theoretical underpinnings. The major controversies on TSA are also provided for a dialectical view on the TSA theories. This review does not attempt to enumerate the TSA definitions and models in an exhaustive manner, but to figure out what is really going on around this fascinating construct.

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