A Systematic Method to Perform Goal Directed Task Analysis with Application to Enterprise Architecture

By

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Méthode systématique pour réaliser l'analyse des taches dirigés par les buts et l'appliquer à l'architecture d'entreprise

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RÉSUMÉ

La conscience de la situation (CS), soit la perception des éléments de l'environnement (niveau 1), la compréhension de leur signification (niveau 2) et la projection de leur état dans le futur (niveau 3), est un facteur qui affecte la performance des opérateurs qui travaillent dans des environnements complexes. Compte tenu de l'importance de la CS pour atteindre les objectifs et éviter les erreurs fatales, la conception orientée-CS est apparue comme une approche pour concevoir des systèmes humain-machines qui favorisent la conscience de la situation. Pour concevoir de tels systèmes, premièrement il faut identifier les exigences CS qui seront transformées ultérieurement pour concevoir un système qui favorise la CS de ses opérateurs. Pour identifier les exigences de CS, l'analyse des tâches dirigées par les buts (ATDB) est une technique largement utilisée pour identifier les exigences SA d'un système. Cependant, ATDB présente plusieurs lacunes : elle est large, conceptuelle et générique, et il n'est pas clair dans la littérature comment effectuer la ATDB dans la pratique, c'est-à-dire qu'il n'y a pas de directives explicites et systématiques pour effectuer la ATDB. Ceci est problématique car ces exigences seront adoptées pour concevoir et évaluer un système qui favorise la CS et par conséquent, l'incomplétude et/ou les erreurs dans la liste des éléments de la CS entraîneront des problèmes de conception.

Par conséquent, le but de cette thèse est de concevoir une méthode qui guide les praticiens pour performer ATDB selon des étapes explicites, systématiques et traçables, et d'étendre l'application de ATDB en dehors du domaine de la conception de systèmes, au domaine de la documentation. La présente thèse est composée de trois études dont chacune vise à atteindre un objectif spécifique : la première étude a exploré la manière dont ATDB est appliquée dans la pratique ; la deuxième étude a conçu une méthode pour effectuer ATDB de manière systématique et explicite basée sur les meilleures pratiques documentées dans la littérature et ISO 15939 ; et la troisième étude étend l'application du modèle CS en dehors du domaine de la conception de systèmes en proposant une méthode basée sur ATDB et ISO 15939 pour évaluer un document technique non procédural. Les résultats de cette thèse contribuent à : 1) mettre en évidence les lacunes de ATDB ; 2) l'avancement de la recherche et de la pratique de la ATDB en proposant une méthode concrète, applicable, systématique et fondée sur la littérature pour performer la ATDB ; et 3) démontrer comment le modèle CS et ATDB peuvent être appliqués en dehors du domaine de la conception du système, au domaine des documents techniques, ce qui montre aux chercheurs et aux praticiens l'importance de considérer le modèle CS dans l'évaluation des documents techniques.

Mots-clés: conscience de la situation, analyse des tâches orientées vers les buts, science de la conception, ISO 15939, document technique.

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ABSTRACT

Situation awareness (SA), the perception of the elements in the environment (level 1), the comprehension of their meaning (level 2), and the projection of their state in the future (level 3) is known to affect the performance of system operators who work in complex environments. Given the importance of SA in achieving goals and avoiding fatal errors, SA-oriented design has emerged as an approach to design human-machine systems that promote a high degree of SA. To design such systems, the first step is to create SA requirements—i.e., a list of SA elements—that will be translated later to design a system that promotes the SA of its operators. Goal-directed task analysis (GDTA) is a commonly used method for identifying SA requirements. However, GDTA has several shortcomings: it is broad, conceptual, and generic, and it is not clear from the literature how to perform GDTA in practice, that is, there are no explicit and systematic guidelines for performing GDTA. This shortfall may lead the SA analyst to create incomplete and/or erroneous SA requirements. This is problematic because those requirements will be adopted to design and evaluate a system that promotes SA and consequently, the incompleteness and/or errors in the list of SA elements will lead to design problems. Therefore, the purpose of this thesis is to design a method that guides GDTA practitioners in performing GDTA in explicit, systematic, and traceable steps, and to extend the application of GDTA outside the system design field to the documentation field. The present manuscript-based thesis is made up of three studies each of which aims to achieve a specific objective: the first study explored how GDTA is performed in practice; the second study designed a method to perform GDTA in a systematic and explicit way based on the best practices documented in the literature and ISO 15939; and the third study extends the application of the SA model outside the system design field by proposing a method based on GDTA and ISO 15939 to evaluate a non-procedural technical document. The findings of this thesis contribute to highlight 1) the shortfalls in performing GDTA; 2) the advancement of GDTA research and practice by proposing a concrete, applicable, systematic, and literature-based method to perform GDTA; and 3) how the SA model and GDTA can be applied outside the system design field, to the technical document field, which shows researchers and practitioners the importance of considering the SA model in technical document evaluation.

Keywords: situation awareness, goal-directed task analysis, design science, iso 15939, technical document.

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LIST OF ABBREVIATION AND ACRONYMS

DSR	Design Science Research
EA	Enterprise Architecture
GDTA	Goal Directed Task Analysis
HMI	Human-machine Interaction
SA	Situation Awareness
SLR	Systematic Literature Review

INTRODUCTION

Situation Awareness (SA), the person's understanding of their environment, plays an important role in systems requiring human-machine interaction (HMI) (Salmon, Walker et Stanton, 2016; Woodhouse et Woodhouse, 1995). SA pertains to what is perceived by a human, how these perceptions are comprehended, and how events are expected to unfold given one's comprehension of these perceptions (Endsley, 1995b). Research suggests that many human-machine system errors are SA-related due to inadequate information provision that affects the operator's SA, and consequently, their ability to accomplish goals (Eskandari, Dumont et Wang, 2015; Salmon, Walker et Stanton, 2016; Sharma, Nazir et Ernstsen, 2019). Nowadays, more and more domains are investing in SA research to design systems that promote the SA of their operators. These domains include traffic control (Endsley et al., 1997; Endsley et Rodgers, 1994), military (Salmon et al., 2009), command and control (Stanton et al., 2009), nuclear power (Crichton et Flin, 2004), maritime transport (Shephard, 2016), military aviation (Uhlarik et Comerford, 2002), and accident and emergency services (Gaba, Howard et Small, 1995). Given the importance of SA in such complex systems, SA-oriented design has emerged as a model to design systems that provide adequate SA to their operators (Endsley et Jones, 2012). SA-oriented design starts by identifying SA elements that are necessary to build an adequate SA for operators. To identify these elements, practitioners perform Goal-Directed Task Analysis (GDTA) which results in a list of SA elements used later to design and evaluate systems that promote the SA of their operators (Endsley, 1993; Endsley et Jones, 2012). However, after conducting a preliminary review of some studies on how GDTA is performed in practice, it seems that there is a lack of clear guidelines for performing GDTA. This lack of complete and explicit instructions (the sequence of steps, transitions between steps, definitions of GDTA concepts) may result in an inaccurate, incomplete, or ambiguous SA requirements list that, in turn, negatively impacts the system designer's ability to identify what is really required to build an effective system. Therefore, the present thesis aims to advance GDTA research and its practices by developing a systematic and explicit method that guides the application of GDTA.

This thesis comprises three studies. The first study is an exploratory study that investigated how GDTA is performed. It conducts a systematic literature review (SLR) using articles was published from 1993 (when the first scientific paper that proposed GDTA) to 2020 in engineering, computer science, and management journals. This study identified the lack of complete and systematic guidelines to perform GDTA. Therefore, this study highlighted the need to advance the agenda of GDTA research by proposing relevant directions for future research.

The second study aimed to fill the gap identified in the first study by proposing a systematic method for performing GDTA. The proposed method was created and evaluated according to the design science research (DSR) approach. This study contributes to the advancement of GDTA research and practice by proposing a concrete, applicable, systematic, and literature-based method to perform GDTA.

The contribution of the second study may facilitate the application of GDTA and consequently open opportunities for applying GDTA in new domains outside the dynamic systems field, such as non-procedural technical documents, which is the aim of the third study. The non-procedural technical is used to describe the structure of systems, in order to provide an adequate representation of the system among the system operators and thereby improve their capacities to make appropriate decisions when operating the system. However, there is no guarantee that the document creator and the users of the document (system operators) share the same understanding of the presented system. Inadequate technical documents may lead to misunderstanding of the structure of the system, which may lead to errors and undesirable results during the operation of the system. Therefore, it is vital to properly evaluate technical documents. However, to date, the used evaluation methods are mostly subjective and reflect the opinions of the document experts, or the document's users, rather than reflecting their understanding of the content of the document. Consequently, there is a need to design an objective evaluation method that reflects what the document users really understand. To address this need, the third study applied the SA model and GDTA to a non-procedural technical document, in order to evaluate it by measuring the SA of its users.

This thesis contributes to GDTA research by developing a systematic approach to apply GDTA that transforms vague and ambiguous GDTA practices into systematic, organized, and traceable practices. It also presents how GDTA can be applied outside the HMI field. The rest of the thesis follows the following structure: Chapter 1 presents the literature review, including the research problem and the research questions. Chapter 2 presents the research questions, research methods, and the link between the three studies. Chapters 3, 4, and 5 present the three studies described above. Chapter 6 concludes the thesis, presents the limitations of the three studies, and suggests directions for future work.

CHAPITRE 1

LITERATURE REVIEW

This chapter presents a literature review of how GDTA is performed and what the problem is and situates the present research in the context of what has already been done. As mentioned previously, the first aim of the present thesis is to advance GDTA research and practices, and the second aim is to extend the application of GDTA into a new domain: technical documentation. Therefore, the following subsections present background on GDTA, its importance, as well as shortfalls with GDTA and the importance of addressing them when performing GDTA. Also, the technical documents field will be introduced as well as its problems and the importance of applying the GDTA in this field.

1.1 The situation awareness background

Human–machine interaction (HMI) is a field of research that focuses on interaction between a human and a machine via a user interface. HMI is currently flourishing due to the gigantic role machines play in human life (Ke et al., 2018). Interaction between humans and machines always results in challenges, such as system breaches, errors and various types of accidents, all of which attract the attention of researchers and practitioners who aim to optimize the performance of system operators (Belli et al., 2012). For example, in the United States, around 44,000 deaths are registered annually in the medical field (Kohn et Corrigan, 1999). In India, in 1984, more than 2500 people died in an accident at the Union Carbide plant (Endsley et Jones, 2016). These accidents, and others in domains such as maritime and in aeronautics, are attributed to human error (Salmon, Walker et Stanton, 2016; Sharma, Nazir et Ernstsen, 2019).

Many of those called human errors are attributed to flaws in the system interface's design, which did not support the operator in detecting significant cues of the problem, or in preventing the events that led to the accident (Endsley et Jones, 2012). What happens is that the complex systems either do not provide the system operators with the needed information, or they overload the operator with irrelevant information. In both cases, system operators' capacity to understand what is going on around them and to make appropriate decisions are negatively impacted. These errors are direct results of technology-centered designs that are not suitable for promoting high levels of operator performance under real-world conditions and challenges (Endsley et Jones, 2012; Irizarry et Gheisari, 2013). Based in technology-centered design perspectives, system designers often integrate the same technology in different domains without considering the needs and capabilities of the end-user (Endsley et Jones, 2012; Irizarry et Gheisari, 2013; Kaber et al., 2006).

To address the problem of complexity and errors induced by technology-centered design models, user-centered design models have emerged as a way to design systems based on the capabilities and needs of the end-user (Endsley et Jones, 2012; Irizarry et Gheisari, 2013). User-centered designs allow to better exploit technologies to support human performance by reducing errors and improving productivity (Endsley et Jones, 2012). In a precise way, the user-centered design model aims to achieve the following objectives:

1) Integrate technologies based on the user's goals, tasks, and abilities.
2) Integrate technologies based on the way users process information and make decisions.
3) Integrate technology in a way that keep the system user in control and promote its awareness of the state of the system.

To fulfill these objectives, the system designers should design systems that promote a high level of situation awareness (Endsley et Jones, 2012).

1.1.1 What is situation awareness?

The origin of the situation awareness (SA) concept goes back to the World War I era where it played an important role in developing defenses against enemy aircrafts (Sharma, Nazir et Ernstsen, 2019). The SA concept and its application in various domains rose in importance in the late 1980s when researchers started to conduct extensive research to scientifically frame the concept and its measurement (Stanton et al., 2006). According to Endsley SA is defined 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" (Endsley, 1995b). According to Endsley's definition, there are three levels of SA the operator can have while interacting with dynamic systems:

1) **Level 1 SA - Perception:** The first level is the perception of the status, attributes and dynamics of elements in the environment (Endsley, 1995b). A pilot would perceive relevant elements such as aircraft, mountains, or warning lights, along with their relevant characteristics (e.g., color, size, speed, location). The elements likely to be important for level one SA depend on the situation within which SA is required.

2) **Level 2 SA - Comprehension:** At this level, system operators seek to comprehend the meaning of the perceived elements in a volume of time and space (Endsley, 1995b). Level 2 SA goes beyond simply being aware of elements which are present to comprehend their significance according to the operator's goals. That is, the operator needs to integrate the elements perceived at level 1 to form a holistic picture of the environment and extract the meanings that are useful to their purpose. For example, the pilot not only detects that an alert has appeared on the display, but also comprehends that an alert indicates the failure of a particular system component.

3) **Level 3 SA - Projection**: At this level, the system operator projects the future state of the perceived elements in the environment, at least in the very near term. This projection is based on the knowledge of the status and the dynamics of perceived elements and comprehension of the situation. Explicitly, the projection is based on the combination of elements perceived at level 1 SA and their meaning at level 2 SA (Endsley, 1995b). This projection allows the operator to understand what is going on around them and consequently allows them to make decisions (Endsley, 1995b). For example, a pilot, based on the location of an enemy aircraft, can project if the aircraft is likely to attack. This projection provides him or her with the necessary knowledge to make an appropriate decision towards achieving their goal (i.e., protect her/himself).

1.1.2 Why is SA important?

SA is important because it is an essential factor in driving decision-making processes and the performance in complex and dynamic systems. Figure 1.1 presents the SA theoretical model that represents the relationship between the SA, decision, and actions (Endsley, 1995b).

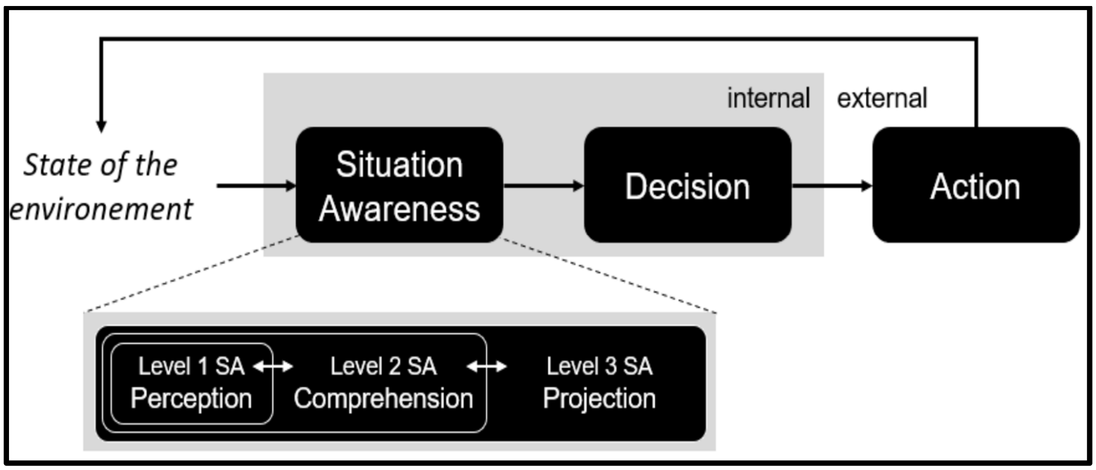

Figure 1.1 SA theoretical model taken from Endsely (1995b)

The SA theoretical model consists of two steps. The first step consists of achieving SA. To achieve SA, an operator must: perceive the elements of the environment, comprehend their significance in light of a pertinent goal, and project their status in the near future (Endsley, 1995b). The three levels feed into one another, meaning that an operator can achieve level 2 SA and level 3 SA without perceiving all the elements at level 1 SA (Endsley, 2015). That means, the operators may, based on their goals and current understanding (level 2 SA) and projections (level 3 SA), return to level 1 SA for data to be able to confirm or deny their assessments (Endsely, 2015). This is represented in Figure 1.1 by the nested boxes for each SA level and the bidirectional arrows connecting them. The second step, decision, consists of choosing appropriate actions to achieve a specific goal. Unlike SA and decision-making, which are internal to the person, actions modify the external environment.

Research suggests that SA is linked to many accidents, a large proportion of which involve the loss of human life. Woodhouse et al. reported that 74% of aviation accidents (Woodhouse et

Woodhouse, 1995), and about 5000 deaths from 1978 to 1992, could be attributed to loss of SA as opposed to impaired proficiency of skill (Gronlund et al., 1998). Likewise, (Härtel, Smith et Prince, 1989) reported that poor SA was a causal factor in 200 aircraft accidents. In the maritime domain, problems in SA account for about 71% of human errors (Sharma, Nazir et al., 2019). In the aeronautical domain, many incidents are related to SA problems, as in the example of the AF 447 airplane crash (Salmon, Walker et Stanton, 2016). Given the importance of SA, the SA-oriented design model has emerged to facilitate the design of systems that promote an adequate SA level.

1.1.3 SA-Oriented design system

SA oriented design is a process that uncover the SA requirements involved in a domain and translates those requirements into a system design that helps to promote SA (Endsley et Jones, 2012) (see Figure 1.2).

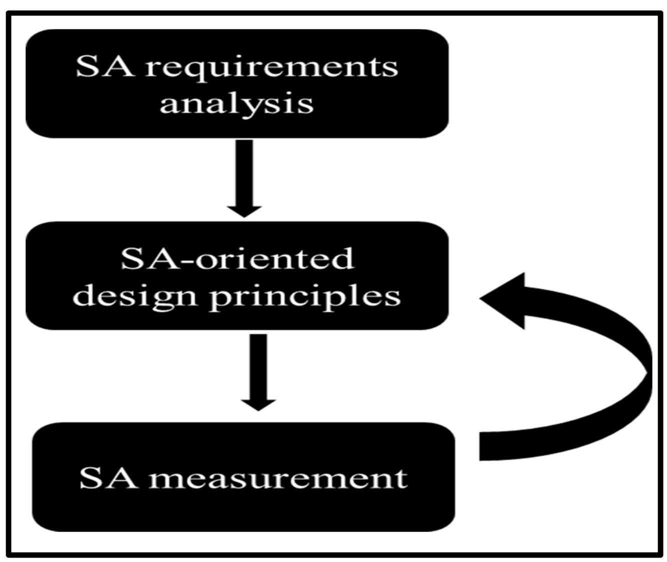

Figure 1.2 Situation awareness-oriented design
taken from Endsley et Jones (2012)

The SA-Oriented Design process consists of three phases: SA requirements analysis, SA-oriented design principles application, and SA measurement. The design process starts with a

SA requirements analysis that aims to identify the SA requirements of the system operators. Second, the system is designed based on the identified SA requirements. Finally, the designed system is evaluated by measuring the SA of its users. The evaluation process determines whether the system will be deployed or go back to the redesign stage. This model is used to improve the design of systems in various domains such as air traffic control (Endsley et al., 1997; Endsley et Rodgers, 1994), military (Salmon et al., 2009), command and control (Stanton et al., 2009), nuclear power (Crichton et Flin, 2004) and maritime transport (Shephard, 2016).

The present research focuses on the first step (SA requirements analysis) of the SA-oriented design model. This step is a prerequisite for creating SA requirements that will be translated later into a system design that promotes the SA of their operators (see Figure 1.3). To complete the SA analysis phase, the analysts use GDTA, which itself is a form of Cognitive Task Analysis (CTA) (Endsley, 1993).

CTA is used to capture how people make decisions in order to perform complex tasks (Gordon et Gill, 1997) and how they react under the pressures of time, risk, and incomplete information (Crandall et Hoffman, 2013). The power of CTA lies in its ability to identify the cognitive requirements the operator needs to perform complex tasks and overcome challenges (Crandall et Hoffman, 2013; Schraagen, Chipman et Shute, 2000). Therefore, CTA has promoted the development of effective solutions in many domains such as technology, training programs, workplace design, and organizational challenges (Schraagen, Chipman et Shute, 2000).

Figure 1.3 The design process of promoting SA system

As mentioned previously, GDTA is used to identify the SA requirements list the system operator needs to make informed decisions to achieve their goals. Based on a preliminary review of GDTA studies such as (Endsley, 1993; Endsley et Jones, 2012; Endsley et Rodgers, 1994; Strater et al., 2001), the studies have agreed on the sequences of the steps of GDTA which can be summarized as following:

1) **Identifying goals.** The first step aims at identifying goals that system operators must achieve.
2) **Identifying sub-goals.** The second step aims to identify the sub-goals necessary for meeting each of the goals identified in the first step.
3) **Identifying decisions.** The third step aims to identify the decisions to be made by system operators. In a GDTA, decisions are not directly identified. Instead, for each sub-goal, a set of questions whose answers will guide decisions are identified.
4) **Information categorization into SA levels.** The fourth step aims to specify which information (SA elements) is needed at each SA level to answer every decision/question identified at step 3 (identifying decisions step).

1.1.4 Goal directed task analysis in the literature

GDTA studies can be classified into two types: foundation studies and application studies. Regarding the foundation studies, they focused on advancing GDTA research and practices by providing practical guidelines to perform GDTA. Thus, these studies provided the steps and the sequence of GDTA. Also, they provided information to distinguish between a goal and a task. A goal is an overarching objective that system operators must achieve. A task, which is technology dependent, is what system operators do to reach their goal and it consists of a series of predetermined steps to be followed by the operators. However, the instructions for performing each step, identifying the GDTA concept at each step, and to move between steps, seemed incomplete and were not based on a solid theory. In this regard, (Endsley, 1993) is the first study that proposed GDTA as a technique to analyze and identify SA requirements of complex systems. She provided general steps to conduct GDTA including identifying the users' goals, identifying questions to answer to achieve each goal, and identifying SA requirements to answer these questions. She also proposed to elicit goals, decisions and SA requirements from domain experts through conducting unstructured interviews. However, the instructions to perform GDTA steps in (Endsley, 1993) seem incomplete. For example, the characteristics of GDTA concepts (goal, SA requirements, etc.) needed to identify them and the instructions to illustrate the relationship between these concepts are not provided.

Another study (Endsley and Roger, 1994) performed GDTA following (Endsley, 1993) to determine the SA requirements for "En route Air Traffic Control Specialist" field that will be used in system design and training programs in that field. This study contributed to GDTA practices by adding a supplementary step to facilitate performing GDTA. The added step consists of subdividing each goal to the many sub-goals that are necessary to achieve each goal. However, the other GDTA steps are performed without any significant extension to facilitate performing of these steps in practice. Also, the study provided some examples of SA requirements at the three SA levels. However, the provided examples are specific to the domain of the study and cannot be adopted as guidelines to perform GDTA in other domains.

Similarly, (Endsley et Jones, 2016; Endsley et Jones, 2012; Ensley, Bolte et Jones, 2003) advanced GDTA research by contributing to the overall understanding of how to perform GDTA by providing additional information on how (Endsley, 1993) steps and instructions can be used to perform GDTA in a particular domain. For example, they gave instructions on how to prepare to perform interviews (e.g., reading available documents about the domain), how to perform the interview, how to validate the goals list, etc. They also provided instructions on how to identify the decisions list (e.g. what is a decision, what is the form of the decision, etc.). However, they did not provide concrete instructions for identifying the GDTA concepts and how to move between the steps, keeping them generic and incomplete. For example, they defined goals as "higher-order objectives essential to successful job performance." This definition of the goal is generic and does not provide the characteristics that would allow the analyst to clearly identify what a goal is. Also, they did not provide instructions on how to move from goals to sub-goals and to identify sub-goals. Moreover, the instructions for identifying SA requirements at different SA levels are incomplete. For example, the definition of level 1 SA requirement is “the status, attribute, and dynamic of relevant elements in the environment” is not complete enough to identify the level 1 SA element.

Although (Yang, Prasanna et King, 2015) mostly followed (Endsley et Jones, 2012) guidelines, they contributed to the sub-goal concept by explaining how the sub-goal list can be created. They stated that the sub-goal list can be identified by formulating questions that allow decomposing a high-level goal to its practical sub-goals (e.g., how to achieve this goal? What tasks are necessary?). The provided instructions were useful in identifying sub-goal lists in practical contexts. Nonetheless, the rest of the GDTA steps and concepts were not explained in further detail.

Similarly, (Endsley et Jones, 2012) followed (Endsley, 1993) in performing GDTA, and their study contributed to defining SA requirements at different levels. For example, they defined level 1 SA elements as "User information data needs." This definition is not clear enough to allow the SA analyst to identify the nature of the information that is needed. Also, they defined level 2 SA elements as “Information to be combined to form the needed comprehension”. However, this definition does not allow the analyst to identify what the bits of information are and how to combine them.

Regarding the application studies, they applied GDTA to improve system design in their domains. Thus, every study that falls into this category contributed to identifying SA requirement specific to their domains. These SA requirements are essential for designing systems that promote system operators’ SA.

For example, (Endsley et Rodgers, 1994) identified SA requirements to improve the design of air traffic control systems. (Kaber et al., 2006) contribution lies in applying the GDTA in the pharmacology domain. They explained how GDTA can contribute to designing interfaces that promote adequate SA of the bio-pharmacologist system users. The study performed GDTA to obtain a list of SA requirements following the same guidelines provided by (Endsley, 1993) without adding significant instructions to facilitate the performing of GDTA. More precisely, the study reformulated (Endsley, 1995b) definitions of SA levels as the following:

1) level 1 SA: observation of the system and its environment;
2) level 2 SA: understanding of the system and environment relative to task goals;
3) level 3 SA: prediction of future system and environment states.

In fact, the adopted definitions target the SA levels and not their elements. Consequently, this definition does not facilitate performing GDTA as these definitions do not provide instructions for identifying SA requirements at SA levels.

(Endsley et Connors, 2014) demonstrated the usefulness of GDTA to cybersecurity. They also provided some examples regarding the different levels of SA elements. However, the provided examples are domain-specific and are not enough to guide analysts during the application of GDTA in other domains. (Sharma, Nazir et Ernstsen, 2019) performed GDTA to identify SA requirements in the maritime domain. This study provided examples of goals and SA elements at each level. Although these examples can be useful for inferring instructions for identifying SA requirements, they are not guidelines to perform GDTA

It can be concluded that the lack of complete instructions for performing GDTA has resulted in errors and ambiguities in studies that applied GDTA. For example, (Strater et al., 2001) performed GDTA to identify the SA requirements of a platoon leader in military situations and provided an ambiguous SA elements list. For example, the "enemy combat power" requirement is categorized at level 3 SA, even though it is not a projection.

Another example that resulted in ambiguous SA requirements is the study by (Endsley et Rodgers, 1994). Their SA requirements ended-up with a classification problem. For example, the requirement "projected time in airspace" is placed in level 2 SA which is not coherent with Endsley’s previous statement that projections belong to level 3 SA (Endsley, 1995b).
Similarly, (Irizarry et Gheisari, 2013) followed the steps provided by (Endsley et Jones, 2012) to perform GDTA. Their study adopted incomplete instructions for defining SA requirements. For example: "[a level 2 SA element] Goes beyond simply being aware of the elements that

are present." In fact, in this statement, the meaning of the word "aware" is not clear and consequently not enough to identify the level 2 SA elements in practice.

(Endsley et Rodgers, 1997) performed GDTA and provided an ambiguous SA elements list. For example, the SA requirement “Fuel sufficiency,” an assessment of the degree to which the current fuel level meets the goal, is categorized as level 2 SA. However, fuel sufficiency also depends on the projection of how far the vehicle needs to travel and how much fuel will be burned at what rate on the trip. The question here is whether this element belongs to level 2 SA or level 3 SA.

Based on the above literature review, it can be concluded that there is a lack of clear guidelines for performing GDTA in practice, since the provided GDTA steps are broad, conceptual, and generic, which makes it difficult to apply them in practical contexts. This may pose serious problems during the application of SA-oriented design models. That is, during the SA analysis phase, the goal of GDTA is to produce a list of SA requirements for designing systems that provide a high level of situation awareness (Endsley and Jones, 2012). The incompleteness of the instructions to perform GDTA may lead to the creation of ambiguous or incomplete SA requirements. When SA requirements are incomplete or ambiguous, it may lead to: 1) designing an inappropriate system since these requirements will be translated to a system that promotes high level SA; and to 2) erroneous evaluation of the designed system because the same SA requirements list will be used to evaluate if the designed system meets the needs of its users and supports them in building a good SA. To improve the system, SA analysts need to identify at which SA level the breakdown has occurred (whether at the perception, understanding or projection level) in order to identify what aspect of the system should be improved, as every SA breakdown needs a different type of intervention. As stated by (Wickens, 2008), “each SA level breakdown may have very different consequences for addressing them. For example, a breakdown of Level 1 SA would lead to the design of better alerts. A breakdown of Level 3 SA would lead to incorporation of predictive displays".

Consequently, there is a need to advance GDTA research and practice by 1) exploring in-depth the state of the art of existing GDTA practices in order to investigate the scope of the identified shortfall (a lack of clear guidelines to perform GDTA), and by 2) developing a systematic method to address the identified shortfall to guide the analyst during GDTA. The main contribution of this thesis is filling this gap in the literature. This contribution may lead to facilitating the performance of GDTA and consequently open opportunities to apply GDTA analysis in new domains outside the field of dynamic systems, such as in the technical documentation field. The next section presents the importance of applying GDTA to technical documents.

1.2 GDTA Beyond the Traditional Applications

As mentioned previously, the goal of performing GDTA is to design systems with interfaces that provide their operators with the information needed to interact adequately with these systems. However, it seems that there are no studies that performed GDTA to evaluate and design a document, even though a document is an artifact designed exclusively to share information with its readers so that they can understand what is presented in it. In this thesis, we will target a specific type of document: a technical document that aims to present the structure and/or the operation of a system to its users so that they can interact with or operate the system (Ganier, 2002). In other words, an inadequate technical document may lead to errors and undesirable results. Consequently, the evaluation of such documents is a necessity that many researchers have aimed to achieve. However, most evaluation practices target either the document creators or document users' opinions without considering the actual understanding of the document content. To further illustrate this problem, the next section presents what a technical document is, the problems it faces, and the importance of performing GDTA to evaluate technical documents.

1.3 The Technical Document

1.3.1 Introduction

Effective communication can be achieved by creating technical documents, documents that meet a set of criteria regarding lexical and grammatical aspects and style construction (Saint-Dizier, 2014). This type of document aims to minimize the distance between language and action, and minimize reader inferences, misunderstandings, and potential errors (Saint-Dizier, 2014). Research on technical documents is divided into two categories: procedural and non-procedural documents (Ganier, 2002). Procedural documents describe steps or procedures needed to perform a specific task, such as using a dishwasher or word processing software, or instructions for evacuating a building in case of fire or making a birthday cake. Non-procedural technical documents present the structure and/or operation of a system (Ganier, 2002). The system can be a network, a device, or an enterprise. The purpose of this kind of document is to create a shared mental representation of the described system with the document user to optimize his or her performance when operating the system.

Given the importance of technical documents in creating a shared mental representation of the described system, it is essential to ensure that the designed documents achieve their purposes (i.e., guiding its users to perform a task, presenting a system, describing a process, etc.). To ensure that the documents achieve their intended purpose, it is important to evaluate them.

1.3.2 Related Works

(Bethke et al., 1991) stated that it is possible to evaluate a technical document using two approaches. The first one is a task-oriented approach that consists of asking subjects to complete a specific task using the document to be evaluated. Then the document will be evaluated based on how well the subjects achieve the specified task. The second approach tasks subjects with answering a questionnaire that consists of twenty-four questions that reveal how easy the document was to use. However, these two approaches are more suitable to procedural technical documents rather than non-procedural ones. The reason is that non-procedural documents aim to present a structure of a system and do not provide steps for achieving tasks. Consequently, the task-oriented approach and evaluation of the ease of use are not adequate for non-procedural documents.

(Bernal, Kirkpatrick et Watt, 2016) argued that technical documents should be effectively written for the target users. Therefore, they proposed a set of criteria for evaluating a technical document, such as the clarity of instructions, the organization of the text, and the quality of visual illustrations. To evaluate a document, the study proposed a task-oriented approach and a questionnaire. More precisely, the evaluation process consists of recruiting a group of subjects that use a draft of the document to complete some tasks, and then answer a questionnaire designed to evaluate the document in terms of its ambiguity, lack of clarity, need for additional visuals illustrations and organizational problems. Based on the feedback of the subjects the document then is revised and improved. However, the proposed evaluation approach targets procedural documents and is not suitable for non-procedural documents, as the latter are not designed for achieving tasks.

Similarly, (Guillemette, 1989) distinguished between behavioral and non-behavioral evaluation of technical documents. Behavioral evaluation focuses on the direct involvement of the representative readers in the evaluation process. The readers attempt to complete realistic tasks using the materials being evaluated and/or by expressing their attitudes and opinions regarding the suitability of those materials. However, behavioral evaluation is not suitable for non-procedural documents. Non-behavioral methods consist in engaging experienced writers with little background in the subject area to anticipate issues related to the accessibility, comprehensibility, or applicability of materials. The non-behavioral evaluation approach can be useful for evaluating the non-procedural document; however, this approach targets the creator of the document, not their users who can have other opinions about the evaluated documents.

(Huston, 2012) adopted a task-oriented approach to evaluate technical documents that guide users to operate an eye-tracking system. In his study, subjects were recruited to use the document to complete a number of tasks on an eye-tracking system. Then, the usability of the document was evaluated based on the capacity of the subjects to complete specific tasks. As mentioned above, this type of evaluation is not suitable for evaluating non-procedural documents.

(Saint-Dizier, 2014) stated that technical documents are designed to be read easily without ambiguity and effort. To evaluate documents, he proposed a set of factors such as the simplicity of the expressions, the coherency of the document, the clarity of the main elements (i.e., the instructions, the objectives, the warnings, the visibility of the font). These criteria have to be evaluated based on the feedback of the document's users or by technical documents experts. Although this evaluation approach can be used to evaluate non-procedural technical documents, it reflects the opinions of the readers rather than their understanding of the represented system, which can be inadequate.

(Dambreville, 2009) proposed to use experts' opinions to evaluate a technical document. The evaluation is done by using questionnaires that focus on a set of factors such as the structure of the document, the organization of the text and the readability of the document. Although this evaluation approach can be used to evaluate non-procedural technical documents, however, this technique reflects the opinion of the experts and ignores the end users who should be the center of the evaluation process.

(Ylimäki, 2008) proposed a set of criteria that can help to evaluate a technical document. He suggested that the document must be based on a well-defined documentation plan, and that the document must provide a consistent and accurate picture of the presented system. However, the study did not propose any approach for evaluating a technical document based on these criteria.

(Lakhrouit, Baïna et Benali, 2014) proposed a generic evaluation model for technical documents inside enterprises. The proposed model included a set of criteria such as clarity, conciseness, granularity, uniformity, cohesion, availability, correctness, and usefulness.

Although these criteria provide bases to evaluate technical documents, the study did not propose any approach or process for evaluating a document based on these criteria.

(Niemi et Pekkola, 2013) conducted interviews with 14 enterprise experts to identify attributes for evaluating enterprise technical documents. Attributes identified include granularity, uniformity and cohesion, correctness, and usefulness. The study did not state how to evaluate a document based on these criteria.

1.3.3 Technical Documents Problem Statement

Based on the reviewed studies, the evaluation of technical documents can take one or a combination of the following two forms:

1) The task-oriented approach, which evaluates to what extent the document is easy to be used to achieve tasks (Bernal, Kirkpatrick et Watt, 2016; Bethke et al., 1991; Guillemette, 1989; Huston, 2012; Postava-Davignon et al., 2004) or
2) Questionnaires answered by a group of experts or document users (Dambreville, 2009; Ganier, 2002; McClelland, 1995; Schriver, 1989).

The problem is that the two types of evaluation are not adequate to evaluate non-procedural technical documents that aim to create a shared mental representation of the described system with the document user, in order to optimize his or her performance when operating the system. The first type, the task-oriented evaluation, is not suitable since non-procedural technical documents do not aim to guide its users to complete tasks. The second type, questionnaire-based, provides subjective evaluations of the content of the document that reflect the opinions of their users rather than their understanding. In other words, even if the readers believe that the quality of the document is good, there is no guarantee that the document users have the same understanding of the described system as that of the document creator (Cruz, 2013). As a result, they may make inadequate decisions that may negatively affect their performance and lead to fatal errors (Cruz, 2013; Kotusev, Singh et Storey, 2015; Lucke, Krell et Lechner, 2010). Therefore, it is important to evaluate the mental representation of the document user, which is not possible with the task-oriented and questionnaire-oriented approaches frequently used to evaluate technical documents. Therefore, this thesis aims to fill this gap in the literature by proposing a method to evaluate non-procedural technical documents by measuring the SA of their users.

To recap, this thesis was set to achieve the following objectives in 3 studies: conduct a systematic literature review to investigate how GDTA is performed in the literature, design a method that provides explicit and systematic steps to perform GDTA, and extend the application of the SA model and GDTA to the evaluation of technical documents. The next chapter presents in detail the objectives and research approach of each study.

CHAPITRE 2

RESEARCH APPROACH

2.1 Introduction

The main objective of this thesis is to propose a systematic and explicit method using scientific approaches to ensure valid and reliable findings. To achieve this objective, the thesis is divided into two complementary studies and one application study. The first study aims to investigate how GDTA is performed and the second study aims to propose a systematic method to perform GDTA. The third study aims to evaluate non-procedural technical documents based on SA model and GDTA. The following sections introduce these studies and justify their relevance to the overarching goal of the thesis.

2.2 Objective and Research Approach of the First Study

The objective of the first study is to explore how GDTA is performed. The study aims to answer the following research question: Is there a systematic method for performing GDTA in practice?

To answer this research question, we analyzed 87 studies using systematic literature review (SLR) method. The SLR aimed to ensure that most papers that contribute to advancing GDTA practice and research are included in the analysis. Therefore, we explored large databases such as Compendex, Scopus, Web of Science, Inspec and Knovel. The chosen databases either specialized in engineering (Compendex, Inspec, Knovel) or were multidisciplinary (Web of Science, Scopus), and are commonly used by universities. Additionally, the SAGE database was also searched to ensure that we did not miss papers that proposed explicit methods for conducting GDTA. The SLR results suggest that there is no complete explicit or systematic method to perform GDTA. This finding paved the way to the next study to design a systematic method to perform GDTA. This first study is published in the IEEE Transactions on Human-Machine systems journal.

2.3 Objective and Research Approach of the Second Study

The second study aims to address the shortfalls identified in the first study. In a precise way, the second study aims to answer the research question: How can a systemic method be designed to accomplish GDTA?

To achieve this objective, the study followed a design science research (DSR) approach to develop a new artefact: a systematic method for performing GDTA. The importance of DSR is that it provides rigorous steps from the identification of the problem to the validation of the solution (e.g., the designed method). The DSR steps were valuable since they provided a holistic vision for designing the proposed method. In other words, it guided us to: identify the scope of the problem in an explicit way; identify the requirements of the targeted solution; design the method based on well-established criteria that are identified based on the requirements of the solution, and finally, evaluate the designed method based on well-defined ex-ante and post-ante evaluation criteria. The ex-ante criteria were applied during the design process of the artifact and the post-ante criteria were verified after the design process was completed.

This study is submitted to IEEE Transactions on Human-Machine Systems journal and is under review.

2.4 Objective and Research Approach of the Third Study

The objective of the third study is to apply the SA model and ISO 15939 to evaluate a technical document by assessing the mental representation of its users. The research question that is investigated is: How can we design a method to evaluate a technical document by assessing the mental representation of its users?

Because the primary goal is to develop a new artifact (method), this study followed a design science research (DSR) approach to identify the problem of technical documents and its relevance from previous research; identify the requirements of the solution of the identified problem; develop a method to evaluate a technical document; evaluate the designed method in the context of technical document field. This study has been submitted to the Business &

Information Systems Engineering journal and is under review.

2.5 Thesis Contribution

This thesis seems to be the first attempt to investigate in-depth how GDTA is performed, to identify gaps in the method, and to address these gaps by proposing a systematic and explicit method for performing GDTA. The second aim of this thesis is to extend the application of the SA concept outside the field of HMI by developing a method based on GDTA and ISO 15939 to evaluate non-procedural technical documents.

In summary, this thesis followed well-known research and design methodologies, such as SLR and DSR, to ensure a rigorous search and analysis method. It also made use of the ISO 15939 standard to ensure valid and reliable results. The findings of this thesis contribute to a better understanding of how to apply GDTA by providing complete guidelines for performing GDTA in an explicit and systematic manner. Additionally, these findings may also help researchers apply GDTA outside of the HMI field.

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CHAPITRE 3

DOES EXPLICIT CATEGORIZATION TAXONOMY FACILITATE PERFORMING GOAL-DIRECTED TASK ANALYSIS?

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3.1 Abstract

Situation awareness (SA) is an important factor that affects the performance of operators who work in complex environments. SA is defined as the perception of elements in an environment (level 1), understanding their meaning (level 2), and the projection of their state into the future (level 3). The first step to assess SA is identifying its requirements, for which goal-directed task analysis (GDTA) is the recommended technique. GDTA is a type of cognitive task analysis that focuses on the goals that a human operator must achieve, and the information required to accomplish them. The result of GDTA is a list of information (SA elements) that are categorized into the three SA levels. However, GDTA-based studies typically categorize SA elements into the three SA levels without stating their categorization rules. Therefore, this study proposes a taxonomy to categorize SA elements obtained via GDTA into SA levels. First, we present the results of a systematic literature review (N = 87) to gain insight into how analysts apply their classification criteria. Then, we propose a categorization taxonomy based on the ISO 15939 standard. To validate the proposed taxonomy, we analyze a subset of GDTA

results in two cases, and the results of the analysis show that the proposed categorization rules are applicable to the two analyzed cases.

3.2 Introduction

The situation awareness (SA) theoretical model, as proposed by (Endsley, 1993), has caught the attention of researchers in the field of complex system design because it helps system designers to identify the information requirements that operators need to perform in complex and sensitive systems such as air traffic control (Endsley et Rodgers, 1997; Endsley et Rodgers, 1994) , military(Salmon et al., 2009), command and control (Stanton et al., 2009), and nuclear and maritime transport (Shephard, 2016). The better the quality of SA, the greater the likelihood of making a good decision (Endsley, 1995b).

Goal-Directed Task Analysis (GDTA) is the most widely used technique to identify SA requirements. It is a form of cognitive task analysis that focuses on 1) the goals to be achieved by the human operator and 2) the information requirements that are needed to make appropriate decisions. GDTA generates a list of requirements (SA elements) that are categorized into three levels of SA: perception, comprehension, and projection (Endsley et Jones, 2012).
Endsley & Jones (2012) provide a list of tips aiming to facilitate the creation of a GDTA. They suggest not to spend too much time trying to assign a SA level to a SA element since what is important is gathering all information needs and how this information will be used. In other words, the conceptual nature of SA level definitions is more of an aid than a concrete rule. Thus, the same SA element can be assigned to a particular SA level by one analyst and to another SA level by another analyst.

This can create a few problems in light of the three steps of SA-oriented design (Endsley et Jones, 2012). Regarding SA requirements, people can waste valuable time arguing at which SA level should a particular SA element be assigned to. Regarding SA design, a systems designer could choose a visual component representing a specific SA element assigned to a certain SA level while the SA element should have been assigned to another SA level requiring a different visual component. Finally, regarding SA measurements, analyzing test results in order to see how to improve SA design would prove difficult since problems would not be assigned to the correct SA level.

Therefore, the purpose of this paper is to propose a SA categorization taxonomy that systematically categorizes SA elements into SA levels based on the ISO 15939 standard (ISO :15939, 2017). The present paper is organized as follows. First, we present the SA model and GDTA. Second, we present the method and the results of the systematic literature review (SLR) that we conducted to gain insight into how GDTA studies applied GDTA principles. Third, we present and explain our categorization taxonomy. Lastly, discussion, conclusion and future work are presented.

3.3 The situation awareness

Figure 1 presents the SA theoretical model (Endsley, 1995b). It consists of two steps. The first one is achieving SA. To do so, an operator must: perceive the elements of the environment, comprehend their significance in light of a pertinent goal, and project their status in the near future (Endsley, 1995b). The three levels feed into one another, meaning that an operator can achieve level 2 and level 3 SA without perceiving all the elements at level 1 SA (Endsley, 2015). This is represented in figure 1 by the nested boxes for each SA level and the bidirectional arrows connecting them.

The second step, decision, consists of choosing the appropriate actions to implement the desired change in the environment in order to achieve a specific goal. Unlike SA and decision-making, which are internal to the person, actions modify the external environment. The next subsection will present the SA levels in detail.

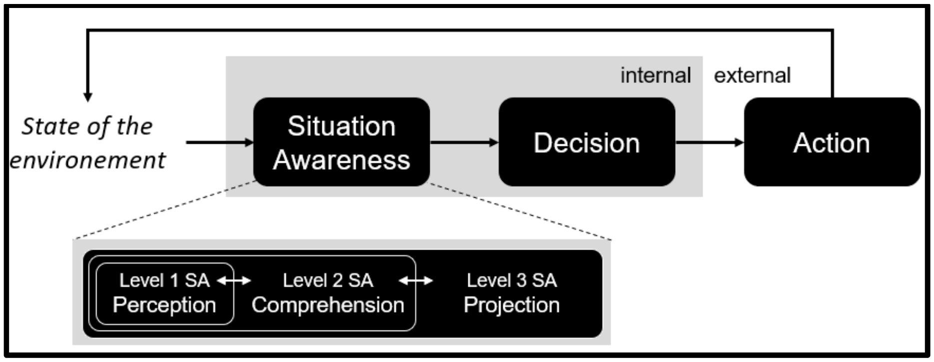

Figure 3.1 The situation awareness theoretical model taken from Endsely (1995b)

3.3.1 Level 1 SA (perception)

At this level, the operators perceive the status and the attributes of relevant elements around them (Endsley, 1995b). The expression “relevant elements” refers to the essential elements the system operators need to perceive in a particular situation (Endsley, 1995b). Otherwise, system operators will concentrate on many useless or irrelevant elements, which will decrease their situation awareness (Endsley, 1995b). To clarify the idea, we will take a concrete example from a study conducted (Endsley et Rodgers, 1997), which describes an experience in an air traffic control domain and is based on creating air traffic scenarios using simulators. The air traffic controller’s job is to understand the situation presented during the scenario in order to make favorable routing decisions. To achieve level 1 SA, the air traffic controller should perceive relevant elements of the simulated environment, including the attributes (identity, airspeed, direction, altitude) of the aircrafts showed in the display in front of them. Therefore, they need to direct their attention to perceiving only the attributes of the displayed aircrafts, and disregard irrelevant elements (the state of the sky, clouds, and mountain heights) as it can burden their working memory and consequently decrease their SA (Endsley et Rodgers, 1994)
.

3.3.2 Level 2 SA (comprehension)

At this level, system operators seek to comprehend the meaning of the perceived elements in a volume of time and space (Endsley, 1995b). That is, they need to integrate the elements perceived at level 1 to form a holistic picture of the environment and extract the meanings that are useful to their purpose. For example, if the goal is to pass safely close to a hostile plane, the operator should combine the perceived elements at level 1 SA (the airspeed, altitude and direction of the other plane) to be able to judge if the other plane is in attack position or not (level 2). However, if the goal is to pass safely close to an allied plane, the operator should combine the same level 1 SA elements to assess if a collision is to occur between two aircrafts. The operator doesn't need to focus on attack position.

3.3.3 Level 3 SA (projection)

At this level, system operators will be able to project the future state of the perceived elements into the near future (Endsley, 1995b) This projection is based on the knowledge of the status and the dynamics of perceived elements and comprehension of the situation. Explicitly, this projection is based on the combination of elements perceived at level 1 SA and their meaning at level 2 SA (Endsley, 1995b). Returning to our example, at level 3 SA, the air traffic controllers should predict if another aircraft will violate the rules in the near future based on the elements perceived at level 1 SA (direction, altitude and the speed of the other aircraft) and on their meaning (level 2 SA). Also, the air traffic controllers should be able to determine the available airspace to make routing decisions. This projection allows the operators to understand what is going on around them and consequently allows them to make decisions (Endsley, 1995b).

3.4 SA achieving

Expertise or long-term memory stores play a vital role in developing SA and decision making. Expert operators are less likely to be affected by the quantity of information compared to novice experts. Experts rely on long-term memory to overcome the shortage in working memory and understand the situation by associating it with a known mental model (Endsley, 1995b). This understanding allows them to identify the course of action that suits the situation. Novices, however, have incomplete mental models that allow them to understand the situation; they must make a considerable amount of effort to understand the situation and make decisions, which increases the load on their working memory.

Because system operators, experts or novices, receive a huge amount of information, relevant as well as irrelevant, that may needlessly burden their working memory and therefore negatively impact SA, identification of the SA requirements is an important step. It is needed to design and evaluate complex and sensitive systems (Schraagen, Chipman et Shute, 2000; Stanton et al., 2009; Wilson et al., 2001; Zhang et al., 2002) that help to improve their capacity to satisfy the needs of the system user to achieve better SA during task performance. To do that, GDTA, a widely used analysis technique, is used to identify the SA requirements in a particular situation. The following section will present GDTA in details.

3.5 Goal directed task analysis

User-centered design is an iterative process involving analysis, design and evaluation activities (ISO, 2010). The evaluation consists of making sure that the designed system complies with requirements obtained from analysis. Thus, when designing a system to support SA, SA must be evaluated by adopting one of the available techniques such as physiological, subjective, or questionnaires (Endsley, 1995a). However, the preferred approach is the Situation Awareness Global Assessment Technique (SAGAT) (Endsley, 1995a; 2016). SAGAT is an objective technique that consists of simulating the system, suspending the simulation at random moments, and questioning the subjects on their perception of the situation. The questions are derived from the informational requirements at the three levels of SA. They are obtained from GDTA, which is the focus of this section.

Task analysis is performed to improve operator performance in workplaces (Gordon et Gill, 1997). It consists of describing the input, actions, output, performance conditions and proficiency requirements. In simple workplaces, a task requires a series of predetermined steps to be followed by the operator to achieve a goal. However, this is far from the case in dynamic and complex systems, where the tasks performed by humans consist of several interdependent steps that involve complex cognitive processes to make decisions concerning actions to be carried out to achieve a specific goal (Crandall et Hoffman, 2013; Gordon et Gill, 1997). As a result, a cognitive task analysis (CTA) is used to capture how people make decisions to perform complex tasks (Gordon et Gill, 1997) and how they react under the pressure of time, risk, and in light of uncertain and incomplete information(Crandall et Hoffman, 2013). The importance of CTA lies in its ability to identify the challenges and cognitive requirements the operator needs to perform complex tasks (Crandall et Hoffman, 2013). Therefore, CTA has promoted the development of effective solutions in many domains such as technology, training programs, workplace design, and organizational challenge (Schraagen, Chipman et Shute, 2000). GDTA is a form of CTA (Endsley, 1993).

SA requirements are usually obtained through unstructured interviews with domain experts (Endsley and Jones, 2012). GDTA consists of four steps, (Endsley and Jones, 2012). To clarify each step, we will use an example from (Strater et al., 2001):

1) Identifying goals. The first step aims at identifying goals that system operators must achieve. There is a difference between a goal and a task. A goal is an overarching objective that system operators must achieve. A task is what system operators do to reach their goal and it consists of a series of predetermined steps to be followed by the operators (Gordon et Gill, 1997). For example, “predict enemy threat” is a goal in a military situation (Strater et al., 2001).

2) Identifying sub-goals. The second step aims at identifying the sub-goals necessary for meeting each of the goals identified in the first step. For example, the goal “predicts enemy threat” can be divided into many sub-goals situation (Strater et al., 2001) like “project enemy behavior,” “avoid danger areas” and “utilize available cover and concealment.”

3) Identifying decisions. The third step aims at identifying the decisions to be made by system operators. In a GDTA, decisions are not directly identified. Instead, for each sub-goal, a set questions whose answers will guide decisions are identified. For example, two decisions can be identified for the sub-goal "project enemy behavior:" 1) what is the most likely course of action of the enemy? 2) What is the most dangerous one?

4) Information categorization into SA levels. The fourth step aims at specifying which information is needed at each SA level to answer every decision/question identified at step 3. Hence, the result of the GDTA is a list of information classified into three SA levels. Sometimes, the same information serves to accomplish more than one decision. Figure 3.2 shows a part of the result of GDTA analysis of the goal: "Predict enemy threat".

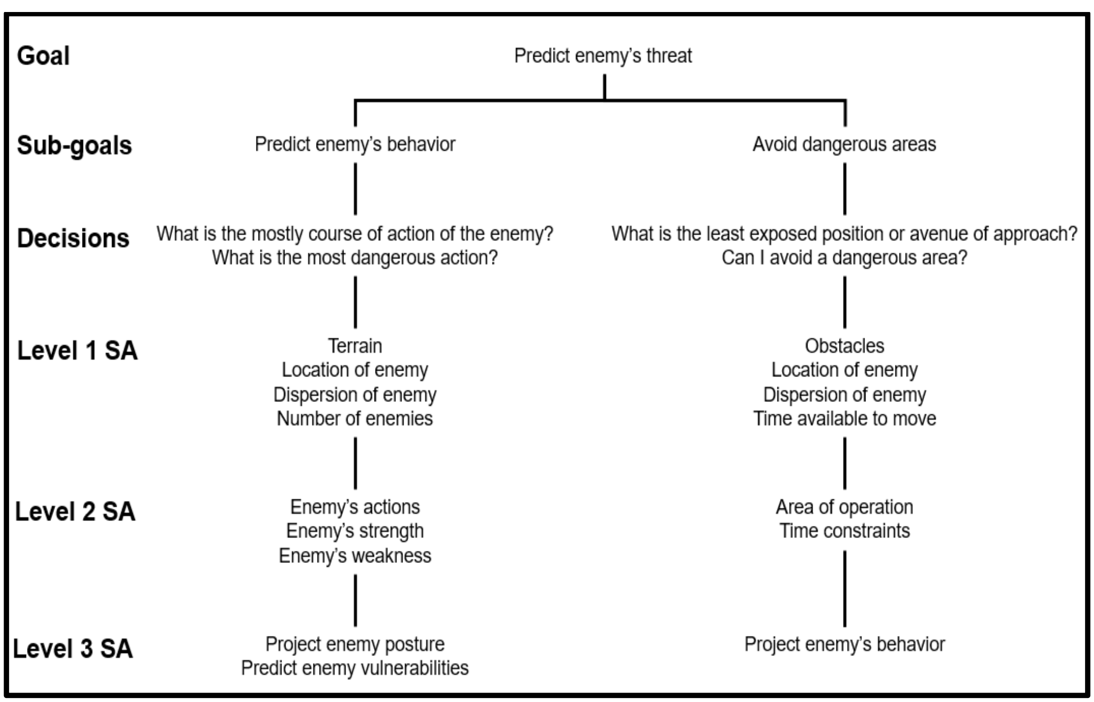

Figure 3.2 A part of the result of GDTA analysis of the goal "predict enemy threat"

However, what is less clear in the literature is how analysts classify information at each SA level when performing a GDTA. To fill this gap, we conducted a systematic research review (SLR) to answer the following question: How do analysts categorize information at the three levels of SA when performing a GDTA?

3.6 Research design

The purpose of a systematic literature review (SLR) is to identify, evaluate, and interpret research papers relevant to a particular research question (Hannes, Petry et Heyvaert, 2018). Based on the recommendations (Hannes, Petry et Heyvaert, 2018; Kitchenham, 2004) regarding the adoption of a SLR, a predetermined protocol is created for selection and decision-making criteria that would facilitate answering the research question. This protocol may ensure a systematic search strategy.

3.6.1 Data collection: Search Strategy and Inclusion Criteria

To ensure that most papers that contribute to the classification of information at different SA levels are covered, we followed three steps in our search. First, we reviewed the original GDTA paper (Endsley, 1993) and all subsequent papers (Bolstad , 2001; Endsley, 1995a; 2000a; 2015; 2016; Jones , Connors et Endsley, 2011; Strater et al., 2001) by the same author (Endsley), from 1993 to 2019. The objective of this step was to look for any categorization rules proposed in these papers. Second, we explored large databases such as Compendex, Scopus, Web of Science, Inspec and Knovel. Among the chosen databases, there were specialized databases in engineering (Compendex, Inspec, Knovel) and multidisciplinary databases (Web of Science, Scopus) which have been adopted by universities. Third, the SAGE database was additionally searched to ensure that we did not miss any paper that has proposed a categorization method. The rationale for choosing SAGE is that it publishes more than 1,000 journals, more than 800 books per year, reference works, and electronic products covering business, humanities, social sciences, sciences, technology and medicine (Sage, 2019). Our goal was to investigate if there are papers that propose classification criteria during the application of GTDA. Therefore, we searched for “goal-directed task analysis” or “goal directed task analysis” in the title, abstract and keywords. Table 3.1 shows the number of papers returned by each request.

Table 3.1 Paper distribution by source

Sources	**Number of papers**	**Inclusion criteria**
Google Scholar	66	“Goal-Directed Task Analysis” or “Goal Directed Task Analysis” in the main document and Endsley in the authors’ names.
Web of Science	13	“Goal-Directed Task Analysis” or “Goal Directed Task Analysis” term in the subject
Scopus	31	“Goal-Directed Task Analysis” or “Goal Directed Task Analysis” in the title, abstract, or keywords.
Engineering Village (Compendex, Inspec, Knovel)	37	“Goal—Directed Task Analysis” term in the title, abstract, or keywords
Sage journals	10	“Goal-Directed Task Analysis” or “Goal Directed Task Analysis” in the title, abstract or keywords

Out of 154 papers, 59 of them were duplicated and 10 were rejected because their electronic versions are not accessible. Finally, 87 papers were selected for further examination.

3.6.2 Data analysis and results

To collect data about GDTA application methods, we carefully analyzed the selected papers by taking notes on how SA requirements were categorized into the SA levels. The results suggested that GDTA technique is applied in many countries and domains in the last 27 years by many researchers/authors. Figures 3.3, 3.4, 3.5, and 3.6 present the scope of GDTA application. Figure 3.3 illustrates that the 87 selected papers span between 1993 and 2019.

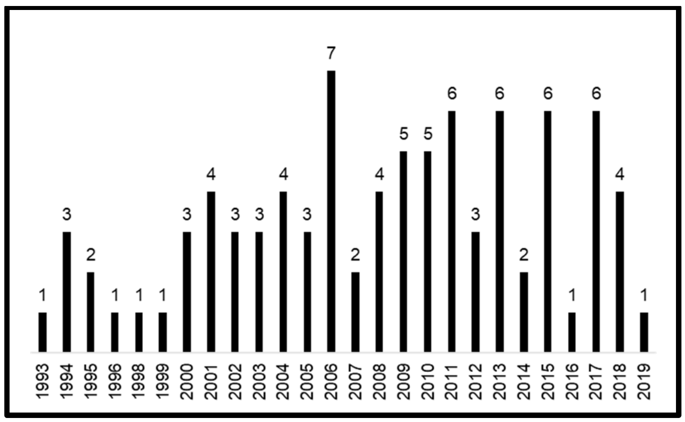

Figure. 3.3. Paper Distribution by Publication Year

Figure 3.4 shows the domains in which GDTA was applied for the 87 papers.

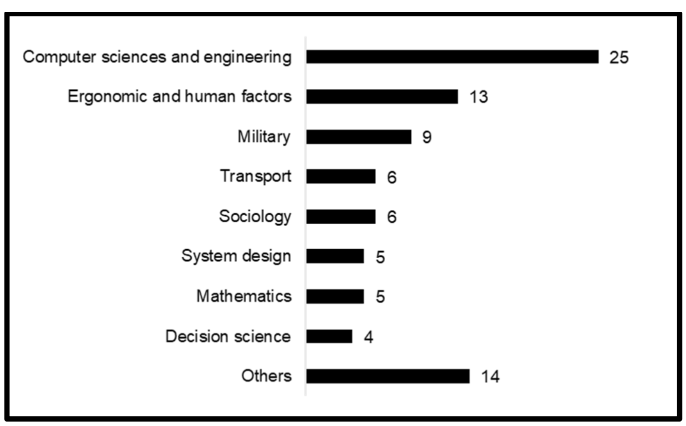

Figure 3.4. Papers' distribution by domain

Figure 3.5 presents the authors of the 87 papers. Many papers have more than one author. The "others" category regroups all authors who have been counted only once.

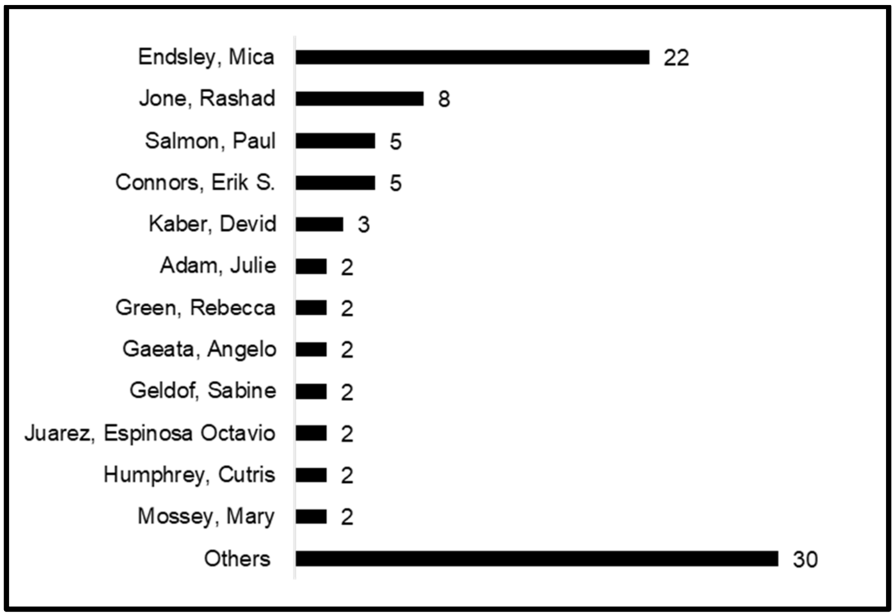

Figure 3.5 Paper distribution by author

Figure 3.6 presents author's country stated on the paper.

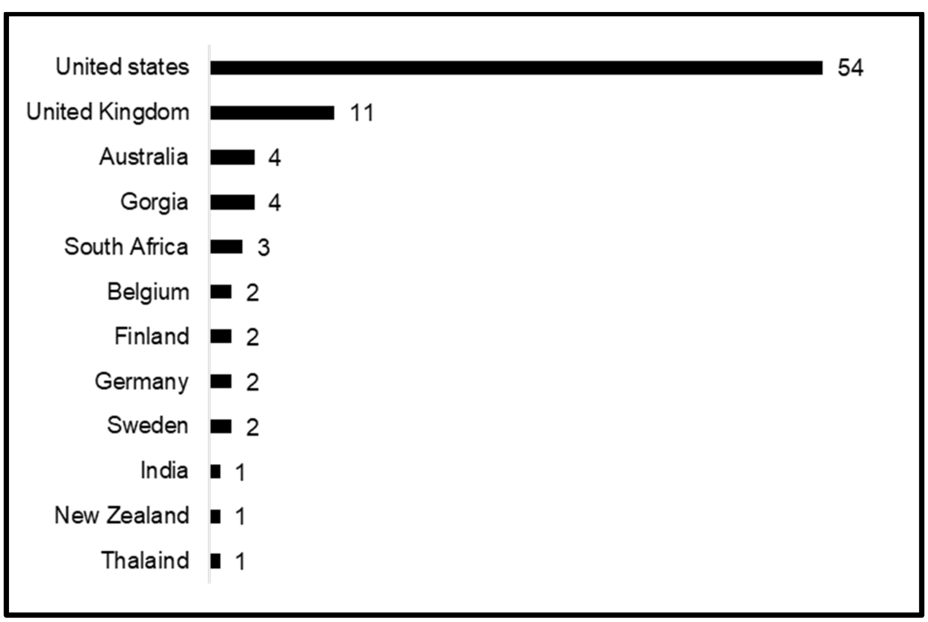

Figure 3.6 Paper distribution by countries

The results suggested that the consulted papers discussed GDTA or presented the results of the GDTA analysis based on the generic definition of SA levels of Endsley (Endsley, 1993; Endsley and Jones, 2012) without presenting how the SA elements were categorized at each level and how the boundary between levels was established. For example, Endsley (Endsley, 1993) presented and applied GDTA to determine the SA requirements of an air-to-air combat fighter operator. This study highlighted the importance of GDTA as a technique that helps create a holistic list of SA requirements in a particular situation. However, it did not provide any rules/steps to categorize SA elements at the three levels of SA. Endsley and Rodgers (Endsley et Rodgers, 1994) have applied the GDTA and provided a list of SA elements without providing rules to categorize SA elements at each level. Wright (Wright , Taekman et Endsley, 2004) in the domain of medicine, and Bolstad (Bolstad, 2001) in the domain of driving simulator have applied the GDTA without mentioning any rule/taxonomy to categorize SA elements at the three levels of SA. The same applies for other studies such as (Endsley et Connors , 2014; Humphrey et Adams, 2011; Irizarry et Gheisari, 2013; Orique et Despins, 2018; Sharma, Nazir et Ernstsen, 2019; Sitterding et al., 2014; Yang, Prasanna et King, 2015). These studies have applied GDTA without proposing any rules or taxonomy to categorize SA elements.

Moreover, we detected some ambiguity in GDTA application in some studies. In military, situation (Strater et al., 2001) has applied the GDTA to identify the SA requirements of leading platoon in military situations. The study provided a list of requirements which contains ambiguously classified requirements. The requirement “enemy combat power” is placed at level 3 SA and the requirement “enemy strength” is placed at level 2 SA without providing any justification that permits the analysts to distinguish the difference in levels between these two requirements. Other studies, (Jones, Connors et Endsley, 2011) and (Wright, Taekman et Endsley, 2004), tried to redefine the SA elements at SA levels, but their definitions were ambiguous and were not based on any theory. For example, Jones et al. (Jones, Connors et Endsley, 2011) defined the level 1 SA elements as "User’s information data needs" which is an ambiguous expression and does not allow the analyst to clearly identify what is the nature of the information that is needed. This same study defined SA Level 2 information as "Information to be combined to form the needed comprehension". In fact, this definition does not allow the analyst to understand what information needs combination and based on what criterion. The same weakness is detected in. (Wright, Taekman et Endsley, 2004) states that "[level 2 SA] goes beyond simply being aware of the elements that are present". In fact, this statement neither provides a definition of the word "aware", nor provides any explanation of the expression “Goes beyond”.

Our observations are in line with (Endsley, 2015) who stated, “in fact, most of my experience in working with experts in a wide variety of fields shows that their perceptions, comprehensions, and projections are fairly tightly integrated, as would be predicted by the mental models that underlay them.”. It can be concluded that the GDTA categorization process looks like a black box or a mystery machine that receives input and generates classified information into the SA levels without any explanation of the classification criteria.

3.6.3 Rational and scope of the research

Based on the results of our review, we concluded that there is no taxonomy to categorize the SA elements at SA levels. Although Endsley and Jones (Endsley and Jones, 2016) stated that there is no need to get too hung up delineating the different SA levels as they are not concrete, black and white items, we believe that it may be useful to have a clear taxonomy to categorize the SA element into SA levels for three reasons.

First, the studies that applied GDTA do not have a clear understanding of the characteristics of the SA elements at each level. This fact is manifested in many studies that provided ambiguous definitions of the SA elements at SA levels or ambiguous categorization of SA elements (Jones, Connors et Endsley, 2011; Strater et al., 2001; Wright, Taekman et Endsley, 2004).

Second, the categorization process of SA elements is a complex process and it is time- and effort-consuming. Thus, providing a structured way to categorize SA elements may reduce the mental load and guide the operators to process information faster and more systematically. To illustrate the complexity of the categorization process, we recall the previous example from situation (Strater et al., 2001) where one sub-goal "Project enemy behavior" needs more than 30 SA elements to be categorized. Table 3.2 illustrates a sub-set of categorized SA elements.

Table 3.2 SA requirements categorized by levels

Level 1 of SA requirements	**Level 2 of SA requirements**	**Level 3 of SA requirements**
Mechanical entry points Explosive entry points Rubble Mud Booby traps Areas of damage Severity of damage Light level available Building vantage points Windows Doorways Rooftops Vegetation Obstacles	Enemy actions Enemy strengths/weaknesses Probability of enemy contact Areas of cover & concealment Exposure areas Enemy LP/OP locations Type of terrain Routes of ingress & egress Fortifications Day/night Features Construction type Conditions Building accessibility	Project enemy posture Enemy vulnerabilities Projected impact of terrain Effects of terrain on communications Estimated time required for movement Projected safety of routes Projected physical requirements of route Projected mental requirements of route

Third, the goal of GDTA is to provide a list of SA requirements that will be translated later into features to design systems that provide a high level of situation awareness (Endsley and Jones, 2012). The SA requirements list is used later to evaluate whether the designed system meets the needs of its users to support them in building good SA. If not, the system should be improved. To accomplish this goal, analysts should identify at which SA level the weakness/error has occurred (e.g., perception, understanding or projection level) to identify what aspect of the system should be improved because every breakdown requires a different type of intervention. As stated by (Wickens, 2008) "each SA level breakdown may have very different consequences for addressing them, through training or system design. For example, a breakdown of Level 1 SA would lead to the design of better alerts. A breakdown of Level 3 SA would lead to incorporation of predictive displays". As in the example of the airplane crash of the AF 447, the incident is directly linked to SA (Salmon, Walker et Stanton, 2016). No matter whether the failure occurred at level 1 (lack/interruption of the information supply) or level 2 (lack of mental models and experience to comprehend the situation), this incident suggests the need to find a structured way to identify the source of the SA weakness in the system. Even Endsley (Endsley, 1995b) attempted to categorize the levels of errors when she stated that seventy-two percent (72%) of SA errors (failure to correctly perceive some pieces of information in the situation) were level 1 SA errors. Twenty-two percent (22%) of the errors (the data was perceived but not integrated or comprehended correctly) were at Level 2 SA. Six percent (6%) of the errors (a failure to properly project the near future based on the aircrew's understanding of the situation) were at Level 3 SA.

For the above-mentioned reasons, finding a structured way to guide the analyst to categorize SA elements seems to be a valuable contribution to the GDTA practitioners and researchers. The reason is that experts in the fields produce an uncategorized list of SA requirements based on a cycle of repeated interviews and questionnaires. The analyst, then, returns several times to the uncategorized SA list to categorize it situation (Strater et al., 2001).

This process is linked to structural thinking which is not a new concept as it has been applied in several fields, especially in the field of system design for more than 40 years years (Ross et Schoman Jr, 1976). Well-structured models combined with a well-defined analysis process provides a strong foundation for actual system designs years (Ross et Schoman Jr, 1976) as they afford a structured approach to the development and evaluation process (Semmens, France et Docker, 1992). In this vein, we build on the structured model design, such as ISO 15939 (ISO :15939, 2017), to systematically categorize the SA requirements of a system. In the following sections, we describe our categorization taxonomy, based on ISO 15939 standard, that aims to guide the analysts to structurally categorize non-categorized SA elements that are already identified by domain experts during the application of GDTA. In other words, our taxonomy aims to provide characteristics of SA elements at each SA level. However, the identification of SA requirements and the resolution of the SA weakness is outside the scope of our study.

3.7 The proposed taxonomy

As mentioned previously, by analyzing the studies that discussed or applied GDTA, we found that there are no studies that have presented explicit rules for classifying requirements at the three SA levels. To address this problem, we propose to use the ISO 15939 standard, which is an example of a structured model. In the next sub-section, the ISO 15939 standard will be presented. Then, the link between the ISO 15939 and the situation awareness model will be illustrated

3.7.1 ISO 15939

ISO 15939 (ISO :15939, 2017) is a standard that describes all the activities needed to initiate and evaluate a measurement process. ISO 15939 provides a model that guides the planning of a measurement process by defining the activities required to identify the necessary measures, perform the measurement, and evaluate the results as well as the measurement process. It can be applied in the fields of system and software engineering and management (ISO :15939, 2017). The model provided by ISO 15939 is a generic model that is not specified to be applied to a specific organization. It does not impose measures, methods or techniques. Model users are responsible for choosing the right measures.

3.7.1.1 Activities and output of ISO 15939 information model

The measurement process aims at producing information the decision makers need to be able to make a decision. The information produced is called an information product. To obtain the information product, ISO 15939 describes a series of activities that start with measure collection and end up with producing the information product. Figure 3.7 shows the activities (oval) and the outputs (rectangle) of every activity from the bottom to the top. The outputs of the lower activities are the inputs for the upper ones. In the next section, we will explain the output of every activity.

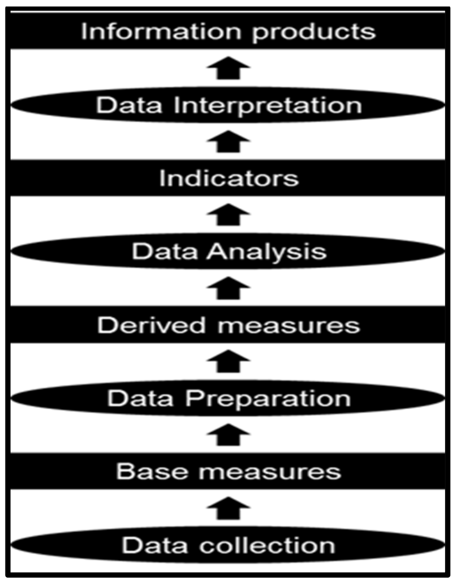

Fig. 3.7 The Activities of the
ISO 15939 Information Model

The outputs of ISO 15939 activities (from bottom up) are:

1) The Base measures

A base measure is the product of the first activity (data collection). A base measure is a value that quantifies or qualifies an attribute of a particular entity in a specific scale (ISO :15939, 2017, Abran, Desharnais et Cuadrado-Gallego, 2012)). The scale can be nominal, ordinal, interval or a ratio (ISO :15939, 2017). For example, in the context of a software project, the size of a project and the effort (in the number of work hours) needed to finalize the project are two attributes of the entity project. The effort quantifies the quantity of work (in the number of work hours) required to finalize the project and the size quantifies the size of the project (in function points number).

2) Derived measures

A derived measure is the output of the second activity (data preparation). A derived measure is defined as a function of two or more values of base measures (ISO :15939, 2017, Abran, Desharnais et Cuadrado-Gallego, 2012). It is important to keep in mind that the main difference between a derived measure and base measure is that a base measure is a value that can be observed directly, and a derived measure is a value that needs further processing from the base measures no matter whether the processing is made by humans or automatically. To clarify the idea, we will present the example of velocity taken from (Abran et al., 2012) where the velocity is defined as a derived measure despite of the fact that it is provided automatically by the system that:

a. captures both base measures (distance and time)
b. divides the base measures to produce a ratio (distance/time) to represent the velocity concept, and
c. displays the measurement results.

3) Indicators

An indicator is the output of the third activity (data analysis). An indicator is the result of analyzing base and/or derived measures according to a particular analysis model. It is an assessment associated with a specific goal. In other words, unlike the value of a derived measure that can be calculated independently from a goal, an indicator should be linked to a specific goal. For example, if the goal is to respect the speed limit, by analyzing the speed of a car based on the current rules, we can obtain an indicator of whether the actual speed conforms or not to the speed limit. This indicator doesn't exist independently of the goal (respect the speed limit) unlike the speed that can be calculated independently of the goal.

4) Information products

Information product is the output of the fourth activity (data interpretation). An information product is the result of the interpretation of indicators based on the vision (decision criteria, targeted value….) of the organization (Abran, Desharnais et Cuadrado-Gallego, 2012). The interpretation produces the information products, which the decision makers need to make decisions. Since it is not mentioned in the definition that the information product is about future exclusively, it may contain information about the current and the future situation. In the example of the software project, the analysis activity produced an indicator that provided an estimate of the effort required to complete the project. During the interpretation activity, this indicator is interpreted according to the company's vision to determine if the project in question meets the organization's criteria (its budget, time, etc.). This interpretation is the information that decision makers need to support the decision-making process (accept, modify, or reject the project).

3.7.2 Mapping between ISO 15939 and SA levels

Figure 3.8 presents the taxonomy that categorizes the SA elements at each SA level based on the outputs of ISO 15939 information model.

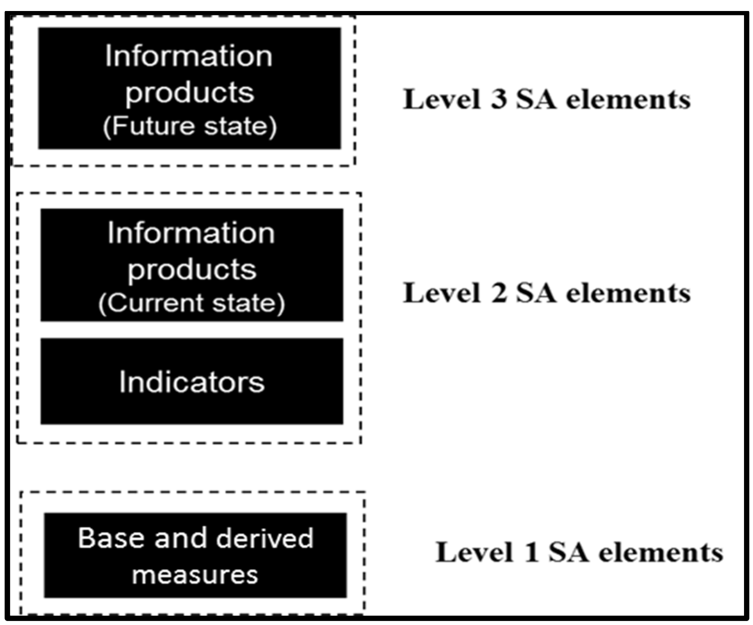

Figure. 3.8. The taxonomy to categorize SA elements

It is important to distinguish between SA levels and SA elements. SA level is a mental state; whereas, SA elements are the information required to achieve this level**.** The proposed taxonomy presents the characteristics of elements at each SA level and presents how the elements move from level to another.

1) Level 1 SA elements

At level 1 SA, humans perceive the status, attributes, and dynamics of relevant objects in the environment (Endsley, 1995b). It is important to distinguish between an object and its attributes. An object is an entity (car, aircraft, terrain) and the attribute to be perceived is a feature of this entity (speed, color, altitude). Based on this description, the information to be captured at level 1 SA corresponds to the base and derived measures in ISO 15939.

A base measure captures the value of an attribute which is a property or characteristic of an entity that can be captured by human or automated means. The captured value can be quantitative (number of soldiers, altitude of a plane) or qualitative (type of a weapon, color of a care) (ISO 15939, 2017). For example, a terrain is not a measure, the terrain is an object. The attributes of the terrain like the nature of the terrain (e.g. rocky, sandy) are the base measures or the level 1 SA that qualifies the nature of the object terrain. The perceived object should be connected to a specific goal and consequently, the base measures must be collected based on specific information needs to be able to achieve the specific goal (ISO :15939, 2017).

A derived measure is defined as a function of two or more values of base measures (ISO :15939, 2017). Although a derived measure is the result of processing of two or more value of level 1 SA elements, it does not belong to level 2 SA. It still belongs to level 1 SA mainly because the derived measure is a value that is calculated independently of the goal and does not provide any understanding of the situation without further analysis. For instance, the airspeed is an example of a derived measure since it is the division of distance by time and its value is not dependent on a goal (e.g. if the speed of an aircraft is 50 km/s, this value doesn`t change whatever the goal). Also, this value does not provide any understanding of the situation without a further analysis (e.g. to understand if the speed is dangerous or not, it needs further analysis based on a specific reference). Once the base and derived measures are ready to be analyzed/processed understand the situation based on the goal of the operator, we move to level 2 SA

2) Level 2 SA elements

To achieve level 2 SA, the operators analyze the level 1 SA elements to obtain an assessment of the aspects of the situation that is directly related to the targeted goal (Endsley, 1995b). Then, the operators should interpret the obtained assessments to understand the current state of the situation. In other words, to achieve the level 2 SA, the operator should:

a. Identify the needed indicator based on decision criteria that is related to the goal. Decision criteria are numerical thresholds or targets used to determine the values/information that are important to make decisions related to the goal.
b. Obtain the values of the indicators based on analysis that requires analysis model, an algorithm or calculation combining one or more base and/or derived measures with the associated decision criteria (Abran, Desharnais et Cuadrado-Gallego, 2012)
c. Interpret the indicators based on adequate mental model/reference to understand the actual state of the situation. This interpretation is a cognitive process that produces information products about the current state of the situation. As mentioned previously, the information product is the information that aims to satisfy the information needs of a decision maker which is a basis for a decision-making process (ISO :15939, 2017, Abran, Desharnais et Cuadrado-Gallego, 2012)

It is important to note that the comprehension (level 2 SA) of level 1 SA elements (based measures) changes based on the situation and the goal. For example, the number of soldiers is a base measure that quantifies the soldiers and, the nature of a terrain (i.e., sandy, rocky) is a base measure that qualifies the terrain. The meaning (level 2 SA elements) of these measures (number of the soldiers and nature of the terrain) is obtained by analyzing them based on a specific analysis model (e.g. military protocol) and the goal. For example, the sandy terrain with a few soldiers can signify that the situation is suitable if the goal is to attack the enemy, but it is not suitable if the goal is to defend an attack.

The confidence of information, which is an evaluation of the accuracy of information received based on its source or reliability (Endsley, 1995b), is an indicator. It is categorized as an indicator because it is an evaluation of the accuracy of the perceived information. This accuracy is obtained by analyzing the source reliability based on the prior operator's knowledge (model). Consequently, the confidence of information is a level 2 SA element.
Once the information product about the current state are collected, the operator can analyze them to project the future state of the situation. To do that, he/she moves to level 3 SA.

At level 3 SA, the operator needs information that assess the future state of the perceived elements in order to make a proper decision. To obtain this information, it is necessary to interpret the data obtained from the previous level according to a mental/reference model (Endsley, 1995c). This model contains a set of mechanism that allows the operator to interpret the data and predict the future state to support the decision-making process (Endsley, 1995b). Thus, SA level 3 elements are information products that describe the potential state of the perceived elements in the near future, which allows the operator to make a decision.

To illustrate how the taxonomy works, we will take an example of a pedestrian who has the goal of "crossing the street safely". The pedestrian must assess the state of the nearest car to assess if it is safe to take a decision of crossing the street. First, he should collect the relevant information about the car. The relevant pieces of information are the base measures (i.e. position and the direction of the car) and the derived measure (speed of the car). The value of the speed of the car is obtained by processing two level 1 SA elements (time divided by distance). However, speed remains a level 1 SA element as its value doesn't depend on the goal and doesn't change if the pedestrian changes his/her goal. Also, the speed of the car doesn't provide any assessment/understanding without further analysis. To do that, the pedestrian needs to move up to level 2 SA.

At level 2 SA, the pedestrian should assess the "safety of crossing road" before making any decision (stop or cross the road). Thus, the pedestrian should obtain two pieces of information: the direction of the car and the time the car needs to cross his/her path. The first is an indicator

that (dis)confirms that the car is directed towards the pedestrian and the second is a prediction of the time (this is an example where a level 3 SA element feeds a level 2 SA element). To identify the heading of the car, the pedestrian should analyze the position of the car (base measure) at multiple times. To predict the time the car needs to cross the road, the pedestrian should analyze the position and the speed of the car (base and derived measures) based on his experience (mental model that presents relationship between speed, distance, and time). Then, the pedestrian should interpret the obtained information (direction and time) based on their expertise (reference model) to assess if the car will hit them in the near future. Finally, he/she can assess the safety of crossing the road and make the appropriate decision.
Based on the above discussion, we can establish the following categorization guidelines:

Guideline 1: Level 1 SA elements are the base measures and the derived measures. The values of the measures of this level are the characteristics of the perceived object that are independent of the goal. In other words, the value of every measure doesn't change based on the goal or the operator (i.e. the color or the speed of a car keeps the same value whatever the goal or the operator).

Guideline 2: Level 2 SA elements are the indicators and, information products about the current situation. The elements of this level are pieces of information that is the result of the processing level 1 SA elements and sometimes the processing of level 3 SA elements. This information can be changed based on the goal. For example, the same road can be safe for a car driver with the goal to drive on the road and unsafe for a pedestrian who wants to cross the road. Here, the processing of the same information (i.e. position of the car, speed of the car) produces different assessments.

Guideline 3: Level 3 SA requirements are the Information products about the future situation. Elements of this level are pieces of information that assess the situation in the near future based on the goal. To obtain this information, it is necessary to interpret the data obtained from the level 2 SA according to a suitable analysis model that contains a set of mechanisms that allows the operator to interpret the data and predict the future state (ISO :15939, 2017, Abran, Desharnais et Cuadrado-Gallego, 2012)).

3.7.3 Validation of the taxonomy

To test the validity of our rules, we will analyze two applications of GDTA from the literature. The objective is to show that the application of our rules allows us to obtain the same results as the studies.

3.7.3.1 Case 1

Table 3.3 shows a subset of SA requirements to achieve the goal “avoid vertical confliction” taken from (Endsley et Rodgers, 1994). Table 3.4 shows the same SA requirements in ISO 15939 terms.

Table 3.3 subset of SA requirements of “avoid vertical confliction” goal

Level 1 SA	**Level 2 SA**	**Level 3 SA**
-Aircraft altitudes Rate change of the altitudes -Assigned altitudes -The vertical separation -The vertical separation rate change (increasing or decreasing	The conformance to required vertical separation	Project the vertical separation between the aircraft

“Altitude’’, “Assigned altitude”, “the vertical separation” and “Rate change of the altitudes” are level 1 SA elements. The altitude is an attribute of the entity aircraft, and a scale-based measure that captures the altitude of the aircraft. “Assigned altitude” are reference altitude to the pilot. “Altitude rate change” is a derived measure (based on multiple observation of the aircraft) that defines the vertical movement of the aircraft (ascending/descending). The “aircraft vertical separation” is a derived measure (obtained by applying a computational formula on the altitude of aircraft) and it doesn’t provide any understanding of the situation without further analysis.

To understand the present situation (move to level 2 SA), the pilot should apply an analysis model on the above base and derived measures (i.e., the altitude of the aircraft, the assigned altitude of aircraft, the "aircraft vertical separation") to assess the compliance of "the aircraft vertical separation" (level 2).

To project the future situation (move to level 3 SA), the pilot should project if the vertical separation will still be safe in the near future. To do that, he/she needs to interpret information (i.e., the derived measure "Altitude rate change" of every aircraft, the indicator "the vertical direction" of every aircraft) based on suitable reference model to predict if the vertical separation will be violated in the near future (level 3 information). This projection is an information product needed to satisfy the information needs of the operator to make decisions (increase/decrease the current altitude).

The above SA elements are categorized in Table 3.4 using ISO 15939 taxonomy.

Table 3.4 Subset of SA requirements of "avoid vertical confliction" goal by iso 159393 terms

ISO 15939 terms	Example
Base measures	Current altitude of own aircraft Current altitude of the second aircraft Assigned altitudes
Derived measure	The vertical separation The rate of change of the altitude The vertical direction of the aircraft (Ascending/descending)
Informtion product (level 2 /understanding)	The conformance to required vertical separation
Information product (level 3/projection)	The future vertical separation distance is obtained by interpreted the level 2 and level 1 information based on suitable reference model.

3.7.3.2 Case 2

Table 3.5 shows a subset of SA requirements to achieve the "Project enemy behavior" goal in a military situation taken from (Strater et al., 2001).

Table 3.5 A subset of SA requirements of
"project enemy behavior" goal

Level 1 SA	**Level 2 SA**	**Level 3 SA**
Location Dispersion Numbers Weapons Unit type Equipment	Enemy actions Enemy strengths Enemy weaknesses Enemy disposition Enemy intent Enemy objective Enemy composition	Anticipated enemy actions

We will analyze and present only a small subset of SA requirements in ISO terms due to the number of SA requirements. The attributes "location," "dispersion" and "numbers" are examples of level 1 SA requirements. They are attributes that capture the status of the soldiers and the weapons of the enemy. The level 2 SA requirements "enemy disposition" and "enemy composition" are two indicators obtained from the analysis of level 1 SA elements (e.g., number of soldiers and number of weapons). The interpretation of these indicators based on a specific model (The military rules) helps to understand the "enemy strength" and "enemy weaknesses". The interpretation is based on a reference model that contains values specified for the context or target values (for example, history that indicates the minimum number of soldiers and weapons required to make an attack).This element (anticipated enemy actions) is an information product that presents the potential actions of the enemy which the decision maker needs to make decision. The SA requirements are shown in ISO 15939 terms in Table 3.6.

Table 3.6 The subset of SA requirements of "project enemy behavior" goal in ISO 15939 terms

ISO term	Example
Base Measures	Numbers of people Number of weapons
Derived Measure	N/A
Indicator	enemy disposition enemy composition
Information product (level 2 /understanding)	enemy strengths enemy weaknesses
Information product (level 3/projection)	Anticipated enemy actions The obtained indicator will be interpreted to predict the potential actions of the enemy to be able to make decision.

3.8 Discussion

In this paper, we examined how analysts categorize information at the three levels of SA when performing a GDTA. Our results indicated that categorization phase of GDTA seems to be arbitrary and does not comply to any structural thinking models that would help analysts systematically categorize the SA elements into SA levels. To shed more light on this issue, we conducted a systematic literature review to get insight into how researchers categorize SA elements into SA levels when applying GDTA. The analysis of 87 GDTA papers indicated that each paper has applied GDTA without presenting any clear guidelines or explicit criteria to categorize SA requirements at each level. Put it differently, each paper has applied GDTA steps by identifying goals, sub-goals and decisions and, finally presenting a categorized list of SA requirements without reporting on how this process was applied. To address this caveat, we proposed a categorization taxonomy to categorize SA requirements at the three SA levels based on ISO 15939.

ISO 15939 permits analysts to categorize SA elements into SA levels in a structured way as it is a generic structural model. As we illustrated, it can be used to assign characteristics for SA elements that would determine to which SA level they belong. In other words, because ISO

159393 clearly describes all the activities required to collect, prepare, analyze and interpret the needed measures, it was used as a structural model to guide the categorization process of SA elements; more specifically, it provided a basis to guide analysts through the categorization process (categorizing SA elements into SA levels). The goal of the proposed categorization taxonomy is to serve as a valuable categorization guide of GDTA that is structured, capable of dealing with ambiguous cases, and technology-free.

First, our taxonomy provides a structured logic that transforms the categorization process from intuitive one based on the generic definitions of SA levels to more systematic categorization based on well-defined characteristics provided by ISO 15939, as illustrated in Figure 3.8. It also explains how the information at each level is processed to move up to the upper level (see Figure 3.8).

Second, our taxonomy is technology free. That is, the categorization of an element at any SA level remains the same whether the element is obtained directly by the operator, viewed on the display, or obtained from another person. For example, the altitude and the location of a perceived plane remain at level 1 SA element no matter what the source of the information is (collected by the operator's eyes, obtained from a display or announced by a microphone by another person). The same logic applies for the level 2 SA elements. For example, if level 2 information indicates that the plane is in attack position, it remains a level 2 element no matter how the information is obtained; from mental calculation of the operator or from alarm system.

3.9 Limitation and conclusion

The present paper has a limitation that should be acknowledged. The proposed guidelines are validated on two case studies only. More research is needed to validate whether it is possible to generalize the proposed classification rules. However, the contribution of the present paper is worth considering. First, on the conceptual level, this is the first paper, to our knowledge, that sheds light on the categorization taxonomy during GDTA application. Second, on the methodological level, we used the principles of the systematic literature review to answer the research question of the present paper. Finally, we proposed a categorization taxonomy to categorize SA requirements at each SA levels. The proposed taxonomy is based on a structured method to categorize SA elements into SA levels. The taxonomy also shows how to move from one level to another. It is characterized by being able to resolve ambiguous elements due to its structured model, i.e., although the taxonomy is presented from bottom up, the analyst can project to level 3 to assess the information needs that will guide them through the categorization process. The taxonomy is technology free as the information can be obtained from different sources: from analyst's mind, from a display system, or from any other external source.

The existence of explicit categorization taxonomy may facilitate the mission of analysts who analyze a huge amount of non-classified information obtained from unstructured interviews with domain experts, and then classify them into SA levels, which consumes a huge amount of time and effort situation (Strater et al., 2001). It may also open new avenues of research on how to systematically apply GDTA in various domains.

CHAPITRE 4

A SYSTEMATIC APPROCH TO PERFORM GOAL DIRECTED TASK ANALYSIS

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4.1 Abstract

Given the importance of the situation awareness (SA) in achieving goals and avoiding fatal errors, SA-oriented design has emerged as an approach to design human-machine systems that promote the SA of their operators. To design such systems, the first step is to create SA requirements—i.e., a list of SA elements—that will be translated later to design a promoting SA system. Goal-directed task analysis (GDTA) is a commonly used method for identifying SA requirements. However, GDTA has several shortcomings: it is broad, conceptual, and generic, and it is not clear from the literature how to perform GDTA in practice, that is, there are no explicit and systematic guidelines for performing GDTA. This shortfall may lead the SA analyst to create incomplete and/or erroneous SA requirements. This is problematic because those requirements will be adopted to design and evaluate a system that promotes SA and consequently, the incompleteness and errors in the list of SA elements will lead to design problems.

Therefore, the purpose of this paper is to design a method that guides GDTA practitioners in performing GDTA in explicit, systematic, and traceable steps. The proposed method was created and evaluated according to the design science research (DSR) approach.

4.2 Introduction

Due to the role machines play in everyday life, the field of Human–Machine Interaction (HMI) is flourishing exponentially. HMI focuses on communication and interaction between a human and a machine via a user interface (Ke et al., 2018). However, the design of HMI systems is affected by many important factors among which is situation awareness (SA). SA pertains to what is perceived, how these perceptions are comprehended and how events unfold given one's comprehension of these perceptions (Endsley, 1995b). SA consists of three levels: level 1 where system operators must perceive the status and attributes (e.g. color, speed, location) of relevant elements around them; level 2 where the operators must integrate the elements perceived at level 1 to form a holistic picture of the environment and extract the meanings required according to their goals; level 3 where the operators must project the state of the perceived elements into the near future based on their knowledge of the status and dynamics of the perceived elements and their comprehension of the situation (Endsley, 1995b).

The quality of a system operator’s SA is essential for the safe operation of human-machine systems as it affects the operators’ performance of the task (Endsley et Jones, 2012). In fact, many errors in human-machine systems are related to inadequate SA (Endsley et Jones, 2012; Eskandari, Dumont et Wang, 2015; Sharma, Nazir et Ernstsen, 2019). For example, in the maritime domain, SA-related problems account for about 71% of human errors (Sharma, Nazir et Ernstsen, 2019). In India, in 1984, more than 2,500 people died in an accident at the Union Carbide plant because of SA-related problems (Endsley et Jones, 2012). In the aeronautical domain, the AF 447 airplane crash was due to SA problems (Salmon, Walker et Stanton, 2016). More specifically, these errors and accidents were attributed to an inadequate provision of information that adversely affected system operators’ SA (Endsley et Jones, 2012; Eskandari, Dumont et Wang, 2015).

Given the importance of SA in complex dynamic systems, the SA-oriented design approach has emerged to help prevent such problems (Endsley et Jones, 2012). This is an approach that starts with a cognitive task analysis to uncover the SA requirements related to a domain and translates those requirements into a system design that promotes an adequate level of SA (Endsley et Jones, 2012). This model is used to improve the design of systems in various domains such as air traffic control (Endsley et Rodgers, 1997; Endsley et Rodgers, 1994), the military (Salmon et al., 2009), command and control (Stanton et al., 2009), nuclear power (Crichton et Flin, 2004), and maritime transport (Shephard, 2016). The SA-oriented design model consists of three phases: SA analysis, SA design, and SA measurement.

The design process starts with an analysis by the designers to determine the SA requirements of the artifact (SA analysis). Then, the design of the artifact is based on these identified SA elements (SA Design). Finally, the designed artifact is evaluated by measuring the SA of its users (SA measurement). The evaluation process determines whether the artifact will be deployed or go back to the SA design phase.

The present paper focuses on the first step only (SA analysis) where the analysts use Goal-Directed Task Analysis (GDTA) to identify the SA requirements (Endsley et Jones, 2012). GDTA consists of four steps: identifying the system operator`s goals;identifying sub-goals necessary for meeting each of the goals identified in the first step; identifying decisions to be made by system operators in the form of questions to be answered to achieve sub-goals; and identification of SA information that is needed at each SA level to answer every decision/question identified at step 3. However, the problem with the GDTA is that the technique offers generic guidelines that are not systematic or explicit enough for application purposes (Nasser-dine, Moïse et Lapalme, 2021). Thus, the present paper aims to fill this gap by proposing an explicit method to perform GDTA.

The rest of the paper follows the following structure: section 2 presents GDTA literature review, section 3 presents the problem statement and the objective of our research, section 4 presents the research methodology including the design and the evaluation of the proposed method. Finally, section 5 concludes the paper, presents its limitations and suggests directions for future work.

4.3 Related work

(Endsley, 1993) was a pioneer in proposing GDTA as a technique to analyze and identify the SA requirements of an air-to-air combat pilot. The importance of her study lies in the fact that it provided a technique for creating SA requirements, and it has been used as a reference in many GDTA studies. (Endsley, 1993) provided general steps to conduct a GDTA, including identifying the users' goals, identifying questions to answer to achieve each goal, and identifying SA requirements to answer these questions. The goals, decisions and SA requirements are proposed to be elicited from domain experts in unstructured interviews. However, the problem with the provided instructions is that they are incomplete. For example, the identifying characteristics of GDTA concepts (goal, SA requirements, etc.,) and instructions to illustrate the relationship between these concepts are not provided.

GDTA performance was pushed a step further by (Endsley et al., 2003; Endsley et Jones, 2016; Endsley et Jones, 2012) as they added more instructions for performing GDTA. For example, they provided instructions on the interview step (e.g., reading available documents about the domain, how to perform interviews, how to validate the goals list, etc.), and for identifying the decisions list (e.g. what is a decision, what is the form of the decision, etc.). However, the instructions for identifying the GDTA concepts and moving between steps were still generic and incomplete. For example, the study defined goals as "higher-order objectives essential to successful job performance." This definition of the goal is generic and doesn't provide the characteristics that allows the analyst to clearly identify what a goal is. Also, instructions on how to move from goals to sub-goals, and to identify sub-goals, are not provided. Additionally, the instructions for identifying SA requirements at different SA levels are incomplete. For example, the definition of level 1 SA requirements is "the status, attribute, and dynamic of relevant elements in the environment," which is not sufficient to properly identify the level 1 SA element.

As (Endsley, 1993) was used as a reference by subsequent GDTA studies (e.g., (Endsley et Rodgers, 1994; Kaber et al., 2006)), and (Endsley et al., 2003; Endsley et Jones, 2012) was used as a reference by other subsequent studies (e.g., (Irizarry et Gheisari, 2013; Jones, Connors et Endsley, 2011; Yang, Prasanna et King, 2015)); the subsequent studies shared the same shortfall; moreover, most of these studies applied GDTA in their domain without providing clear or complete instructions on how GDTA was performed.

For example, (Endsley et Rodgers, 1994) performed GDTA following (Endsley, 1993) to determine the SA requirements for air traffic control specialists. The contribution of their study was the addition of a supplementary step to facilitate the performance of GDTA. This added step consisted of subdividing each goal into the many sub-goals that are necessary to achieve it. However, the other GDTA steps were performed without any significant extension to facilitate the performing of these steps in practice. Also, although the study provided some examples of SA requirements at the three SA levels, the provided examples were specific to the domain of the study and are unlikely to be adopted as guidelines to perform GDTA in other domains.

(Kaber et al., 2006) performed GDTA to understand the SA requirements in the bio-pharmacology domain, to design interfaces that promote an adequate SA for their users. The study performed GDTA following the same guidelines provided by (Endsley, 1993) without mentioning instructions on how to perform GDTA. The study adopted (Endsley, 1995b) definitions of the three SA levels: level 1 SA: observation of the system and its environment; level 2 SA: comprehension of the system and environment relative to task goals; level 3 SA: prediction of future system and environment states. These definitions target the SA levels rather than their elements. Consequently, these definitions, as those in other studies, do not facilitate the performance of GDTA as they do not provide instructions for identifying SA requirements at each level.

(Jones, Connors et Endsley, 2011) followed (Endsley, 1993) to perform GDTA. Although this study mostly followed the instructions provided by (Endsley, 1993), it provided some instructions to help to define SA requirements at different levels. For example, the study defined level 1 SA elements as "User information data needs." However, this definition is not clear enough to allow the analyst to identify what is the nature of the information that is needed. Also, the study defined level 2 SA elements as “Information to be combined to form the needed comprehension.” However, this definition does not allow the analyst to identify what the needed information is and how to combine its pieces together.

(Irizarry et Gheisari, 2013) followed the steps provided by (Endsley et Jones, 2012) to perform GDTA. Therefore, their instructions to define SA requirements were incomplete as they did not report on how each step in GDTA was performed. For example, a level 2 SA element is defined as "[level 2 SA element] goes beyond simply being aware of the elements that are present." The meaning of the word "aware" in the statement is not clear, and consequently, not enough to identify the level 2 SA elements in practice. It can be concluded that this study has not provided more instructions than (Endsley et Jones, 2012) to facilitate GDTA performance.

The same problem occurred in a study (Humphrey et Adams, 2011) who performed GDTA based on the steps mentioned in (Endsley et al., 2003), and did not mention any additional instructions for performing GDTA.

Similarly, (Yang, Prasanna et King, 2015) followed the steps of (Endsley et Jones, 2012) to perform GDTA. The only step they added was identifying the sub-goals list by providing more instructions on how to do so. They proposed formulating questions that allow decomposing a high-level goal to practical sub-goals (e.g., how to achieve this goal? what tasks are necessary, etc.). The provided instructions are useful for identifying the sub-goals in a practical context. However, the other GDTA steps and concepts were not clearly identified.

Also, (Endsley et Connors, 2014) applied GDTA in a cybersecurity context to demonstrate its usefulness and provided some examples regarding the different levels of SA elements. However, the provided examples were domain-specific and are not enough to guide the analyst during the application of GDTA in other domains. Likewise, (Sharma, Nazir et Ernstsen, 2019) performed GDTA to identify SA requirements in the maritime domain to identify factors that affect an operator’s SA. Although Sharma et al.’s study provided examples of goals and SA elements at each level, their instructions are not sufficient to be used as guidelines to perform GDTA.

4.4 Problem Statement

It can be concluded from the above literature review that the steps for performing GDTA are broad, conceptual, and generic, which makes it difficult to apply them in practical contexts. The difficulty of applying GDTA in practical contexts may pose serious problems during the application of SA-oriented design models (Nasser-dine, Moïse et Lapalme, 2021). That is, during the SA analysis step, the goal of GDTA is to produce a list of SA requirements to design systems that provide an adequate situation awareness (Endsley et Jones, 2012). The incompleteness of GDTA instructions may lead to ambiguous or incomplete SA requirements lists, as seen in many studies. For example, (Strater et al., 2001) categorized the "enemy combat power" requirement at level 3 SA despite the fact that it is not at the projection level. Also, (Endsley et Rodgers, 1994) placed the requirement "projected time in airspace" at level 2 SA, which is not coherent with (Endsley, 1993) who states that the projection belongs to level 3 SA. Similarly, (Endsley et Rodgers, 1997) placed the SA requirement "Fuel sufficiency" at level 2 SA. This is an ambiguous categorization since fuel sufficiency also depends on the projection of how far the vehicle needs to travel and how much fuel will be burned at what rate on the trip. The question here is whether this element belongs to level 2 or level 3.

In addition, ambiguities or errors in a SA requirements list may cause: problems in the system design, since this requirements list will be used to identify the features we need to design an effective system; and erroneous evaluation of the designed system because the same SA requirements list will be used to evaluate if the designed system meets the needs of its users and support them to build an adequate SA. That means that the analysts will need to identify at which SA level the breakdown has occurred (whether at perception, comprehension or projection level) in order to identify what aspect of the system should be improved, as every SA breakdown needs a different type of intervention (Wickens, 2008).

Based on the above-mentioned reasons, designing a systematic method for performing GDTA is needed because such a method may guide SA analysts in producing a complete SA requirements list. Therefore, this study aims to fill this gap by designing and assess a systematic method to perform GDTA.

4.5 Research Methodology

Because our primary goal is to develop a new artifact—a method to perform GDTA—this study followed a design science research (DSR) approach (Baskerville, Pries-Heje et Venable, 2009; Gregor et Hevner, 2013; Hevner et al., 2018). DSR provides a rigorous process to design artifacts that aim to solve a specific problem. According to (Baskerville, Pries-Heje et Venable, 2009; Peffers et al., 2007), DSR approach comprises the following steps:
1) search and problem identification
2) solution identification
3) evaluation criteria identification
4) artefact construction
5) artefact evaluation. The DSR approach used in this study is summarized in figure 1 and the steps are explained in the following sections.

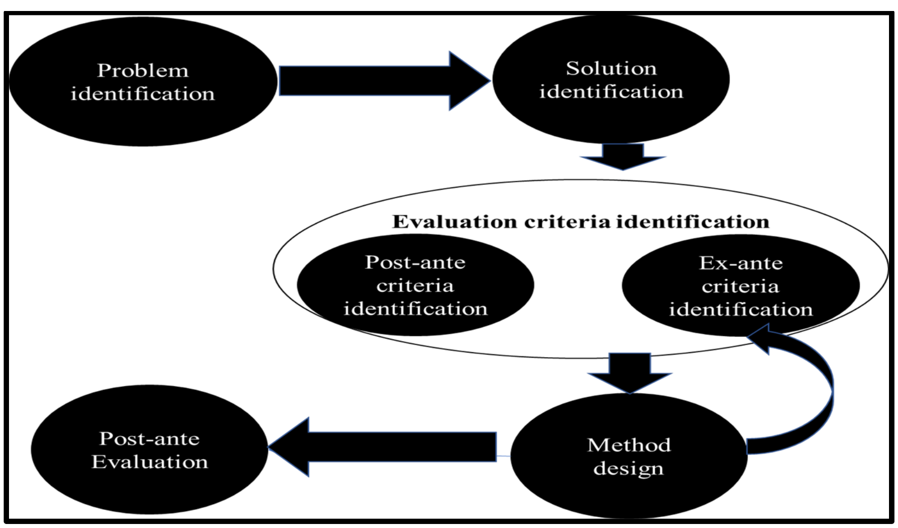

Figure 4.1: the DSR approach

4.5.1 Problem Identification

First, we identified the problem. (Nasser-dine, Moïse et Lapalme, 2021) conducted a systematic literature review to investigate how GDTA has been applied. Their findings suggested that there are no complete systematic instructions for conducting GDTA, and the SA elements at each level are not identified, which results in incomplete or erroneous SA requirements list. Their findings are consistent with our preliminary analysis of a set of studies that have discussed or applied GDTA (e.g., (Bolstad, 2001; Endsley et Jones, 2012; Endsley et Rodgers, 1994; Jones, Connors et Endsley, 2011; Strater et al., 2001)). We found the following shortfalls during these studies' applications of GDTA:

1) The instructions to pass from one step to the next are fragmented and incomplete (i.e. how to pass from goal to sub-goals).
2) The definitions of GDTA concepts (goal, sub-goal, decision, level 1 SA element, level 2 SA element and level 3 SA element) are conceptual in nature; they lack, partially or completely, practical guidelines.
3) Practical guidelines which allow categorization of SA elements at the different levels are not mentioned.

These shortfalls seem to correspond to inaccurate, ambiguous, or incomplete lists of the final GDTA results (list of goals, sub-goals, etc.), which affect the design and evaluation process of the targeted system

4.5.2 Solution Identification

Second, we proposed a solution. Based on the identified gaps in the literature, the proposed solution was a method to guide analysts to perform GDTA in a systematic way. The method aimed to provide instructions that would:

1) Identify the first step and the subsequent steps of the GDTA analysis.
2) Perform every step in the GDTA and explain when to move to the next step.
3) Identify every GDTA concept in a concrete and practical way.

The proposed solution is described in the section: The proposed method.

4.5.3 Evaluation criteria identification

The third step in the DSR approach is establishing the evaluation criteria. To evaluate our method, we combined two approaches: ex-ante and post-ante (Baskerville, Pries-Heje et Venable, 2009). Although some studies adopt only one of the two approaches to evaluate the designed artifact, the combination of both approaches increases the credibility of the proposed method as recommended by (Baskerville, Pries-Heje et Venable, 2009).

The first, ex-ante evaluation, aimed to ensure the validity of the steps adopted along the DSR design process to avoid creating an invalid artifact (Baskerville, Pries-Heje et Venable, 2009). The advantage of ex-ante evaluation is that it saves time and effort in designing new artifacts as it allows the designers to evaluate each acceptability criterion independently, in order to fix what needs fixing before the design stage (Drechsle (Drechsler, 2012; Venable, Pries-Heje et Baskerville, 2016).

The second approach, post-ante evaluation, aimed to demonstrate the utility of our method in a practical context after the design was done. Post-ante evaluation consists of applying the designed artifact in its real context (Cleven, Gubler et Hüner, 2009; Sonnenberg et Vom Brocke, 2012). As we are not able to apply our GDTA method in a real setting, we resorted to the literature to demonstrate the utility of our method. That is, we tested our method's ability to detect errors and ambiguities in studies using GDTA.
The next sections present in detail how evaluation criteria were established.

4.5.3.1 Pre-method design evaluation: EX-Ante Evaluation Criteria

The acceptability criteria of our method were based on the objectives of the method and the characteristics that it should possess (Hevner et al., 2018; Peffers et al., 2012; Venable, Pries-Heje et Baskerville, 2012). As the objective of the proposed method was to address the shortfalls identified in the problem identification section, the proposed method should be characterized by the following: be backed-up by the literature so that 30 years of GDTA practices are not ignored; be practical to guide GDTA application; provide systematic and explicit instructions for performing GDTA in a way that minimizes the inference of who performs GDTA; and be metrology-based to increase its credibility and its validity. Based on these characteristics, the ex-ante acceptability criteria are detailed below:

Criterion 1: The method must be backed-up by the literature.

By this criterion, we mean that the proposed method should be supported by GDTA studies in order not to neglect thirty years of GDTA practices. Therefore, the method is based on:

1) The best practices, which are the guidelines, processes, actions or instructions provided by prior GDTA studies regarding the whole performance of GDTA (i.e., what documents to be consulted, what to prepare to perform the analysis, what kind of people should participate).
2) The instructions in the literature that explain the sequence of the steps of the analysis and how to move from one step to another.
3) The definitions or instructions in the literature that allow the analyst to identify GDTA concepts (goal, sub-goal, decision, level 1 SA element, level 2 SA element, level 3 SA element).

To achieve these conditions, we reviewed the GDTA studies by selecting a set of suitable studies, extracting the relevant information, and analyzing it. The details of this process are presented later in the section: Details of study analysis for criterion 1

Criterion 2: The method must be systematic.

Based on the Oxford English dictionary (2021), systematic method means that the method is “done according to a system or plan, in a complete, efficient or determined way.” Therefore, our method is systematic when it provides instructions for every sub-criterion below:

1) Steps of the analysis.
2) The sequence of the steps
3) When (at which step) to identify GDTA elements (goals, the sub-goals, the decisions and SA elements at each level).

If the method doesn't respect one of the 4 above sub-criteria, then it is considered to be partially systematic.

Criterion 3: The method must be explicit.

This criterion is set to ensure that the method is explicit. By explicit we mean that the method articulates the instructions to perform the analysis. This criterion is met if the method respects the following sub-criteria:

1) The instructions required to complete each step is mentioned explicitly (e.g., to complete the step X the SA analysis should do action 1, action 2 and so on).
2) The instructions required to move from one step to another are mentioned explicitly (e.g., once condition X is achieved, we can move to the next step).
3) The instructions required to identify the goal, sub-goal, decisions, SA elements at all levels are provided and labeled explicitly (e.g., to identify the goals, the SA analyst should do action 1, action 2, etc. and so on).

Criterion 4: The method must be applicable (practical).

This criterion means the method must provide complete definitions of GDTA concepts.

As mentioned earlier (in criterion 1), by complete definitions, we mean that the definitions allow the analyst to identify every GDTA concept, its nature and characteristics, in practice. In the context of GDTA, this criterion is met if the following condition is applied: the definitions of the goal, sub-goal, decision, level 1 SA, level 2 SA, and level 3 SA respectively provide their nature and characteristics (what the goal and its characteristics are, what the sub-goals and their characteristics are, and so on). As SA elements represent measures that are necessary to evaluate SA, we resorted to ISO 15939 to make our definition solid and based on a well-established model. The reason for choosing ISO 15939 standard is that we identified a relationship between SA elements at the three SA levels and ISO 15939 measures that are well-defined. In a precise way, ISO 15939 provides definitions for measurement terms commonly used within system and software industries as well as the relationship between these measures. Therefore, we adapted the definitions of ISO 15939 measures and the relationship between them to identify SA elements at each level and to explain the relationship between them. ISO 15939 and its contribution to our method are fully explained later.

The frame of the ex-ante evaluation is presented in Table 4.1. The first column presents the criteria to be validated. The second field presents the concrete sub-criteria required to validate each criterion. The third column presents the result of the validation as well an explanation of how our method respected the examined criteria. The results of the ex-ante evaluation are presented in section 6 (method evaluation) of the article.

Table 4.1 The Frame to Validate the Ex-Ante Criteria

Criterion	Sub-criterion to assess	Results
Systematic	The sequence of the analysis and the logic to perform each step is provided: 1. At which level the analysis starts 2. When (at which step) and how to identify the goals, sub-goals and SA elements at each level	
Explicit	1. Is the level where the analysis will start mentioned explicitly? 2. Are the instructions required to identify the goal labeled explicitly? 3. Are the instructions required to identify the sub-goal labeled explicitly? 4. Are the instructions required to identify the decisions labeled explicitly? 5. Are the instructions required to identify SA elements at each level labeled explicitly?	
Practical	The definition of each GDTA element provides its nature and its characteristics	
Backed up by Literature	The nature and characteristics provided to identify the GDTA terms are backed up by literature	
Based on ISO 15939	The definitions of SA terms are ISO 15939-based	

4.5.3.2 Details of the studies analysis for criterion 1

Studies selection

First, we reviewed Endsely and Jones'book (Endsley et Jones, 2012) where GDTA is presented in detail. Then, we searched databases such as Compendex, Scopus, Web of Science, Inspec, and Knovel. Among the chosen databases, there were specialized databases in engineering (Compendex, Inspec, Knovel) and multidisciplinary databases (Web of Science, Scopus). We used expressions such as "Goal-directed task analysis" and "GDTA" in the title and the abstract of the papers between 1993 (when the first GDA scientific paper is published) and 2020. To make the analysis manageable and effective, we examined the abstract and the introduction of the obtained studies to filter them based on the following criteria: 1) The study has discussed or performed GDTA, and 2) The study was accessible/downloadable through our institutional affiliation. After filtration and removing duplicate studies, we ended-up with 42 studies in total.

Data extraction and analysis

After selecting relevant GDTA studies, we extracted the best practices regarding the whole performance of GDTA, including any instructions that explained the sequence of the steps of the analysis and how to move between steps, and the list of GDTA results. We also extracted any fragment of text that contained a definition of one of the GDTA concepts (goal, sub-goal, decision, etc.). Then, we analyzed the extracted data by:

1) Examining the best practices to understand how to perform GDTA in different contexts.
2) Examining the logic of the analysis, which is defined in this study as the sequence of steps, the instructions to perform every step and to move to the next step. Consequently, the logic of the analysis can be:
    a. Complete: when the instructions that identify the first step and the subsequent steps of the analysis are provided, and when the instructions to perform every step and to move from one step to another are also provided.
    b. Incomplete: when the instructions to sequence the steps, to perform every step, or to move from one step to another are missing.

3) Examining the definitions of GDTA concepts (goal, sub-goal, etc.). We examined if the used definitions were complete and coherent with Endsley 's definitions (Endsley, 1995b), as most reviewed studies adopted as reference. In our research, the (in)completeness of a definition was based on the recommendation of (Alred, Brusaw et Oliu, 2009; Phillips, 1968). By "complete definition", we mean the definition provides instructions to identify the nature of the concept, to distinguish it from other concepts, and provides concrete characteristics of the concept in order to identify it in a practical context (Alred, Brusaw et Oliu, 2009; Phillips, 1968). For example, the definition "A SA level 1 element is a measure that describes an attribute of an object. The attribute can be qualitative (color, location, direction) or quantitative (speed, size, number)" is an example of a complete definition. This definition provides the reader with examples of measurable components that allow identifying the concept in practical contexts. However, the definition "SA level 1 elements are cues that are received from one or more of the five senses" is an example of incomplete definition because the nature and the characteristics of the concept "level 1 SA element" are not clear. To summarize, we categorized the definitions into complete, incomplete, and coherent or incoherent with Endsley's recommendations (Endsley, 1995b) as presented in Table 4.2.

Table 4.2 presents the frame we applied for every study. From the left, the first column presents the GDTA elements whose definitions we examined. The second column, "Sequences of the steps and logic to move between steps," indicates the result of examination of the sequence of GDTA steps and the instructions to move between steps, as well as a justification of the result. The third column presents the definition of the GDTA concept as provided by the study, as well as the results of the examination of the definition.

Table 4.2 : The Analysis Frame

The GDTA elements	**Sequences of the steps and logic to move between steps**	**Definition of the GDTA is:**			
		Absent	Incomplet	Complete	Coherent with Endsley
Goal					
Sub-goal					
Decision					
Level 1 SA					
Level 2 SA					
Level 3 SA					

4.5.3.3 Post Evaluation Criteria

The purpose of the post-ante evaluation was to evaluate the method after its construction; therefore, the post-ante evaluation criterion targeted detecting errors and ambiguities in the previous GDTA studies. This criterion is:
The method must be useful in detecting errors and ambiguities that have occurred in the previous GDTA studies. This criterion targeted 2 types of errors and ambiguities: those in the GDTA results, and those in the GDTA definitions.

1) Error and Ambiguity in the GDTA Results List

Errors occur when a particular concept in the list does not respect the definition of its category provided by our method. For example, placing the SA element “type of the weapon” at level 3 SA is an error because this element is a proper attribute of the weapon, and so does not respect the definition of a level 3 SA element, which is a projection of the future state of the weapon.

Ambiguity occurs when an element of the GDTA list can be associated with more than one level. For example, the term "fuel sufficiency" is ambiguous. It is unclear whether the term means: the distance we can travel with the current amount of fuel (understanding); or if the quantity of fuel allows us to reach the goal (projection).

2) Error and Ambiguity in Definitions

Errors in a definition of a GDTA concept occur when the provided definition contradicts the definition in our method. For example, the definition “a level 3 SA element is an anticipation of the required actions” is an error because SA level 3 anticipates the state rather than the actions to do.

Ambiguity occurs when the definition of a concept does not provide clear information to identify the nature of the concept. For example, the definition “the decisions could be the actual decisions” is ambiguous because it doesn’t provide the nature of the concept “decision”.

The frame of the post ante evaluation is presented in Table 4.3. The results of the post evaluation will be presented in section 6 (method validation) of the article. The first column at the left presents the level of the detected problem (at the goal level, sub-goal level, decision, etc.). The second column presents the type of the problem. The third column presents the original text extracted from the studies where the problem is detected, and the last column presents a justification as to why it is a problem as based on our method.

Table 4.3 The Frame of The Post Ante Evaluation

The level of the GDTA problem	Type of the problem (Error or ambiguity)	Description of the problem	Justification

4.5.4 Artifact Construction: Design and development of the proposed method

The proposed method is based on three components: the best practices to perform the GDTA as extracted from the literature, the compiled definitions of the GDTA, and the ISO 15939 standard.

4.5.4.1 The best practices

The first component integrated in the method is best practices. Based on the analysis of the practices provided by the GDTA studies (based on the analysis protocol presented in the sub-section Data extraction and analysis), SA analysts should start the GDTA by consulting available materials about the domain where the GDTA is to be performed to understand the important aspects of this domain as well as the main operators' jobs (Endsley et Jones, 2012). Then, the SA analysts should interview experienced system experts (Endsley et Jones, 2012; Irizarry et Gheisari, 2013) and novice systems operators (Yang, Prasanna et King, 2015). Every interview is to be recorded individually (Yang, Prasanna et King, 2015). The interviews with the expert can be conducted face-to-face or via a teleconference application such as Skype (Sharma, Nazir et Ernstsen, 2019). To ensure maximum benefit from the interview, the interviewer (SA analyst) needs to prepare a list of questions ahead of time which can be used to facilitate conversation when other topics are exhausted (Endsley et Jones, 2012). Every interviewee is asked about the overall goals relevant to successful job performance, and the participant's responses are used as a starting point for the rest of the interview. The GDTA results should be formatted in a hierarchical way to provide an easy trace from the goals down to the SA requirements (Endsley et Jones, 2012; Kaber et al., 2006). The initial GDTA results must be validated by a larger number of experienced operators to ensure that they include all the relevant goals, decisions, and SA requirements. Due to the lack of space, the details of the practices are presented in Annex II.

4.5.4.2 Steps of GDTA and definitions of its concepts

The second component integrated in the method design is a compilation of GDTA steps and concepts definitions. The analysis and results regarding the GDTA steps (based on the analysis protocol presented in the sub-section Data extraction and analysis) suggest that all the studies agreed on the sequence of steps, which can be summarized as following:

1) Goals identification, which consists of interviewing domain experts to identify the goals of system operators.
2) Sub-goals identification, which consists of deriving the sub-goals of every goal.
3) Decisions identification, which requires identifying the set of questions underlying the decisions one has to make in order to achieve every sub-goal.
4) SA information identification, which consists of identifying the SA information required to answer the questions identified in the previous step.

Regarding the definitions of GDTA concepts (goal, sub-goal, decisions, and SA information), the results of the analysis (based on the analysis protocol presented in the sub-section Data extraction and analysis) showed that these definitions are incomplete most of the time. For example, (Endsley et Jones, 2012) have provided the sequence of the steps of the analysis, but the instructions to identify the GDTA concepts are conceptual and lack practical characteristics to identify every concept in practice. The incompleteness of GDTA concept definitions makes it ambiguous to move from one step to another (i.e., to move from step 1 to step 2, one needs instructions to derive the sub-goals from goals).

(Yang, Prasanna et King, 2015) followed the definitions of (Endsley et Jones, 2012) and provided some more instructions for identifying the sub-goals list. Studies such as (Humphrey et Adams, 2011; Irizarry et Gheisari, 2013; Jones, Connors et Endsley, 2011; Sitterding et al., 2014; Sulistyawati, Wickens et Chui, 2009) and others have performed GDTA by adopting (Endsley, 1995b) and its conceptual definitions of GDTA concepts without adding significant instructions to those provided by the subsequent studies (Endsley et al., 2003; Endsley et Jones, 2012). (Wright, Taekman et Endsley, 2004) is among the studies that provided some examples of GDTA concepts. However, their examples were domain-specific and cannot be considered references to identify GDTA concepts. Other studies such as (Jones, Connors et Endsley, 2011; Sitterding et al., 2014) reformulated the definitions of (Endsley, 1995b) in an ambiguous way which may lead to more confusion while performing GDTA (e.g., “Level 1 SA elements are the critical factors in the environment” (Jones, Connors et Endsley, 2011), “Level 3 SA is anticipation of required interventions” (Sitterding et al., 2014)). Other studies such as (Humphrey et Adams, 2011; Sulistyawati, Wickens et Chui, 2009; Wright, Taekman et Endsley, 2004) have not provided the GDTA results.

The results of analyzing GDTA concept definitions and sequence of steps provided by the reviewed studies are provided in Annex I.

In conclusion, the main shortfall in the studies that performed GDTA is that the instructions for identifying GDTA concepts (goals, sub-goals, decisions, etc.), and the relationship between these concepts that allow the analyst to move from one step to another, are incomplete. To address this shortfall, we resorted to ISO 15939, which provides definitions for measurement terms commonly used within system and software industries, as well as the relationship between these measurement terms. We adapted the definitions of ISO measures and the relationships between them to identify SA elements at each level and to explain the relationships between them.

4.5.4.3 ISO 15939

The third component that is integrated to design our method is the ISO 15939 standard which provides a model that guides the planning of a measurement process. ISO 15939 provides definitions for measurement terms commonly used within system and software industries as well as the relationship between these measurement terms. Therefore, we resorted to ISO 15939 standard to build definitions of the SA elements at each SA level. The measures defined by this standard are: base and derived measures, indicators, and information products.

Below, we present the definition of each ISO measure and the justification of mapping it to a specific SA level.

A base measure is a value that quantifies or qualifies an attribute of a particular entity in a specific scale (Abran, Desharnais et Cuadrado-Gallego, 2012). The scale can be nominal, ordinal, interval or a ratio. The output of this activity is a list of base measures without any analysis (i.e. color of a car, number of weapons).

A derived measure is defined as a function of two or more values of base measures (Abran, Desharnais et Cuadrado-Gallego, 2012). For example, the speed of a car is a derived measure because it is the result of dividing the distance by time. Also, the derived measure does not provide any understanding of the situation without further analysis.

Based on the definitions of the derived and the base measures, the level 1 SA elements can be considered as the base and derived measures of ISO 15939. The reasons for this are:

1) At level 1 SA, the operator perceives the status, attributes, and dynamics of relevant objects in the environment. An object is an entity (car, aircraft, terrain) and the attribute to be perceived is a feature of this entity (speed, color, altitude).
2) A derived measure is a combination of two or more elements based on a logic or formula that does not depend on the goal and because it does not provide any understanding of the situation without further analysis.

An indicator is a measure that is sought according to specific needs or goals and provides an assessment or estimation of an attribute that is not collectible during the collection of base and derived measures. Indicators are the result of analyzing base measures and derived measures according to a particular analysis model (Abran, Desharnais et Cuadrado-Gallego, 2012).
Indicators can be associated with level 2 SA elements, which are the result of analyzing one or more level 1 SA elements based on a specific analysis model.

An information product is the information that the decision-makers need to make decisions. This information is produced by interpreting the indicators based on the vision (decision criteria, targeted value, etc.) of an organization (Abran, Desharnais et Cuadrado-Gallego, 2012). This produces two categories of information: information about the future and information about the current state of the situation. The first categories match level 2 SA and the second category matches level 3 SA.

Table 4 illustrates the mapping between SA levels and ISO 15939 measures.

Table 4.4 Mapping between ISO 15939 And SA levels

The SA element	The correspondent ISO 15939 measure
Level 1	the base and derived measures
Level 2	The indicators and information product about the current state of the situation
Level 3	information product about the future state of the situation

4.5.5 The proposed method

As a result of the integration of the above components, our method consists of 6 steps starting with goal identification and ending with level 1 SA information identification. The steps are as follows:

1) Goals Identification;
2) Sub-goals Identification;
3) Decisions Identification;
4) Level 3 SA Information Identification ;
5) Level 2 SA Information Identification;
6) Level 1 SA Information Identification;

In the Goals Identification step, the SA analyst identifies and defines the system operators' goals. The method defines what a goal is and provides instructions for creating the goals list and transitioning to the next step.

In step 2, Sub-goals Identification, the SA analyst identifies the sub-goals necessary for achieving the goals identified in the previous step. The method defines what a sub-goal is, provides instructions for identifying them, and instructs the analyst how to transition to the next step.

Next, in the Decisions Identification step, the SA analyst identifies the decisions that the operator must make in order to achieve the sub-goals identified in step 2. The method provides a definition of these decisions, instructions for creating the decisions list, and instructions for transitioning to the next step.

Lastly, steps 4 to 6 provide definitions and examples for SA elements at the three different SA levels, as well instructions for explaining the relationships between these elements and identifying them during GDTA. The details of every step are presented below.

Step 1: Goals Identification

This step consists of identifying the list of goals the system operator needs to achieve. To do so, the SA analyst reviews available documentation to get a general understanding of the domain and the nature of the operator's job and goals. Second, the SA analyst performs unstructured interviews with subject matter experts (SMEs), who are indispensable sources for GDTA information-gathering.

Unstructured interviews are used so as not to frame the answers of the SMEs and let them provide all of the details, and not risk losing information that can be useful. The SA analysts should start by asking the SMEs the following question: what are the main goals of the system operators?

As SMEs are not GDTA experts, the SA analyst then formulates the information provided by the SME as a list of goals. The analyst may need to ask many questions to clearly understand the answers of the SMEs and build the goals list. Based on our analysis of GDTA studies, our definition for a goal is: A goal is a change in the environment that the system operator aims to achieve. The change can be a physical change that affects the elements of the environment, or a mental change that affects the mental state of the system operator. Concrete examples of goals include:

1) A physical change that affects the outside environment elements (i.e., managing an event, sweep all adversaries) (Sulistyawati, Wickens et Chui, 2009), kill enemy aircraft (Endsley, 1993).
2) A mental activity that supports the capacity of the system operator to control elements of the environment, such as monitoring the progress of events, (Sharma, Nazir et Ernstsen, 2019), monitoring activities within the facility (Irizarry et Gheisari, 2013), or emergency evaluation (Humphrey et Adams, 2011).

After the list of goals has been assembled, the SA analyst should confirm the validity of each goal with the SMEs. That means the identification of all goals may need several rounds with the SME (Endsley et Jones, 2012) before finalizing the final hierarchy of goals. Further interviews with SMEs are useful to identify necessary modifications to the goals list by adding, deleting, or rearranging goals (Endsley et Jones, 2012).
As the goals list presents high-level goals, the SA analyst needs to decompose every goal to more practical or concrete sub-goals. To do that, the SA analyst proceeds to Step 2.

Step 2: Sub-goals Identification

This step aims to identify the sub-goals of the goals identified in the previous step. Based on our analysis of GDTA studies (based on the analysis protocol presented in the sub-section Data extraction and analysis), our definition of sub-goals is as follows: A sub-goal is a concrete achievement that is required to achieve a particular goal There is a difference between a goal/sub-goal and a task. A task is technology dependent and a goal may be accomplished by means of different tasks (Endsley and Jones, 2012). A sub-goal is a decomposition of a goal and it is the answer of the question: “what is necessary to achieve a goal”. However, a task is the answer to the question: “How to achieve a sub- goal”. In other words, a task is what system operators do to reach their goal/sub-goal and it consists of a series of predetermined steps to be followed by the operators using the existing system.

To identify the sub-goals for a particular goal, the SA analyst asks the SMEs question such as “what is concretely required to achieve this goal?”.

The responses to these questions allow the SA analysts to decompose and refine the goal and move from high-level goals to operational sub-goals (Yang, Prasanna et King, 2015). Concrete examples of sub-goals can be:

1) Exchange of information, such as verbal exchanges about key vessel characteristics or any abnormality (Sharma, Nazir et Ernstsen, 2019), or other form of information exchange.
2) Assess a state, such as route plan assessment (Sharma, Nazir et Ernstsen, 2019), health assessment (Humphrey et Adams, 2011), or parameter assessment (Humphrey et Adams, 2011).
3) Plan or execute a procedure, e.g., determine target aircraft (Endsley, 1993), avoid obstacles and shallow waters, avoid traffic and no-go areas (Sharma, Nazir et Ernstsen, 2019), dispatch first responders (Humphrey et Adams, 2011) , achieve position of advantage (Endsley, 1993).

To clarify the idea, we take the example of the goal “negate enemy threats” (Endsley et Rodgers, 1994). This goal can be divided into two sub-goals by posing the question “How to negate enemy threats?” The sub-goals are: prioritize enemy threat, and make enemy position untenable.

Once the list of sub-goals has been identified, the analyst returns to the goals list to verify with the SMEs if the sub-goals list covers all of the goals (Yang, Prasanna et King, 2015). This cycle is repeated until the SMEs confirms that the sub-goal list covers all the goals in the list.

To achieve the sub-goals, the SA analyst needs to identify what information one needs to achieve every sub-goal. Thus, the SA analyst needs to identify a set of questions that guides the information collection process. To do so, the SA analyst proceeds to Step 3.

Step 3: Decisions Identification

This step aims to identify the questions one needs to answer in order to make the right decisions required to achieve the sub-goals identified in the previous step. Despite the fact that the reviewed studies such as (Endsley et Jones, 2012; Endsley et Rodgers, 1994; Jones et al., 2010) and others uses the term “decision”, they rather present a set of questions based on which SA elements are identified to answer them. Steps 4 to 6 describes the identification process of theses SA elements. Based on our analysis of GDTA studies, our definition for a decision in GDTA context is a question that the system operator needs to answer to fulfill his or her sub-goal. A concrete example of such question can be an information question such as:

1) “where will the enemy expect me?” (Jones, Connors et Endsley, 2011), or
2) “what is the possibility of locating the casualties?” (Yang, Prasanna et King, 2015).

Once the list of questions is identified, the SA analyst returns to the sub-goals list to verify with the SMEs if the questions list covers the sub-goals. This cycle is repeated until the SMEs confirm that the questions list covers all the sub-goals in the list.

To clarify the idea, we recall the previous example, the sub-goal “Prioritize enemy threat” taken from (Endsley et Rodgers, 1994). The questions are: what is the relative danger relevant to my mission? and, What damage can it do? The answers to these questions are the information the system operator needs to complete the sub-goal “prioritize enemy threats” (Endsley et Rodgers, 1994).

Once the list of questions is identified and approved by SMEs, the SA analyst must collect the SA information required to answer this list. To do that, the SA analyst proceeds to Step 4.

Step 4: Level 3 SA Elements Identification

This step aims to identify the level 3 SA elements required to answer the list of questions identified in the previous step. Therefore, for every question, the SA analyst asks the SMEs the following question: What projections does the system operator need to answer this question?

As the SMEs are not SA experts, the SA analyst formulates the answers in the form of level 3 SA. Based on the GDTA analyzed studies, and because level 3 SA elements are considered the information product of ISO 15939 (see section 5.3), our definition for a level 3 SA element is as follows: A level 3 SA element is an "information product" that anticipates the future state of one or more elements in the environment. This information product is obtained by analyzing one or more level 2 SA elements based on an analysis model specific to the context. In concrete terms, level 3 SA elements can be:

1) Anticipation of a future action of an object, such as projected movement of targets (Sharma, Nazir et Ernstsen, 2019).
2) Anticipation of a future state of an object, such as projected traffic congestion (Sharma, Nazir et Ernstsen, 2019).
3) Anticipation of a future position or trajectory of an object in the environment, for example, a projected aircraft flight path (Endsley, 1993).

Once the list of level 3 SA elements has been identified, the SA analyst verifies with the SMEs if the SA level 3 elements list is adequate to the list of questions identified in the previous step. As the level 3 SA elements are generated by analyzing the relevant level 2 SA elements based on a suitable analysis model, the analyst should identify these relevant level 2 SA elements. To do so, the SA analyst proceeds to Step 5.

Step 5: Level 2 SA Elements Identification

In this step the analyst identifies the relevant level 2 SA elements required to generate the level 3 SA elements identified in the previous step. Based on the analysis of GDTA studies, and since the level 2 SA elements are associated to the indicators and information product of ISO 15939 (see section 5.3), our definition of a level 2 SA element is as follows: A level 2 SA element is an interpretation of one or more level 1 SA elements that allow the system operator to understand a particular aspect of the situation. This interpretation can be an indicator or understanding based on a particular analysis model suitable to the context. Concrete examples of level 2 SA elements include:

1) An indicator, such as a pedestrian's heading (Kim et Gabbard, 2019).

2) An information product based on the interpretation of one or more level 1 SA elements, for example, the meaning of patient cues (Sitterding et al., 2014).

Once the list of level 2 SA elements has been identified, the SA analyst verifies with the SMEs if the SA level 2 list is suitable to the level 3 SA elements identified in the previous step.

To clarify the idea, we will take an example of the level 2 SA element “enemy aircraft attack position.” This element is an indicator that confirms or denies if the airplane is in attack position or not. This indicator is obtained by interpreting level 1 SA information (the direction of the airplane, its position, its airspeed, etc.). This interpretation, which is based on a particular analysis model (i.e., the attack rules), aims to produce an understanding if the enemy aircraft is in attack position or not. Once the level 2 SA elements have been identified, the next step for the SA analyst is to collect the level 1 SA elements that are required to generate the SA level 2 elements. Therefore, the SA analyst proceeds to Step 6.

Step 6: Level 1 SA Elements Identification

In this step, the SA analyst identifies what the system operator needs to perceive in order to generate the level 2 element list identified in the previous step. As mentioned previously, the level 1 SA elements correspond to the base and derived measures of ISO 15939. Therefore, our definition for a level 1 SA element is as follows: A level 1 SA element is a measure that quantifies or qualifies an attribute of a perceived object. The perceived value does not depend on context and it belongs to the perceived object and does not provide any understanding without further analysis. For example, a level 1 SA element can be:

1) A value that quantifies the initial state of elements in the environment, such as the number of weapons (Endsley et Rodgers, 1994), a pedestrian’s location (Kim et Gabbard, 2019), the speed of a car, number of soldiers, or airspeed of aircraft (Endsley, 1993).
2) A value that qualifies the initial state of elements in the environment, such as an interruption specific to clinical cues (Sitterding et al., 2014), the color of a traffic light (Kim et Gabbard, 2019), or the density of traffic (Sharma, Nazir et Ernstsen, 2019).

Once the level 1 SA elements have been identified, the SA analyst should verify with the SMEs if the level 1 SA elements are suitable to produce the level 2 SA elements list and modify the list if needed.

4.5.6 Evaluation of the method

This section presents how the ex- and post-ante evaluation criteria were met. For the ex-ante evaluation, we verified if the identified ex-ante criteria and its sub-criteria were fulfilled during the design phase of the method. The validation process showed that our method has fulfilled the identified ex-ante criteria. Table 4.5 presents the ex-ante evaluation results. It is a completed version of Table 4.1, as described in section 4.3.1.

Table 4.5 Ex-ante evaluation results

Criterion	Sub-criterion to check	Results of the check
Systematic	The sequence of the analysis and the logic to perform each step is provided: 1. At which level the analysis starts 2. When (at which step) and how to identify the goals, sub-goals and SA elements at each level.	These sub-criteria are respected during the design step since the method provided the analysis in the form of 6 steps that illustrated precisely at which level the analysis starts, and when to identify each GDTA element and how to move from one element to another. (See the steps in the section: The proposed method)
Explicit	1. Is the level where the analysis starts mentioned explicitly?	Sub-criterion 1 is respected since the method provided explicit instructions to start the analysis and how to perform and finalize the first step (see step 1 in the section: The proposed method)
	2. Are the instructions required to identify the goal labeled explicitly?	Sub-criterion 2 is respected during the design phase since our method provided explicit instruction with examples to identify the goals list (see step 1 in the section: The proposed method)
	3. Are the instructions required to identify the sub-goal labeled explicitly?	Sub-criterion 3 is respected during the design phase since our method provided explicit instructions with examples for identifying the sub-goals list (see step 2 in the section: The proposed method).
	4. Are the instructions required to identify	Sub-criterion 4 is respected during the design phase since our method provided explicit instruction with examples to identify the decisions (see step 3 in section: The proposed method).

	the decisions labeled explicitly? 5. Are the instructions required to identify SA elements at each level labeled explicitly?	Sub-criterion 5 is respected during the design phase since our method provided explicit instruction with examples to identify SA elements at each level (see steps 4, 5 and 6 in section: The proposed method).
Practical	The definition of each GDTA element provides its nature and its characteristics.	The method provided the nature and the characteristics of the goal (see step 1 in section: The proposed method).
		The method provided the nature and the characteristics of the sub-goal (see step 2 in section: The proposed method).
		The method provided the nature and the characteristics of the decision (see step 3 in section: The proposed method).
		The method provided the nature and the characteristics of the level 3 SA element (see step 4 in the section: The proposed method).
		The method provided the nature and the characteristics of the level 2 SA element (see step 5 in the section: The proposed method).
		The method provided the nature and the characteristics of the level 1 SA element (see step 6 in section: The proposed method).
Backed-up by the Literature	The nature and characteristics provided to identify the GDTA terms are backed-up by the literature.	The nature and characteristics of every GDTA concept are extracted from the literature (see section: The proposed method).
Based on ISO 15939	The definitions of SA terms are ISO 15939 based	The definition of level 1 SA elements is matched to a type of measure provided by ISO 15939 and the argument showing the matching is provided. (see step 6 in section: The proposed method).
		The definition of level 2 SA elements is matched to a type of measure provided by ISO 15939 and the argument showing the matching is provided. (see step 5 in the section: The proposed method).
		The definition of level 3 SA elements is matched to a type of measure provided by ISO 15939and the argument showing the matching is provided. (see step 4 in the section: The proposed method).

For the post-ante evaluation, we analyzed 15 random studies from the 42 studies we collected, and we detected errors or ambiguities in 5 of them. It is important to keep in mind that the goal of post evaluation step was to show that our method can detect errors or ambiguities (if they exist) at each GDTA level rather than finding all errors and ambiguities in all studies. To this end, once one error for the goal list was found across the selected GDTA studies, we stopped looking for errors in the goal list since the ability of our method to detect the error or ambiguity was proved. We then moved on to looking for errors or ambiguities in the decisions lists across the GDTA studies. The same process was repeated until we found one error in the decisions list, level 1 SA list, level 2 SA list, and level 3 SA list respectively. This technique allowed us to show that our method was able to detect errors in the lists of goals, sub-goals, decisions, and in the SA levels. Analyzing 15 studies was enough to provide an example of an error in the lists of goals, decisions, and the three SA levels.

The results of the post evaluation step demonstrated the ability of our method to detect error or ambiguity in GDTA results. Table 4.6 presents the list and the type of each error or ambiguity detected in the examined studies, as well as the justification for every error or ambiguity. This is a completed version of Table 4.3 described in the section: Post-Ante Evaluation Criterion.

Table 4.6 Errors and ambiguities detected by the proposed method

The level of the GDTA problem	**Type of the problem (Error or ambiguity)**	**The text from studies where the problem is detected**	**Justification**
Goal	Error	"A goal is the most important action to take"(Irizarry et Gheisari, 2013)	A goal is not an action; we perform actions to achieve a goal (Gordon et Gill, 1997).
	Ambiguity	A goal is what is most important to accomplish at a particular time (Sitterding et al., 2014)	The definition is ambiguous, because the nature of the concept "goal" is not clear. It can be an action, a task or any other thing.

The level of the GDTA problem	Type of the problem (Error or ambiguity)	The text from studies where the problem is detected	Justification
Decision	Error	“A decision is the choosing between available actions”(Yang, Prasanna et King, 2015).	The decisions are essentially the questions the decision maker must answer in order to achieve a specified goal (Endsley et Jones, 2012)(Endsley et al., 2003; Hoffman, 2005).
	Ambiguity	The decisions that need to be addressed during task performance.(Jones, Connors et Endsley, 2011).	Based on (Alred, Brusaw et Oliu, 2009), this definition is ambiguous, because the nature of the concept “decision” is not clear. Based on this definition, we cannot identify the decisions list as we are not sure what a decision is in GDTA context (e.g., action, a question, etc.)
Level 1 SA elements	Ambiguity	Level 1 SA elements are "User’s information data needs" (Jones, Connors et Endsley, 2011).	This is an ambiguous expression that does not allow the SA analyst to clearly identify what is the nature of the information that is needed
Level 2 SA elements	Error	“Location of the causalities” is a level 2 SA element (Yang, Prasanna et King, 2015).	The location is a level 1 SA element because it is an attribute proper to the object “causalities” and it doesn’t provide any understanding of the situation without further analysis.

The level of the GDTA problem	Type of the problem (Error or ambiguity)	The text from studies where the problem is detected	Justification
Level 2 SA elements	Ambiguity	The SA element "fuel sufficiency "is categorized as Level 2 SA (Endsley et Rodgers, 1994).	The meaning of this element is not clear. It can be either an assessment of the degree to which the current fuel level meets the goal, or a projection of how far the vehicle needs to go and how much fuel will be burned at what rate on the trip
Level 3 SA elements	Error	The SA element "anticipation of required interventions" is a level 3 SA element (Sitterding et al., 2014).	A level 3 SA element is an anticipation of the future state of environment, (Endsley, 1995b) not of required actions.
	Ambiguity	The SA element "impact of the communication" is a level 2 element. However, the element "**I**mpact of safety equipment" is a level 3 element (Irizarry et Gheisari, 2013).	The study doesn't provide any justification for the reasons behind this difference.

4.6 Conclusion, Limitations and Future Research

SA is an important factor that affects the capacity of system operators to make appropriate decisions during task performance. To design systems promoting SA, GDTA is an important method for identifying what information the system operator needs to make appropriate decisions and achieve their goals. The importance of that information lies in the fact that it will be translated into features used to design systems that promote the SA of its operators. Consequently, the performance can be optimized, and fatal incidents avoided.

Despite growing interest in the use of GDTA in many domains to improve the design of SA-promoting systems, GDTA suffers from a shortfall of complete systematic practical instructions to perform it in practice. Such shortfall may result in incomplete or erroneous SA requirements lists that will be used to design and evaluate a SA-promoting system, with negative consequences. Several studies have performed GDTA to identify the SA requirements of many systems in various domains in order to design SA-promoting systems. However, only a few studies have described GDTA steps in sufficient depth to provide practical guidelines for performing GDTA. These studies provided the steps and the sequence of the analysis. However, the instructions for identifying the GDTA concept at each step and moving between steps seemed incomplete and were not based on a solid theory.
To address this shortfall, the present paper proposed a systematic method to perform GDTA based on compiled fragmented definitions of GDTA concepts, GDTA best practices, and the ISO 15939 standard. As a result, the proposed method provided a structured logic to transform GDTA analysis from an intuitive one based on generic descriptions to a more systematic approach based on well-defined steps.

The proposed method has several advantages. First, it is systematic and explicit as it provides the sequence of the analysis in the form of steps, and every step has explicit instructions, including when and how to proceed to the next step. Second, the proposed method is operational as it provides operational definitions as recommended by (Alred, Brusaw et Oliu, 2009). These operational definitions present the nature of GDTA concepts and their characteristics to help identify them in practical contexts. Third, the proposed method provides a logic that is 1) based on the metrology—ISO 15939—to provide the nature of the SA element at each level, and 2) backed-up by the practices of the studies that performed GDTA in the past 30 years to provide the characteristics of GDTA concepts. These two bases are used to build a practical definition that helps the SA analyst to identify the GDTA concepts and to move up or down between these concepts.

Regarding the limitations of the proposed method, it should be noted that the method was not applied in a real context to investigate its usability. That means that the method is not applied by GDTA practitioners to identify the SA requirements in a specific domain to validate its usability and its ability to avoid errors and ambiguities in real contexts. However, our method detected errors and ambiguities in GDTA results as demonstrated by the post ante evaluation step. Future research is required to address this limitation and to identify the potential shortfalls and needed improvements.

CHAPITRE 5

A METHOD TO EVALUATE ENTERPRISE ARCHITECTURE DOCUMENTS BY MEASURING THE SITUATION AWARENESS OF THE DOCUMENT USERS

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5.1 Introduction

In a complex world of business, organizations, defined as systems of consciously coordinated activities of one or more people (Barnard, 1968), look for efficient ways to communicate and understand potential problems and possible holistic solutions before moving to actions (Bellman et Griesi, 2015). It is through communication that the members of an organization manage to coordinate themselves (Davenport et Prusak, 1997). Effective communication can be achieved by creating technical documents, documents that meet a set of criteria regarding lexical and grammatical achievements and style construction (Saint-Dizier, 2014), that aim to minimize the distance between language and action, and minimize user inferences, misunderstanding, and potential errors.

However, the problem with technical documentation is that there is no guarantee that technical document users may have the same mental representation of the state of the organization as that of the document writers (Beynon-Davies, 2010; Cruz, 2013). When document users do not have an adequate mental representation of the enterprise state, they may make inadequate decisions that may negatively affect the performance in the enterprise (Kotusev, Singh et Storey, 2015; Lucke, Krell et Lechner, 2010). Therefore, researchers have conducted research to find ways to properly evaluate technical documents.

Research on technical documents is divided into two categories: procedural and non-procedural documents (Ganier, 2002). Procedural documents are intended to describe steps/procedures needed to perform either a specific task, such as using a dishwasher or word processing software or instructions to evacuate a building in case of fire or make a birthday cake. Non-procedural technical documents are documents that explain the structure and/or the operation of an item (Ganier, 2002). The item can be a device like a bicycle, a system like a galaxy, or a process like making a chair.

The evaluation of procedural documents is based on its usability (Bernal, Kirkpatrick et Watt, 2016; Bethke et al., 1991; Guillemette, 1989; Huston, 2012; Postava-Davignon et al., 2004). That is, technical documents are evaluated by asking human subjects to complete a specific task following the instructions in the technical documentation. However, research on evaluation of the non-procedural technical documents is scarce compared to research on procedural documents. Evaluation of non-procedural technical papers takes the form of questionnaires answered by a group of experts (Dambreville, 2009; Ganier, 2002) or the form of "reply cards" containing evaluation questionnaire answered by the users (McClelland, 1995; Schriver, 1989). However, the problem with non-procedural technical document evaluation techniques is that these techniques provide subjective evaluations of the content of the document and do not reflect the understanding of the users of the document. In other words, even if the users consider that the quality of the document is good, there is no guarantee that they have the same mental representation as that of the document writer because the evaluation method reflects their opinions, not their awareness of the situation described in the document. Since non-procedural technical documents used in the enterprise are important for effective decision making in the organization and since they facilitate communication between the professionals in the organizations (Banaeianjahromi et Smolander, 2019; Farwick et al., 2016; Kotusev, Singh et Storey, 2015; Niemi et Pekkola, 2017), this study contributes to the research on specific kind of non-procedural technical documentation, enterprise architecture (EA) document. It proposes an evaluation method that measures the mental representation of the document users.

In the next section related work in the field is presented followed by methodology used to conduct this study. A rationale and theory behind the proposed method to evaluate EA documents are presented. Then, validation of the method is presented. The paper ends with implications for researchers and future research.

5.2 Literature review

EA is a practice that involves the analysis, design, planning, and implementation of the organization for the development and execution of its strategy by taking a holistic approach at all times (FEAPO, 2013; Kappelman et Zachman, 2013). The EA practice aims to facilitate an organization's ability to communicate with all its components, which leads to more effective decision support and the alignment of business, application, data, and technological architectures that comprise them (Sauer, 2003).

This practice results in technical documents that describe different aspects of the organization, such as business strategies, business risks, organizational models, business process models, logical models of data, as well as models representing the physical infrastructure (Farwick et al., 2016; Kotusev, Singh et Storey, 2015; Niemi et Pekkola, 2017). These documents are used by different stakeholders—such as management, software developers, project managers, operations teams, and many others (Kotusev, Singh et Storey, 2015) as a tool of communication to understand the state of the company and make critical decisions about the future (Kotusev, Singh et Storey, 2015). Therefore, it is essential for EA documents to have the following characteristics (Kotusev, Singh et Storey, 2015; Niemi et Pekkola, 2017; Roth et al., 2013): 1) provide a holistic view of the different components of the enterprise ; 2) have the right information to have a common understanding of the state of the enterprise ; 3) enable stakeholders to make informed decisions about the future.

However, in practice, EA documents suffer from many problems. First, the EA documents represent subjective interpretations of reality that are provided by multiple stakeholders with different backgrounds (Farwick et al., 2016). Second, the stakeholders may not have a common vocabulary to ensure adequate mental representation of the organization represented by EA documents (Arbab et al., 2007). Third, the documentation process can be isolated and may not integrate all the stakeholders (Kotusev, Singh et Storey, 2015).
Research on EA documentation has taken several approaches which resulted in three lines of research. In the first line, researchers focused on the definition of the documents to be produced (Haren, 2011; Salinesi et Thevenet, 2008; Zachman, 2006). In the second line of research, researchers proposed methods to save effort and resources during the documentation process, such as automating the process of data collection and document generation (Buckl et al., 2009; Buschle et al., 2010; Farwick et al., 2016; Hauder, Matthes et Roth, 2012; Roth et al., 2013). In the third line of research, researchers proposed generic models for evaluating enterprise architecture documents (Davoudi et Aliee, 2009; Khayami, 2011; Lakhrouit, Baïna et Benali, 2014; Niemi et Pekkola, 2017; Ylimäki, 2008).

Our focus in this paper is on the third type. To evaluate an EA document, (Ylimäki, 2008) proposed a set of criteria such as 1) the document must be based on a well-defined documentation plan, 2) the document must define business process and architectural requirements, 3) the document must provide a consistent and accurate picture of the enterprise. However, (Ylimäki, 2008) has not proposed a way to validate the clarity of the document to its users. Similarly, (Khayami, 2011) has proposed a model that provides a set of criteria and sub-criteria to evaluate the EA document. However, his model was generic and targeted the writer, rather than the user of the document. (Lakhrouit, Baïna et Benali, 2014; Niemi et Pekkola, 2013; Ylimäki, 2008) have focused on EA document quality attributes and generated the following attributes of EA document: clarity, conciseness, granularity, uniformity, cohesion, availability, correctness, and usefulness. These attributes provide guidelines to evaluate EA documents. Although establishing criteria and attributes to evaluate the EA document is an important practice to improve the EA document, we still need to find a way to objectively assess EA document user understanding of the document to improve communication in the enterprise. As stated by (Banaeianjahromi et Smolander, 2019), the documentation process is immature, and the produced documents affect the communication process between the stakeholders, which is a core obstacle in the decision-making process in an enterprise.

5.3 Research methodology

Because our primary goal is to develop a new artifact, this study follows a design science research (DSR) approach (Gregor et Hevner, 2013; Hevner et al., 2004). The designed artifact can be a construct, model, method, or instantiation (Hevner et al., 2004). In this paper, our artifact is a method to evaluate EA document. The DSR approach consists of the following steps: problem identification and motivation, solution identification, design and development and, evaluation (Peffers et al., 2007) The importance of DSR lies in the fact that it provides a rigorous process to design artifacts that aim to solve a specific problem that takes the form of a research question. The research question that this study addressed was:
How can we develop a method to evaluate EA documents by assessing the mental representation of its users?

Following the DSR approach, in the following sections, we present the gap in the literature that we try to address (problem identification). Next, we describe the theoretical concepts on which the method to evaluate the mental representation of the document in users is built (solution identification) and how these concepts were integrated in the method design (design and development). Afterwards, we describe the proposed method (design and development). Finally, we evaluate the proposed method by using a descriptive approach (evaluation). A descriptive approach (Hevner et al., 2004; Prat, Comyn-Wattiau et Akoka, 2015) is a dominant evaluation approach and has been used in more than half of the scientific papers that evaluated artifacts. The descriptive approach was chosen because it contains an "illustrative scenario" technique, which is suitable to evaluate methods as artifacts, i.e., an artifact which is a method (Peffers et al., 2012; Prat, Comyn-Wattiau et Akoka, 2015). The illustrative scenario technique is used in about the half of papers that have used descriptive evaluation approaches (Prat, Comyn-Wattiau et Akoka, 2015). Our illustrative scenario presents a step-by-step example of how our method can be applied in an EA document context. To increase the credibility of our method, we will simultaneously use another evaluation technique which consists of providing logical arguments to evaluate an artifact and has been used in many papers to evaluate methods such as artifacts (Peffers et al., 2012). Therefore, each step of our scenario will be justified by informed arguments based on the used conceptual foundations.

5.4 The problem identification

As stated in the literature review section, technical communication and EA practices have underestimated the role of EA document users. Research (Khayami, 2011; Lakhrouit, Baïna et Benali, 2014; Niemi et Pekkola, 2013; Ylimäki, 2008) has focused on evaluating the documents from writers and experts' point of view ignoring the document users' point of view, which suggests that the document users' mental representation of the situation can be different from the mental representation of the writer. This fact results in documents that affect the communication process between the stakeholders (Banaeianjahromi et Smolander, 2019) and consequently, inadequate communication fails in creating a good awareness of the situation in document users who contribute to the decision-making process in an enterprise. This can lead to catastrophic results on the future of the enterprise (Cruz, 2013; Lucke, Krell et Lechner, 2010).

However, there are no studies that have emphasized the importance of evaluating the documents from the users' mental representation. The reviewed studies have proposed methods to evaluate the quality of technical documents by focusing on the writer of the document or on the experts (Khayami, 2011; Lakhrouit, Baïna et Benali, 2014; Niemi et Pekkola, 2013; Ylimäki, 2008), which means that the documentation process is isolated and does not take document users into consideration and their needs (Kotusev, Singh et Storey, 2015). Since the purpose of the EA document is to create a shared mental representation of the situation of the enterprise, failure to provide the EA user with the targeted mental representation results in inadequate understanding of the state of enterprise and may lead to catastrophic results in the enterprise (Banaeianjahromi et Smolander, 2019; Kotusev, Singh et Storey, 2015). This study is set to fill this gap.

5.5 The solution identification

The research question that guided this research was how to develop a method to evaluate an EA document by assessing the mental model of its users. Therefore, our solution lies in proposing a method to evaluate EA documents by measuring the mental representation of its users to determine the potential gap between their mental representation and the mental representation targeted by the document's writer. Accordingly, we looked for ways mental models were assessed/measured. To do that, we collected papers about the situation awareness model concept and its measures. We explored large databases such as Compendex, Scopus, Web of Science, Inspec, and Knovel. Among the chosen databases, there were specialized databases in engineering (Compendex, Inspec, Knovel) and multidisciplinary databases (Web of Science, Scopus) which have been adopted by universities. We used expressions such as "situation awareness evaluation" and "situation awareness model" in the title and the abstract of the papers. Then, the papers were examined manually to keep only the ones that are relevant to the study.

The main inclusion criterion that guided our search was the presence of "measure" OR "evaluation" AND "situation awareness" expressions in the title or abstract of the papers during the screening phase of the papers. The second inclusion criterion was based on the presence of evaluation models whether theoretical or practical in the paper.
We found that a mental model can be represented by a situation awareness model (SA) (Endsley, 1995b) and therefore, methods used to evaluate situation awareness of humans can be applied to evaluate a mental model that represents the understanding of the EA documents users. The next section presents the theoretical underpinnings of the proposed method.

5.5.1 The mental model and SA

As the purpose of the paper is to evaluate mental representation of EA document users, it is important to understand what mental representation (mental model hereafter) is. A mental model is defined as a mental mechanism that generates system descriptions, purpose and form, system functioning explanations and states, and future predictions (Endsley, 1995b). Researchers operationalize mental models through the situation awareness (SA) theoretical model.

SA is defined as the "perception of the elements of the environment in a volume of time and space (level 1), the understanding of their meaning (level 2), and the projection of their state into the near future (level 3)" (Endsley, 1995a). As illustrated in Figure 5.1, SA influences decisions, which in turn influences actions. The decision consists of choosing the actions to be carried out, making it possible to modify the environment according to the achievement of a goal. The action is implementing the desired change in the environment. As much as SA and decision-making are internal processes in people, actions modify and affect the external environment. Good SA does not guarantee a good decision, just as a good decision does not guarantee good action. However, the better the quality of SA, the greater the likelihood of making a good decision (Endsley, 1995b).

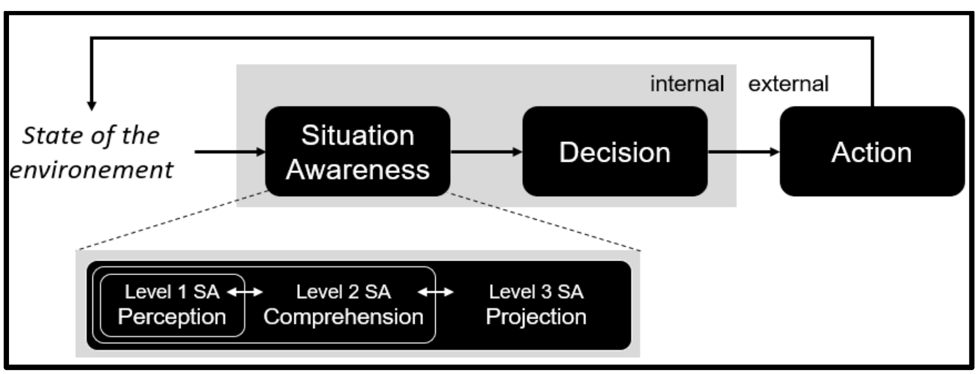

Figure 5.1 Situation awareness model taken from Endsley (1995b)

The level of perception (level 1) refers to the ability to perceive the states and attributes of relevant elements of the environment. The person here seeks to collect accurate and relevant information based on time and space. The notion of time and space usually plays an important role in gaining SA. In some areas, such as aviation, decisions are usually made in a limited time, which is not the case for certain business decisions, such as granting a loan to a company. Thus, the characterization of the notions of time and space can vary from one area to another and even from one decision to another.

The level of comprehension (level 2) refers to the ability to integrate perceived elements at level 1 to understand the situation in light of the goals to be achieved. The person can see if they are on the way to achieving the goal.

Finally, the projection level (level 3) refers to the ability to grasp possible scenarios that may occur in the near future. To reach the level of projection, the person must rely on the first two levels. Moreover, since the awareness of the situation is obtained by the person at a time before the action, the ability to anticipate the state of the environment is essential in achieving the goal. SA is analyzed and measured based on a theoretical model called the Situation Awareness (SA) Oriented design that is presented in the next section.

5.5.2 The situation awareness-oriented design

The SA Oriented Design model (Endsley et Jones, 2012) is "a process that starts with a cognitive task analysis to uncover the SA requirements involved in a domain and translates those requirements into a system design that helps to promote high levels of SA" (Endsley et Jones, 2012). In this study, it is adopted as the theoretical framework to evaluate EA document users' mental representation.

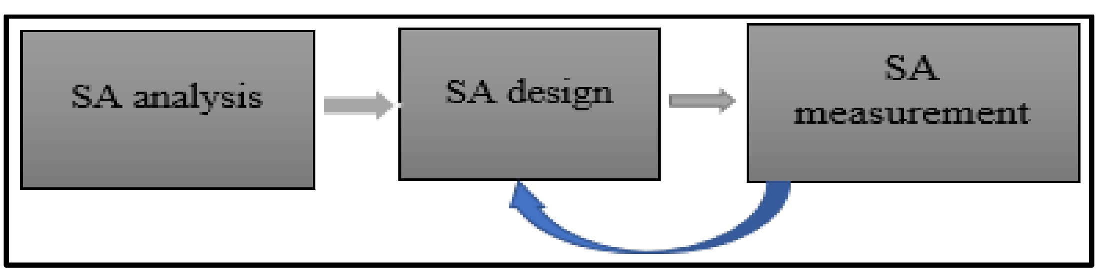

Figure 5.2 Situation awareness-oriented design taken from Endsely et Jones (2012)

SA Oriented Design model consists of three components: SA analysis, SA design, and SA measurement. The design process starts with the analysis of SA by the experts to determine SA requirements of the artifact (SA analysis). Then, the design of the artifact based on the identified SA elements (SA Design). Finally, the designed artifact is evaluated by measuring the SA of its users (SA measurement). The evaluation process determines whether the artifact will be deployed or go back to the redesign stage. This model was used to improve the design of systems in various domains such as air traffic control (Endsley, 2000; Endsley et Rodgers, 1997; Endsley et Rodgers, 1994), airline piloting (Endsley et al., 1998), railway control (Wilson et al., 2001), and anesthesiology (Zhang et al., 2002).

5.6 Design and development: The proposed method

To create our EA document evaluation method, we focused on the first and the third step of the theoretical model SA Oriented Design. The first step (SA analysis) was used as a basis to analyze the SA requirements of enterprise architecture document users. The second step (SA design) of the theoretical model is outside the scope of this study because we are evaluating already existing documents. The third step (SA measurement) was used as a basis to evaluate the EA document. The EA document evaluation model is presented in Figure 5.3. A circle represents an action and the rectangle represents an output.

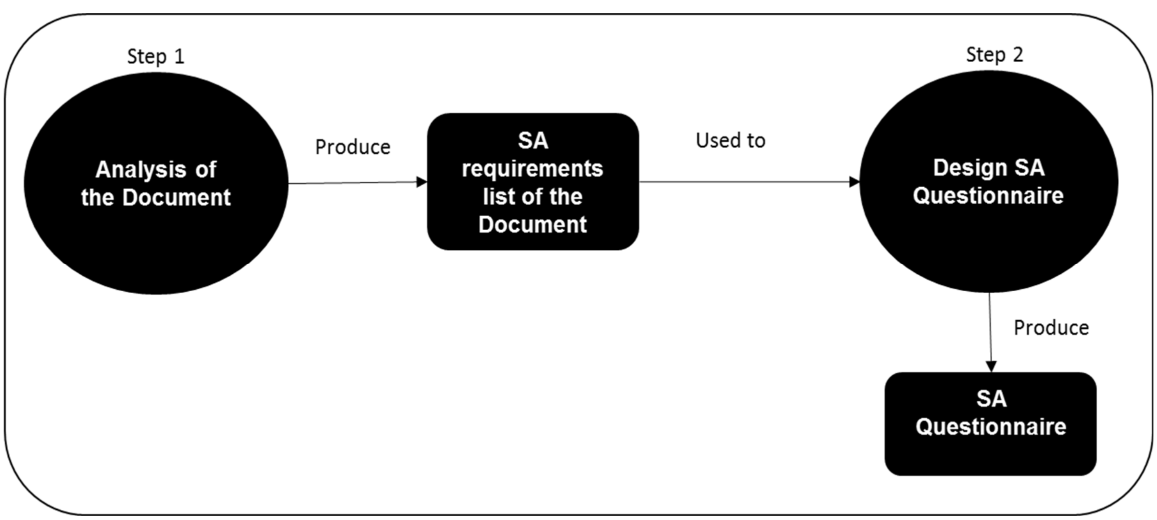

Figure 5.3 EA document evaluation model

The first step in our method consists of analyzing the document to identify the SA requirements targeted in the document. This step produces a list of SA requirements which is used to design a questionnaire (step 2, Figure 5.3) that measures the SA of the document user at the three levels of SA. The next section will explain how SA requirements analysis of the document is performed and how SA questionnaire is designed.

5.6.1 SA analysis

SA analysis is performed by applying a technique called Goal-Directed-Task-Analysis (GDTA). GDTA is a form of cognitive task analysis performed by analysts to identify SA requirements. To do that, the analyst identifies the goals that system operators must achieve and the information they need to make appropriate decisions (Endsley et Jones, 2012). In terms of EA documentation, system operators are analogous to document users. SA requirements are usually obtained through unstructured interviews with domain experts (Endsley, 1993). GDTA consists of four steps (Endsley, 1993) . To clarify each step, we will use an example from the military sector (Strater et al., 2001):

1) The first step aims at identifying the goals that system operators must achieve. There is a difference between a goal and a task. A goal is an overarching objective that system operators must achieve. A task is what system operators do to reach their goal and it consists of a series of predetermined steps to be followed by the operators (Gordon et Gill, 1997). For each goal, system operators have to focus on a particular point. For example, “predict enemy threat” is a goal in a military situation (Strater et al., 2001).
2) The second step aims at identifying the sub-goals necessary for meeting each of the goals identified in the first step. For example, the goal “predict the enemy threat” can be divided into many sub-goals (Strater et al., 2001) like “project the enemy behavior”, “avoid danger areas” and “utilize available cover and concealment”.
3) The third step aims at identifying the decisions to be made by system operators. A decision can take the form of a question to be answered by the system operators to identify the information needed to achieve their sub-goals. Each decision covers a

particular aspect of the needed information. The set of all decisions must cover all aspects of the needed information to achieve a goal. For example, two decisions can be identified for the sub-goal "project enemy behavior": what is the most likely course of action of the enemy? and, what is the most dangerous one?

4) The fourth step aims at specifying which information is needed at each SA level to answer every decision/question identified in step 3. Hence, the result of the GDTA is a list of information classified into three SA levels.

As GDTA did not present guidelines to classify SA information into the three levels of SA (Bolstad, 2001; Endsley, 1995a; 2000; 2011; 2015; Endsley et Rodgers, 1994; Jones, Connors et Endsley, 2011; Strater et al., 2001), we resorted to the information model of the standard ISO 15939 (see Figure 4) as it provides guidelines to classify information at the three levels of SA. ISO 15939 (ISO:15939, 2017) is a generic model that describes all the activities needed to design and evaluate a measurement process by defining the activities required to identify the necessary measures. The measures provided by ISO 15939, the base measures, the derived measures, the indicator, and the information product, were used to classify SA into SA levels. To clarify, each ISO measure can be matched with SA levels according to the following ISO 15939 rules:

1) **Rule 1**: The level 1 SA requirements are associated with the "base measures" and the "derived measures" which quantify the value of a single attribute of a particular entity in a specific scale (ISO:15939, 2017; (Abran, Desharnais et Cuadrado-Gallego, 2012)). These measurements allow system operators to perceive the states of the relevant elements in the environment by quantifying or qualifying their attributes.
2) **Rule 2**: The level 2 SA elements are associated with "indicator" because an indicator is a measure that allows the decision-maker to understand the state of perceived elements in a holistic way, taking into account the goal. The value of the indicator is obtained by analyzing basic measurements and/or derived measures according to a recognized analysis/standard model.
3) **Rule 3**: Finally, the level 3 SA element is associated with "information product" because it presents the potential future effect of the state of perceived elements on the

goal to initiate the decision-making process. The information product is obtained by interpreting the indicators (level 2 SA) according to a logic/vision specific to the organization, and its content depends directly on the context and goal.

5.6.2 SA measure

Once the SA requirements are identified, step 2 in the EA document assessment model (Figure 5.3) is to measure identified SA requirements. Before choosing a technique to measure the SA of the EA document user, we will present the SA measurement techniques physiological and performance measures and their limitations (Endsley, 1995a).

1) Physiological measure:
   Physiological measures depend on observing the reactions of the participants by following, for example, the movements of the eyes or by making electroencephalographic analyses. These techniques make it possible to determine the elements of the environment perceived and treated by the participants. However, these techniques do not allow researchers to determine how much information remains in memory and whether the information is recorded correctly or not. Besides, with this measurement, it is difficult to determine how the information is understood by the participants.

2) Performance Measure: Performance Measure consists of 3 types of measurements: global measures, external tasks measures, and embedded task measures.

   a. Global measures. This type of measurement involves measuring the total performance of a system/operator to evaluate a system. Performance measurement provides the result of a long series of cognitive processes. Therefore, it provides little information regarding the causes of poor performance. Poor performance can be a result of several factors such as lack of information, overwork, poor integration, or bad decisions, all of which are not related to SA. Therefore, this measure is not suitable for our evaluation model.

b. External task measures. This type of measurement consists of changing or hiding parts of the information on the screen and observing the time required for the operator to react to this change. This technique can provide misleading results. It may give the impression that the operator is performing in a certain way, while, in reality, the operator is adopting previously prepared plans to perform under these circumstances. Also, this measurement technique is based on an incorrect assumption as it can swap the operator's current task and can even affect their attention and SA.

c. Embedded task measures. This type of measurement involves examining the operator's performance while performing a specific subtask. The goal of this measure is to collect certain information regarding SA. The main weakness of this technique comes from the embedded nature of the components of a system. A system can simultaneously contain one component that provides elevated awareness and another that provides reduced SA. In addition, the operator may have biased attention to the item that is under assessment.

3) Situation Awareness Global Assessment Technique (SAGAT) This third measurement technique consists of simulating the system, suspending the simulation at random moments, and questioning the subjects on their perception of the situation. SAGAT is the preferred assessment approach among other SA measurement techniques (Endsley, 1995a) because it is an objective technique that overcomes the weakness of other techniques. Therefore, we will choose SAGAT to assess the SA of the EA user (SA measurement). The next section presents the application of the proposed method on an EA synthetic document.

5.7 Evaluation of the proposed method

As it was mentioned previously, we will adopt a descriptive approach to validate the proposed EA document evaluation method. The descriptive approach was chosen because it justifies the use of an "illustrative scenario" technique, which is suitable to validate artifacts in Design Science Research (Prat, Comyn-Wattiau et Akoka, 2015). A validation approach is a common approach used in almost half of the papers that adopted descriptive evaluation approaches (Prat, Comyn-Wattiau et Akoka, 2015). The scenario can be real or synthetic. A synthetic scenario is suggested when collecting real data is difficult (Peffers et al., 2012; Prat, Comyn-Wattiau et Akoka, 2015). Therefore, we will use a synthetic EA document that contains one scenario because it is difficult to obtain real EA documents and the objective of the EA document in our study is to provide a proof of concept of how the proposed model works in an EA document context. Even though the EA scenario is not taken from a real EA document, it describes a case that is very common in enterprises. To increase the credibility of our method, in addition to presenting how the proposed model is applied to an illustrative scenario, we provided a step-by-step justification for the obtained results. Integrating a step-by-step justification is a validation technique that is based on providing logical arguments to evaluate an artifact (Peffers et al., 2012). Therefore, our validation method consists of applying the proposed EA document evaluation model to the EA scenario integrated with the step-by-step argumentation technique. The next section presents the EA document scenario and the application of the EA document evaluation model.

5.7.1 The EA Document Scenario

"Our company provides internet installation service. We receive and process orders. However, the company's daily capacity to receive orders is limited and the order processing time is long. The objective of the company is to improve the service of receiving and processing the commands of the clients. Currently, there are 20 servers with an average availability of 16 hours per day. Every server can receive 20 commands per day. 50 employees can process 80 commands per day. The average time to process a command is 3 days. Every server needs a maintenance time of 2 hours every day. The IT department aims to increase the capacity of receiving up to 100 commands per day, to decrease the time needed to process demand to 3 hours and to increase the availability of server to 22 hours per day".

1) Analysis of the document (step1): The first step in the proposed model (Figure 5.3) is to analyze the document to identify the SA requirements. To identify the requirements of the SA, the GDTA technique was applied and resulted in the following:
    a. Goal: "Reduce the time needed to receive and process customer commands to 3 hours. To achieve this goal, we should evaluate the current resource capabilities of the enterprise (human and material).
    b. Sub-Goal: Evaluate the human resources: The sub-goal "evaluate the human resources" allows the decision-maker to decide if the available human resources are sufficient to achieve the goal.
    c. Decision/Question: To identify the information needed to achieve this sub-goal, it is necessary to respond to two questions: Are human resources sufficient? Are they well-exploited?
    d. SA Requirement list: To answer the above questions, we identified the SA requirement list at three SA levels. The requirement list is presented in Table 5.1.

Table 5.1 SA requirements list

Level 3 SA requirements	**Level 2 SA requirements**	**Level 1 SA requirements**
• Project the effect of the number of employees • Project the effect of the employee task distribution	• The actual average capacity of employees (e.g. how many commands can be processed per day) • The needed human capacity (target) • The actual productivity of the employees	• The number of employees • The number of received commands • The number of untreated commands • The duration of processing a command

Keeping in mind that SA levels are processed bottom-up, we explain in this section how the list was obtained using ISO 15939 rules. The SA level 3 information is the "information product" (in ISO 15939 terms) that the decision-maker needs to initiate the decision-making process. For the sub-goal "Evaluate Resource Capabilities," the decision-maker needs information to project the current state of the human resources on the goal (i.e. predict if there are enough employees, well exploited or not).

SA Level 2 information is required to have a holistic understanding of the situation. For our sub-goal "Evaluate Resource Capabilities," at level 2 SA, we need indicators to understand the effect of the human team. The indicators are obtained by analyzing the level 1 SA information based on a standard or formula that will be chosen according to the targeted goal. For example, the productivity of the employees is an indicator that can be obtained by dividing the number of work hours by the number of completed commands (level 1 SA information). Therefore, one needs to look for level 1 SA information to be able to generate the level 2 SA information.

SA level 1 information is the information we need to generate the level 2 SA information. These are derived and base measures that capture the states of perceived elements (human and materiel in our scenario).

2) SA questionnaire design (step 2): The second step in the EA document evaluation model (Figure 3) is to design a questionnaire based on the obtained list of requirements. Every question targets a specific SA requirement. The questions can be either multiple-choice questions or true/false questions. The duration and quality of responses are two important criteria in the EA document evaluation. Below is an example of these questions.

Level 1 SA (perception)

Question 1: The current availability of server 1 is:

1) 23 hours a day
2) 22 hours a day
3) 23.5 hours a day

Question 2: The processing time of a request is:

1) 1 hour
2) 3 hours
3) 7 hours

Question 3: Each employee can process:

1) 5 commands per day
2) 3 commands per day
3) 6 commands per day

Level 2 SA (understanding)

Question 1: The average capacity of the human resources is sufficient to process:

1) 5000 commands per day
2) 1000 commands per day
3) 2000 commands per days

Question 2: The human resources are exploited by:

1) 50%
2) 60%
3) 70%

Question 3 (True/False): The load is the same on all servers.

Question 4 (True/False): The California server works only 25% of the time.

Question 5 (True/False): We have up to 50% daily requests accumulation in Boston.

Level 3 SA (projection)

Question 1: The Boston server will produce a loss of:

1) 100 commands per day
2) 200 commands per day
3) 300 commands per day

Question 2: The actual capacity of human resources will process command in:

1) 5 hours
2) 8 hours
3) 2 hours

Question 3 (True/False): Thanks to a 5GH server in New York, we will be able to receive more requests.

Question 4 (True/False): The number of employees at the New York site is not enough to stop the accumulation of the commands.

Question 5 (True/False): The number of employees in Chicago is not enough to process a command in 3 hours.

5.8 Conclusion

The purpose of EA documents is to enable stakeholders to understand the overall situation of the enterprise and then make informed and justified decisions about the future. In other words, the EA document writers aim to share their awareness of the situation with the enterprise stakeholders, so that they would be able to make decent decisions. The clearer the communication between the document writer and the enterprise stakeholders, the better decisions can be assured. Therefore, it is vital to ensure that the document users and document writers share a common understanding of the EA. The potential gaps between the SA of the EA document writer and the SA of the users affect the harmony of decision-making processes and may produce decisions with catastrophic effects on the future of the enterprise. Therefore, this study was set to propose an EA document evaluation model given that such models do not exist up to date, to the best of our knowledge.

We opted for a DSR approach to evaluate SA of the EA document users using the SA theoretical model and the ISO 15939 standard within SA Oriented Design theoretical framework. The proposed model consisted of two steps: SA analysis to create a list of SA document requirements and SA questionnaire based on the obtained list of requirements. The proposed EA document evaluation model has many advantages summarized as the following:

First, the proposed model that is based on theoretical foundations draws the technical document writers' attention to the importance of adopting a user-centered approach for evaluation purposes. The reason is that a technical document is created specifically to communicate and share a common understanding of an EA state. If the document does not achieve this goal, the documentation process will be a waste of time, effort, and money.

Second, the EA document evaluation model measures the SA of the user at three SA levels: perception, comprehension, and projection, which results in a granulated assessment of SA rather than an overall assessment. This granulation allows the detection at which SA level the SA is degraded, and consequently, addresses the problem.

Third, the EA document evaluation model is objective and is not based on subjective measures of the document writers or users. The objectivity comes from evaluating the mental representation of the EA document users by using an objective questionnaire without subjective judgment of the external observations/assumptions of the users.

The main limitation of our study is that the application of the EA document evaluation model was applied to a simple synthetic scenario because we did not have access to a real EA document. Real EA documents are much more complex and identifying the list of requirements is not an easy task. The validation process was limited to an application of an EA document evaluation model on a scenario combined with a step-by-step argumentation approach to prove the concept. Future research is needed to empirically validate the EA document evaluation model in an EA setting by recruiting EA document users.

Nonetheless, the present paper serves as an eye-opener for researchers and practitioners to the importance of considering the SA of EA document users to optimize the performance of the EA. The present paper may open avenues for future research in the following areas:

1. Evaluation of technical documents: In the present paper, we applied our model on only one kind of technical document, the nonprocedural document, but future research can apply the proposed model to evaluate other types of technical documents such as procedural documents.

2. Research methods that improve the efficiency of technical document: The proposed model offered a research method based on the theoretical foundations of the SA model, SA Oriented Design approach, and GDTA to objectively assess SA of the document user. This study may encourage research in this area to find more effective ways/structures to design comprehensive technical documents based on user-based approaches.

CHAPITRE 6

DISCUSSION, LIMITATIONS AND FUTURE RESEARCH

6.1 Discussion

The present chapter sheds light on the three contributions of the current thesis to GDTA research and discusses their advantages to GDTA practitioners. The first contribution of this thesis is that it pinpointed, through a systematic literature review, that GDTA lacks complete systematic practical instructions for performing GDTA. In other words, this finding showed that many studies (e.g., Endsley & Connor, 2014; Endsley and Roger,1994; Jones et al. 2011; Sharma et al., 2019) applied GDTA even though the GDTA guidelines were incomplete. One possible explanation for this is that they performed GDTA based on their own interpretations of GDTA steps to compensate for the missing instructions. On the one hand, these studies have not documented their interpretations of the steps and how to apply them so that they can be followed by subsequent studies. On the other hand, the analysis of these studies showed many cases of errors in SA requirements. This is problematic since designing systems that effectively promote SA cannot be done without clear and complete SA requirements. As a result, developing a systematic method to perform GDTA came as a solution to fill the gap of a lack of complete GDTA guidelines, and is the second contribution of this thesis.

The second contribution of this thesis is that it proposed a way to advance GDTA research by developing a comprehensive method to account for the lack of explicit and systematic guidelines for performing GDTA. The proposed method has many advantages on practical and methodological levels.

On the practical level, the proposed method has two advantages. First, the method can be considered systematic since it provides detailed transitions from one step of GDTA to another, allowing the analyst to identify when every step starts and ends and how to move from step to another. Another advantage of the method is that it includes well-structured definitions for each GDTA concept (goal, sub-goal, decision, three SA levels). Second, the proposed method is explicit and complete. It is explicit as the fragmented instructions obtained from previous GDTA studies were collected and reformulated into explicit instructions that can be used to perform GDTA. These explicit instructions are enriched with details and examples to minimize the inference of the analyst applying the method. In other words, the proposed method has mentioned explicitly how to start every step, what to do to perform every step of GDTA, and how to end every step. Also, the method provided explicit definitions with concrete characteristics of every GDTA element to facilitate the identification of GDTA elements (goal, sub-goal, etc.) at each step. It is complete as it covered all steps of GDTA from goal identification to SA information identification at every level.

On the methodological level, the proposed method has four advantages. First, it is grounded on solid foundations that helped to address the challenges of designing and validating the method. That means the method was designed and validated based on the solid scientific foundations of DSR, which provided a solid framework with rigorous steps from the identification of the problem to validation of the method. In fact, the validation step was the biggest challenge that was addressed by DSR. That is, the acceptability criteria identification step in DSR has helped in identifying the acceptability criteria of the method based on its objectives. This step enabled identification of the acceptability criteria of the method before even starting the design phase, so as to avoid ending up with a non-valid method. Another challenge that was resolved by DSR was the post-ante validation of the method. As it was impossible to validate the method in a real context, we resorted to post-ante evaluation, which is a step within DSR for validating our method after the design process is done. The post-ante evaluation allowed us to validate the ability of our method to detect errors in previous studies that were done in real contexts, which increases the credibility of our method in real contexts.

Second, the proposed method is based on the ISO 15939 metrology standard, which guided us on how to enrich the method with systematic instructions for identifying GDTA concepts and the relationships between these concepts in an explicit and clear way. This is a novel application of ISO 15939 because it provided a solid structure that may facilitate the identification process of these concepts when applying GDTA. Although, the method is consistent with the existing knowledge of SA elements, advances in technology may have an effect on the classification logic. For example, the future position of a plane is a projection that should be classified at level 3 SA. The question is: if the system displays this information directly, will it be at level 1 SA? Future research is needed to investigate the effect of the technologies on the proposed taxonomy.

Third, the proposed method is based on a well-defined extraction and analysis protocol to ensure the reliability of the data extraction and analysis process. The extraction step was useful for systematically extracting the instructions and practices applied in previous GDTA studies. The analysis step was based on well-established rules (e.g., the structure of a complete definition based on Alred (2009), the meaning of systematic based on Oxford dictionary, etc.) that allowed us to examine and retain what is useful from the previous studies and to systematically identify what is missing.

Fourth, the method is explicit enough to be used in new domains where GDTA has not been applied before, which brings us to the third contribution of this thesis. Put it differently, it was shown in this thesis how GDTA can be applied to evaluate non-procedural technical documents that are designed to present the structure of a system in order to facilitate interaction with it by users. The advantage of applying the proposed method in a new domain is that it serves as a starting point for researchers to apply the method in new areas. Successful application of GDTA in a technical documentation context can provide a new vision about the evaluation process of non-procedural documents, a vision that is more valuable than current evaluation approaches. Current approaches rely on questionnaires that reflect the opinions of the document users rather than their understanding of it. The advantage of the proposed method is that it focuses on objective evaluation of what information the users need to have an adequate understanding of the described system, rather than what is said or thought about needed information. This puts the document user at the heart of the design of technical documentation and makes the design process flexible and adaptable. This is important because a technical document is used to describe many kinds of systems (enterprise components, business process, information system, etc.) and consequently, the users' needs that may change from one system to another or from one group of users to another.

In sum, the scientific contributions of the present thesis are:

1) A better understanding of the state and shortfalls of GDTA performance.
2) an explicit and systematic method that guides the SA analyst in performing GDTA in a practical way.
3) more structured knowledge for understanding the importance of categorization of SA elements in the SA evaluation process.
4) a structured taxonomy for categorizing SA elements into SA levels, a practice that was not explored before.
5) a relevant demonstration of applying the design science research approach.
6) a better understanding of the role of non-procedural technical documents in creating a shared situation awareness among document users and the importance of evaluating the SA of the users.
7) a demonstration of how to perform GDTA to evaluate a technical document.
8) a relevant demonstration of the application of the metrology such as ISO standard to perform GDTA.

6.2 Limitations and Future Research

Although the proposed method has many advantages as described above, there are limitations that need to be acknowledged. The main limitation of this thesis is that the proposed method was not validated in a real context which means that the method may have gaps that needs filling. Future research can advance this line of research by validating its usability and identifying any potential weakness of the proposed method in real application context.
Another limitation of the thesis was that it did not investigate the applicability of the proposed method across domains. Future research may investigate if the method is applicable across disciplines and what challenges can be faced in its application across disciplines. Another limitation of the thesis is that the application of the GDTA evaluation model (study 3) was

applied to a simple synthetic technical document—enterprise architecture (EA) document—because there was no access to a real EA document. Real EA documents are much more complex and consequently performing GDTA analysis and identifying SA requirements are not easy tasks. Future research is needed to empirically validate a non-procedural technical document evaluation model on more complete and complex non-procedural technical documents.

CONCLUSION

Despite growing interest in goal directed task analysis (GDTA) in many domains for improving the design of complex systems, GDTA suffers from incomplete systematic practical instructions to perform it in practice. This shortfall may result in incomplete or erroneous SA requirements, which are crucial for designing and evaluating a system that promotes SA. This means that the incompleteness or errors in the SA requirements can lead to inappropriate system design. Several studies have performed GDTA to identify the SA requirements of many systems in various domains, in order to design SA-promoting systems. However, only few studies have described the GDTA steps in sufficient depth to provide practical guidelines to perform it. These studies provided the steps and the sequence of the analysis, however the instructions for identifying the GDTA concept at each step and to move between steps seemed incomplete and were not based on a solid theory. Consequently, there is still a need for deeper investigation into the lack of practical systematic guidelines for performing GDTA, and to propose a method that addresses this shortfall. The main objective of this thesis was to fill this gap.

To achieve this objective, this thesis conducted an exploratory study (first study) which made use of well-known methodological designs and techniques to provide insight into the shortfall of systematic instructions to perform GDTA and the importance of such instructions. This study conducted a systematic literature review of published studies from 1990 to 2019 in engineering, computer science, and management journals, and identified sources of variety in the literature which was essential to ensure that most papers that contribute to advance GDTA were included.

The second study addressed the shortfalls identified in the first study by deeply analyzing the guidelines, instructions and best practices provided by previous GDTA studies to design a method, based on the identified practices, for performing GDTA in a systematic and explicit way. The designed method is grounded on well-established practices and theory as it is backed-up by 30 years of GDTA practices and based on ISO 15939, which is an international standard in metrology. Also, the method is designed and evaluated based on a design science approach which is rigorous and well-known. The third study extended the application of the SA model outside the HMI field and proposed to evaluate non-procedural technical documents by measuring the SA of their users.

Researchers and practitioners of GDTA can use the contributions of this research (second study) to better understand how to apply GDTA in a more systematic way. Systematicity in applying GDTA may result in avoiding erroneous or incomplete GDTA results, which in turn, can optimize the designing of SA-promoting systems. More research is needed to validate its effects and its shortfalls in real contexts. The maturity of GDTA guidelines may encourage the use of it outside of HMI, such as in technical documentation, as proposed in the third study, for evaluating non-procedural technical documents. Future research is needed to empirically validate the evaluation model on complex non-procedural technical documents.

ANNEX I

RESULTS OF THE DEFINITIONS ANALYSIS

Table A I.1 Results of the analysis of GDTA concepts definitions

<table>
<tr><td colspan="3">Analysis of the article: A Survey of Situation Awareness Requirements in Air-to-Air Combat Fighters (Endsley, 1993)</td></tr>
<tr><th>GDTA concepts</th><th>Definition of the concept
(Absent, complete, incomplete, coherent)</th><th>Sequences of the steps and logic to move between steps</th></tr>
<tr><td>Goal</td><td>Absent</td><td rowspan="6">Incomplete
Justification:
The sequence of the steps is provided. However, instructions to perform each step and to transit between steps are not complete.</td></tr>
<tr><td>Sub-goal</td><td>Absent</td></tr>
<tr><td>Decision</td><td>Absent</td></tr>
<tr><td>Level 1 SA</td><td>The definition “Level 1 is perception of the elements in the environment within a volume of time and space” is incomplete but, coherent with Endsley.
Justification: The concrete characteristics to identify the concept “level 1 SA element” in a practical context are not provided</td></tr>
<tr><td>Level 2 SA</td><td>The definition “level 2 is the comprehension of meaning of the perceived elements” is incomplete but, coherent with Endsley.
Justification
The concrete characteristics to identify the concept in practice are not provided.</td></tr>
<tr><td>Level 3 SA</td><td>The definition “level 3 is the projection of the element’s status in the near future” is incomplete but, coherent with Endsley.
Justification
The concrete characteristics to identify the concept in a practical context are not provided</td></tr>
</table>

Analysis of the Book: Designing for Situation Awareness (Endsely and Jones, 2012)		
GDTA concepts	**Definition of the concept (Absent, complete, incomplete, coherent)**	**Sequences of the steps and logic to move between steps**
Goal	The definitions below are incomplete but, coherent with Endsley. "Goals are higher-order objectives essential to successful job performance" is incomplete "The goals are not tasks or information needs" "Items that are appropriate for designation as goals are those items that require cognitive effort and that are essential to successful task completion" "The goals themselves are not decisions" **Justification:** The caracteristics of the concept "goal" are not provided.	Incomplete **Justification** The sequence of the steps of the analysis is provided. However, the instructions to perform some steps are not complete. For example: The instructions to derive sub-goals from goals are not provided
Sub-goal	Absent	
Decision	The definitions below are complete and coherent with Endsley. "Decisions are posed in the form of questions" "GDTA decisions reflect open-ended questions that are answered through evaluation and synthesis of the associated SA requirements rather than questions that can be answered with a "yes" or "no."" **Justification:** The nature (question) and the characteristics (open-ended questions) of the concept "decision" are provided. Also, concrete examples are provided.	
Level 1 SA	The definition "the status, attributes, and dynamics of relevant elements in the environment" is incomplete but, coherent with Endsley. **Justification:** The characteristics of the concept "level 1 SA element" are not provided	
Level 2 SA	The definition "understanding what the data and cues perceived mean in relation to relevant goals and objectives. It involves integrating many pieces of data to form information and prioritizing that	

	combined information's importance and meaning" is incomplete but, coherent with Endsley. .**Justification:** The characteristics of the concept "level 2 SA element" are not provided	
Level 3 SA	The definition is: "it is the ability to predict what those elements will do in the future (at least in the short term) that constitutes Level 3 SA" This definition is incomplete but, coherent with Endsley. **Justification:** The characteristics of the concept "level 3 SA element" are not provided	

The analysis of the article: GDIA: Eliciting information requirements in emergency first response. (Yang et al., 2015)		
GDTA concepts	**Definition of the concept (Absent, complete, incomplete, coherent)**	**Sequences of the steps and logic to move between concepts**
Goal	The definitions: "Goals are a useful abstraction to represent stakeholders' needs and expectations" "Goals are defined as something that stakeholders hope to achieve in the future" The definitions are incomplete, but, coherent with Endsley. **Justification:** The concrete characteristics of the concept "Goal" are not provided	Incomplete **Justification** Instructions to perform the identification of SA elements are not provided
Sub-goal	The definition is: "it is advised to carry out refinement or iteration via interview probes containing the question ''How?'' until all the sub goals are elicited" The definition is incomplete but, coherent with Endsley. **Justification:** The nature and the characteristics of the concept "sub-goal" is not mentioned explicitly	
Decision	The definition is: "A decision is the selection between possible actions to achieve a Goal. It could be either the actual decisions or other statements in the form of questions, problems, or any other issues that indicate the decisions needed to reach the goal" The definition is incomplete but, coherent with Endsley. **Justification:** The provided definition is circular because it restates the term decision without clarifying it (e.g., decision is an actual decision, which is not clear what is meant by decision). The concrete characteristics to identify the concept in a practical context is not provided.	
Level 1 SA element	The definition is: "Level 1 is mere perception and awareness of facts" The definition is incomplete but, coherent with Endsley. **Justification:**	

	The term “awareness of facts” is not clear and can be interpreted differently (Alred et al., 2009). For example, fact awareness can be noticing, understanding, or projection.	
Level 2 SA	The definition is: “level 2 is comprehension and understanding of the overall current situation”. The definition is incomplete but, coherent with Endsley. **Justification** The concrete characteristics to identify the concept in a practical context is not provided.	
Level 3 SA	The definition is: “level 3 is projection of the current situation into the future” The definition is incomplete but, coherent with Endsley. **Justification** The concrete characteristics to identify the concept in a practical context are not provided	

Analysis of the article: Objective measures of situation awareness in a simulated medical environment (Wright et al., 2004)		
GDTA concepts	**Definition of the concept** (Absent, Complete, Incomplete, Coherent with Endsley)	**Sequences of the steps and logic to move between concepts**
Goal	ABSENT	Incomplete **Justification:** Generic description of the steps
Sub-goal	ABSENT	
Decision	ABSENT	
Level 1 SA	The definition:"SA level 1 elements may include awareness of patient vital signs such as heart rate, blood pressure, oxygen saturation, breathing rate and awareness of equipment function including potential problems" The definition is incomplete but, coherent with Endsley. **Justification:**The nature of the concept is not provided. The study provided examples of SA elements. Also, the concrete characteristics to identify the concept in a practical context is not provided.	
Level 2 SA	The definition "At level 2 SA, the anesthesiologists will synthesize and integrate information regarding patient physical signs and patient information to identify the most probable cause in a complex differential diagnosis. They will understand the significance of a sudden drop-in heart rate, based on knowledge of a surgeon's recent procedures and other vital signs" is incomplete but, coherent with Endsley. **Justification** Provides concrete examples of level 2 SA elements. However, the nature of the concept and its characteristics are not provided	
Level 3 SA	The definition "Anesthesiologists with a high degree of level 3 SA will be able to project the response of the patient" is incomplete, but coherent with Endsley. **Justification** Provides concrete example of level 3 SA element. However, the nature of the concept and its characteristics are not provided	

Analysis of the article: Analysis of complex team-based systems: augmentations to goal-directed task analysis and cognitive work analysis (Curtis, 2011)		
GDTA concepts	**Definition of the concept** (Absent, Complete, Incomplete, Coherent with Endsley)	**Sequences of the steps and logic to move between concepts**
Goal	Absent	Generic description of the steps
Sub-goal	Absent	
Decision	Absent	
Level 1 SA	Level 1 SA—Perception of the elements in the environment The definition is incomplete but, coherent with Endsley .**Justification:** The concrete characteristics to identify the concept in a practical context are not provided. Yes	
Level 2 SA	The definition: Level 2 SA—Comprehension of the current situation is incomplete, but coherent with Endsley. **Justification:** The concrete characteristics to identify the concept in a practical context are not provided	
Level 3 SA	The definition: Level 3 SA—Projection of future status is incomplete, but coherent with Endsley. **Justification:** The concrete characteristics to identify the concept in a practical context are not provided	

Analysis of the article: Exploring the Concept of Team Situation Awareness in a Simulated Air Combat Environment (Sulistyiwaty et al., 2009)		
GDTA concepts	**Definition of the concept** (Absent, Complete, Incomplete, Coherent with Endsley)	**Sequences of the steps and logic to move between steps**
Goal	X	Generic description of the steps
Sub-goal	X	
Decision	X	
Level 1 SA	X	
Level 2 SA	X	
Level 3 SA	X	

Analysis of the article: Using fuzzy cognitive mapping techniques to model situation awareness for army infantry platoon leaders (Jones, 2011)		
GDTA concepts	**Definition of the concept** (Absent, Complete, Incomplete, Coherent with Endsley)	**Order of the analysis is provided**
Goal	Absent	Generic description of the steps
Sub-goal	The definition: "Sub-goals are necessary for meeting each of the goals" is incomplete, but coherent with Endsley. **The definition is incomplete: since t**he nature of the concept "sub-goal" is not clear. It can be an action, a task or a process.	
Decision	The definition: "The decisions are that need to be addressed during task performance" is incomplete, but coherent with Endsley. **Justification:** The nature of the concept "Decision" is not clear. It can be an action, or any other thing. NA	
Level 1 SA	The definition: "Level 1 SA elements are the critical factors in the environment" is incomplete, but coherent with Endsley. **Justification**: **t**he nature of the concept **"factors"** is not clear. The concrete characteristics to identify the concept in a practical context are not provided	
Level 2 SA	The definition "Understanding the signification of the perceived factors" is incomplete, but coherent with Endsley. **Justification:** The concrete characteristics to identify the concept in a practical context are not provided	
Level 3 SA	The definition "Anticipating what will happen with the situation in the near future" is incomplete, but coherent with Endsley. **Justification:** The concrete characteristics to identify the concept in a practical context are not provided	

Analysis of the article: Situation Awareness and Interruption Handling During Medication Administration **(Sitterding et al., 2014)**		
GDTA concepts	**Definition of the concept** (Absent, Complete, Incomplete, Coherent with Endsley)	**Order of the analysis is provided**
Goal	The definition "A goal is what is most important to accomplish at a particular time" is incomplete but, coherent with Endsley. **Justification:** The nature of the concept is not clear. The "most important" can be an action, a task or any other thing.	No
Sub-goal	X	
Decision	X	
Level 1 SA	The definition "clinical cues relevant to the patient and his or her environment" is incomplete but, coherent with Endsley. **Justification**: The nature of the concept is not clear. The study provided examples of SA elements. Also, the concrete characteristics to identify the concept in a practical context are not provided.	
Level 2 SA	The definition "Comprehension and assignment of meaning to those cues (level 1) specific to the interruption resulting in a patient-centric sense of salience" is incomplete but, coherent with Endsley. **Justification:** The study provided examples of SA elements. However, the concrete characteristics to identify the concept in a practical context are not provided. Yes	
Level 3 SA	The definition is "Projection and/ or anticipation of required interventions based on those meaning assigned from interruption cues" . The definition is incomplete. **Justification:** The concrete characteristics to identify the concept in a practical context is not provided The definition incoherent with Endsley. **Justification** Because the level 3 SA is not about choosing action or intervention, it is about what will happen based in the current state of perceived elements.	

Analysis of the article: Situation Awareness (SA), a Qualitative User-Centered Information Needs Assessment Approach (Irizarry & Gheis, 2013)		
GDTA concepts	**Definition of the concept** (Absent, Complete, Incomplete, Coherent with Endsley)	**steps and logic to move between concepts**
Goal	Absent	The sequence of the steps of the analysis is provided. However, the instructions to perform each step are partially provided
Sub-goal	"which are necessary to accomplish the main goal". **Justification**: The nature of the concept is not clear. The expression "which are necessary" can be an information, action, a task or any other thing.	
Decision	ABSENT	
Level 1 SA	"Perception of the elements in the environment" **Justification**: The nature of the concept "level 1 SA element" and its characteristics are not provided Yes	
Level 2 SA	"Comprehension of the current situation based on a synthesis of disjointed Level 1 elements" **Justification**: The nature of the concept "level 2 SA element" and its characteristics are not provided ABSENT	
Level 3 SA	"Level 3 SA is the Projection of future status" "predicting future events based on his own understanding" **Justification**: The nature of the concept "level 3 SA element" and its characteristics are not provided	

Analysis of the article: Using the situation present assessment method to measure situation awareness in simulated submarine track management (Loft, 2014)		
GDTA concepts	**Definition of the concept** (Absent, Complete, Incomplete, Coherent with Endsley)	**Order of the analysis is provided**
Goal	No	
Sub-goal	No	
Decision	No	
Level 1 SA	No	
Level 2 SA	No	
Level 3 SA	No	

Analysis of the article: A Systematic Review and Meta-Analysis of Direct Objective Measures of Situation Awareness: A Comparison of SAGAT and SPAM (Endsley, 2019)		
GDTA concepts	**Definition of the concept** (Absent, Complete, Incomplete, Coherent with Endsley)	**Sequence of the steps and instructions to move from step to another**
Goal	ABSENT	No
Sub-goal	ABSENT	
Decision	ABSENT	
Level 1 SA	Not complete Justification: The nature of the concept is not provided	
Level 2 SA	Not complete Justification: The nature of the concept is not provided	
Level 3 SA	Not complete Justification: The nature of the concept is not provided	
Analysis of the artice: Uncovering the Requirements of Cognitive Work (Roth et al., 2008)		
GDTA concepts	**Definition of the concept** (Absent, Complete, Incomplete, Coherent with Endsley)	**Sequences of the steps and logic to move from step to another**
Goal	ABSENT	No
Sub-goal	ABSENT	
Decision	ABSENT	
Level 1 SA	ABSENT	
Level 2 SA	ABSENT	
Level 3 SA	ABSENT	
Analysis of the article:Situation Awareness Requirements for a Critical Infrastructure Monitoring Operator (Rummukainen et al., 2015)		
GDTA concepts	**Definition of the concept** (Absent, Complete, Incomplete, Coherent with Endsley)	**Sequence of the steps and instructions to move from step to another**
Goal	No	
Sub-goal	ABSENT	
Decision	ABSENT	
Level 1 SA	ABSENT	
Level 2 SA	ABSENT	
Level 3 SA	ABSENT	

Analysis of the article: Development of a Situation Awareness Assessment Tool for Rail Signalers (Thomas-Friedrich et al., 2018)		
GDTA concepts	**Definition of the concept** (Absent, Complete, Incomplete, Coherent with Endsley)	**Sequence of the steps and instructions to move from step to another**
Goal	ABSENT	Incomplete Justification: The sequence is provided. However, the instructions to perform each step are not provided
Sub-goal	ABSENT	
Decision	ABSENT	
Level 1 SA	ABSENT	
Level 2 SA	ABSENT	
Level 3 SA	ABSENT	

Analysis of the article: Team and Shared Situation Awareness in Disaster Action Teams (Cuevas et al., 2011)		
GDTA concepts	**Definition of the concept** (Absent, Complete, Incomplete, Coherent with Endsley)	Sequence of the steps and instructions to move from step to another
Goal	ABSENT	Incomplete **Justification:** The sequence is provided. However, the instructions to perform each step are not provided
Sub-goal	ABSENT	
Decision	ABSENT	
Level 1 SA	ABSENT	
Level 2 SA	ABSENT	
Level 3 SA	ABSENT	

Analysis of the article: ConteAbsenttual inquiry in signal boAbsentes of a railway organization (Van Kerckhoven, 2010)		
GDTA concepts	**Definition of the concept** (Absent, Complete, Incomplete, Coherent with Endsley)	**Sequence of the steps and instructions to move from step to another**
Goal	ABSENT	Incomplete **Justification:** The sequence is provided. However, the instructions to perform each step are not provided
Sub-goal	ABSENT	
Decision	ABSENT	
Level 1 SA	ABSENT	
Level 2 SA	ABSENT	
Level 3 SA	ABSENT	

Analysis of the article: Incorporating the Human Analyst into the Data Fusion Process by Modeling Situation Awareness Using Fuzzy Cognitive Maps (Jones et al., 2009)		
GDTA concepts	**Definition of the concept** (Absent, Complete, Incomplete, Coherent with Endsley)	**Sequence of the steps and instructions to move from step to another**
Goal	ABSENT	Incomplete **Justification:** The sequence is provided. However, the instructions to perform each step are not provided
Sub-goal	ABSENT	
Decision	ABSENT	
Level 1 SA	ABSENT	
Level 2 SA	ABSENT	
Level 3 SA	ABSENT	

Analysis of the article: perspective view displays on situation awareness during command and control (van der Meulen et al., 2015)		
GDTA concepts	**Definition of the concept** (Absent, Complete, Incomplete, Coherent with Endsley)	**Sequence of the steps and instructions to move from step to another**
Goal	ABSENT	Incomplete **Justification:** The sequence is provided. However, the instructions to perform each step are not provided
Sub-goal	ABSENT	
Decision	ABSENT	
Level 1 SA	Level 1 SA (perception of data and information elements),	
Level 2 SA	Level 2 SA (comprehension of meaning)	
Level 3 SA	Level 3 SA (projection to the near future)	

Analysis of the article: SYSTEM ENGINEERING TO SUPPORT THE FAA'S NEABSENTTGEN AIRSPACE SECURITY CAPABILITY *(Bolczak, et al., 2009)*		
GDTA concepts	**Definition of the concept** (Absent, Complete, Incomplete, Coherent with Endsley)	**Sequence of the steps and instructions to move from step to another**
Goal	ABSENT	Incomplete **Justification:** The sequence is provided. However, the instructions to perform each step are not provided
Sub-goal	ABSENT	
Decision	ABSENT	
Level 1 SA	ABSENT	
Level 2 SA	ABSENT	
Level 3 SA	ABSENT	

Analysis of the article: User, Robot and Automation Evaluations in High-Throughput Biological Screening Processes (Segall et al. 2006)		
GDTA concepts	**Definition of the concept** (Absent, Complete, Incomplete, Coherent with Endsley)	**Sequence of the steps and instructions to move from step to another**
Goal	ABSENT	Incomplete **Justification:** The sequence is provided. However, the instructions to perform each step are not complete.
Sub-goal	ABSENT	
Decision	ABSENT	
Level 1 SA	ABSENT	
Level 2 SA	ABSENT	
Level 3 SA	ABSENT	

Analysis of the article: Applying SA-Oriented Design to the Integrative Collaborative Control of Multiple Unmanned Vehicle Systems (Connor et al., 2008)		
GDTA concepts	**Definition of the concept** (Absent, Complete, Incomplete, Coherent with Endsley)	**Sequence of the steps and instructions to move from step to another**
Goal	ABSENT	Incomplete **Justification:** The sequence is provided. However, the instructions to perform each step are not complete.
Sub-goal	ABSENT	
Decision	ABSENT	
Level 1 SA	ABSENT	
Level 2 SA	ABSENT	
Level 3 SA	ABSENT	

Analysis of the article: Situation Awareness in the Power Transmission and Distribution Industry (Connor et al., 2007)		
GDTA concepts	**Definition of the concept** (Absent, Complete, Incomplete, Coherent with Endsley)	**Sequence of the steps and instructions to move from step to another**
Goal	ABSENT	Incomplete Justification: The sequence is provided. However, the instructions to perform each step are not provided
Sub-goal	ABSENT	
Decision	ABSENT the critical decisions in the form of questions that operators need to ask themselves to meet the goal **Justification:** The characteristics of the concept “Decision” are not provided”	
Level 1 SA	ABSENT	
Level 2 SA	ABSENT	
Level 3 SA	ABSENT	

Analysis of the article: Situational awareness in public health preparedness settings (Merhaji et al., 2005)		
GDTA concepts	**Definition of the concept** (Absent, Complete, Incomplete, Coherent with Endsley)	**Sequence of the steps and instructions to move from step to another**
Goal	ABSENT	Incomplete **Justification:** The sequence is provided. However, the instructions to perform each step are not complete.
Sub-goal	ABSENT	
Decision	ABSENT	
Level 1 SA	ABSENT	
Level 2 SA	ABSENT	
Level 3 SA	ABSENT	

Analysis of the article: Endsley, Mica R, et Michelle M Robertson. 1996. « Team situation awareness in aviation maintenance». (Ensley, 1996)		
GDTA concepts	**Definition of the concept** (Absent, Complete, Incomplete, Coherent with Endsley)	**Sequence of the steps and instructions to move from step to another**
Goal	No. ABSENT	No
Sub-goal	ABSENT	
Decision	ABSENT	
Level 1 SA	ABSENT	
Level 2 SA	ABSENT	
Level 3 SA	ABSENT	

Analysis of the article: HUMAN-ROBOT INTERACTION DESIGN: UNDERSTANDING USER NEEDS AND REQUIREMENTS (Adams et al., 2005)		
GDTA concepts	**Definition of the concept** (Absent, Complete, Incomplete, Coherent with Endsley)	Sequence of the steps and instructions to move from step to another
Goal	No. ABSENT	No
Sub-goal	ABSENT	
Decision	ABSENT	
Level 1 SA	ABSENT	
Level 2 SA	ABSENT	
Level 3 SA	ABSENT	

Analysis of the article:Modeling Situation Awareness for Army Infantry Platoon Leaders Using Fuzzy Cognitive Mapping Techniques (Jones et al., 2010)		
GDTA concepts	**Definition of the concept** (Absent, Complete, Incomplete, Coherent with Endsley)	**Sequence of the steps and instructions to move from step to another**
Goal	No.	No
Sub-goal	ABSENT	
Decision	ABSENT	
Level 1 SA	user's information data needs Justification: The nature of the information is not provied	
Level 2 SA	needed comprehension	
Level 3 SA	Projection of future events	

Analysis of the article: MiAbsented Method Approach to Identify Analytic Questions to be Visualized for Military Cyber Incident Handlers **(**Buchanan et al., 2016)		
GDTA concepts	**Definition of the concept** (Absent, Complete, Incomplete, Coherent with Endsley)	**Sequence of the steps and instructions to move from step to another**
Goal	No.	Not provided
Sub-goal	ABSENT	
Decision	ABSENT	
Level 1 SA	ABSENT	
Level 2 SA	ABSENT	
Level 3 SA	ABSENT	

ANNEX II

THE BEST PRACTICES PROVIDED BY GDTA STUDIES

Table A II.1 The best practices of GDTA results

The best practices of the book: Designing for Situation Awareness An Approach to User-Centered Design (Endsley and Jones, 2012)
-Performing GDTA involves interviewing experienced operators to identify the goals, decisions, and SA requirements - This initial GDTA is then validated by a larger number of experienced operators to ensure that it encompasses all the relevant goals, decisions, and SA requirements - The GDTA is formatted in a hierarchical fashion to provide an easy trace from the goals down to SA requirements. - The goal hierarchy is further decomposed into individual goals, associated decisions, and relevant SA requirements - GDTA interviews are unstructured interviews that focus on goals and information requirements rather than technology or system specific displays or task flows - the interviewer should review all available material pertaining to the domain in order to have a general understanding of the domain and the nature of the operator's job - The interviewer must be cautious, however, not to develop a preconceived notion of what the operator's goals are likely to be based on pre-interview research and, as a result, seek only confirming information in the interview - Ideally experts will be interviewed individually to ensure that each expert has ample opportunity to convey his/her thoughts - Typically, the interviewee is asked about the overall goals relevant to successful job performance, and the participant's responses are used as a starting point for the remainder of the interview - After a statement of initial goals, the interviewee may (1) pause and wait for further questions, or (2) continue the dialog without pause - When the interviewee pauses, one of the identified areas can be selected for further discussion - the interviewer should also make notes regarding other areas of interest that may be returned to when the conversation pauses. - To ensure maximum benefit from the interview, the interviewer needs to prepare a list of questions ahead of time which can be used to facilitate conversation when other topics are exhausted. - Although each researcher will develop a unique style for accomplishing this task, one approach is to begin by reorganizing the notes from the interviews into similar categories - The categorization can be done by beginning each new category on a page and adding statements from the notes to these categories as appropriate

- The goals within the hierarchy are not sequenced according to any type of timeline nor are they arranged in a priority order - After defining a preliminary set of goals, review the goal structure to determine if goals that originally seemed distinct, albeit similar - The decisions that are needed to effectively meet each goal in the goal hierarchy are listed beneath the goals to which they correspond - During the course of analysis, listing all possible decisions and then thoroughly evaluating each one helps ensure that all the relevant domain information is captured - Decisions are posed in the form of questions, and the subsequent SA requirements provide the information needed to answer the questions. - After the initial set of goals and decisions are identified, the task of delineating the SA requirements can begin. SA requirements are identified by evaluating each decision in turn and identifying all the information the operator needs to make that decision.
The best practices of the article: GDIA: Eliciting information requirements in emergency first response (Yang et al., 2015)
To perform GDTA, generally, end-users are interviewed, observed, and recorded individually. The resulting analyses are pooled and then validated by a large number of end-users. The information obtained from these is organized into charts depicting a hierarchy of goals, subgoals, decisions relevant to each subgoal, and the associated SA requirements for each decision To obtain the goals and the sub-goals, Semi structured interviews are conducted with both novice and experienced end-users (preferably with the same end users who described the tasks) to identify the goals and subgoals. With the previously captured task structures, the IS development practitioner can ask specific questions: ''Why do you want to carry out this task, or that task…?'' ''Why do you think this task, or that task… is important?'' ''What goals can be met by conducting these tasks in the scenarios?'' A set of primary goals are finally satisfied by means of secondary goals. It must be noticed that it may not be necessary to have tertiary goals or lower-level subgoals for every job role. It should also not be expected that all the goals derived from the scenarios and executable tasks via the interviews are at the lowest level in the goal structure. Actually, the goal fragments elicited from the interviews may be mapped to a goal at any level in the goal structure. It is crucial that the goal structures are sound before moving on to use them in the remaining steps…… Distribute the initial goal structures among the end users already interviewed. • Carry out a brainstorming session with end-users who were previously interviewed (or meet end-users individually) and revisit the goal and subgoal diagrams with them to minimize initial anomalies. • Discuss the goal structures with different end-users whorepresent other relevant organizations or regions.

The best practices of the article: Objective measures of situation awareness in a simulated medical environment (Wright and al., 2004)
Not provided
The best practices of the article: Exploring the Concept of Team Situation Awareness in a Simulated Air Combat Environment (Sulistyiwaty et al., 2009)
Not provided
The best practices of the article: « Analysis of complex team-based systems: augmentations to goal-directed task analysis and cognitive work analysis » (Curtis, 2011)
(GDTA) and it is a specific form of cognitive task analysis that focuses on identifying the goals and critical information needs for a task context. The product of the GDTA is a hierarchy that identifies the major goals of a particular job class along with the major sub-goals necessary for meeting each of the goals. Associated with each sub-goal are the major decisions that need to be addressed during task performance. These decisions are identified along with the specific SA elements (related to perceptions, comprehensions, and projections) needed for making the decisions and accomplishing the sub-goals. The SA requirements focus on what data is needed, as well as on how the data should be integrated or combined to make decisions. The study give a specific example how to apply the GDTA, not a guide line or clear practice to apply in general.
The best practices of « Situation Awareness and Interruption Handling During Medication Administration » **(Sitterding et al., 2014)**
Not provided

The best practices of the article « Situation awareness (SA), a qualitative user-centered information needs assessment approach » (Irizarry & Gheis, 2013)
Application of the GDTA involves semi-structured interviews in which the interviewer would ask each Subject Matter Expert (SME) about his/her main goal as a manager. The interviewer will continue to enquire about the sub-goals, which are necessary to accomplish the main goal. These sub-goals would serve to set the direction of the remainder of the interview and clarifying the information needs to accomplish the sub-goals of a manager. Creating a comprehensive GDTA for a particular job would take anywhere from 3 to 10 interviews, depending on the complexity of the position (Endsley et al., 2003). One-on-one interviews were conducted with those managers following the GDTA methodology. The interviews lasted approximately one hour and were video recorded for the purpose of reviewing responses. A study protocol was prepared and reviewed by the Georgia Tech Institutional Review Board (IRB) for compliance with Human Research Subjects regulations. Based on the protocol, subjects provided their consent before the interviews. The information obtained from the GDTA was organized into figures depicting a hierarchy of the three main components of the GDTA (i.e., goals/subgoals, decisions relevant to each subgoal, and the associated SA requirements for each decision). After completing the final GDTA, it was validated with a larger group of SMEs. Endsley et al. (Endsley et al., 2003) recommends 10-20 SMEs should be provided with the final GDTA together with required instruction on how to interpret the presented data. Then they should be asked to identify “missing information or errors” (Endsley et al., 2003). The required corrections will be made based on the feedback. The modified GDTA hierarchy, together with the feedback provided from the questionnaire, would form the basis for designing guidelines for accessing the required information and supporting managers in achieving their SA-requirements.
The best practices of the article: Using the situation present assessment method to measure situation awareness in simulated submarine track management (Loft et al., 2014)
Not provided
The best practices of the article: Uncovering the Requirements of Cognitive Work (Roth et al., 2008)
Not provided

The best practices of the article: « Using multiple cognitive task analysis methods for supervisory control interface design in high-throughput biological screening processes » (Kaber et al., 2006)
The general steps to conducting a GDTA include identifying the users' major goals, identifying sub-goals to support overarching goals, identifying operational tasks to achieve the subgoals, identifying questions as part of decision-making in task performance, and developing information requirements to answer these questions. This information is elicited from a domain expert in structured interviews. The experts are typically presented with a task scenario and asked to mentally place themselves in the situation and to describe performance in the absence of any existing automated support systems. The analyst then creates a goal tree (or outline) describing the information requirements, independent of the technology that may ordinarily be used. The analysis is based upon operator goal states in the scenario and not on specific states of the task environment or support systems.
The best practices of « Situation awareness misconceptions and misunderstandings » (Endsely, 2015)
Not provided
The best practices of the article: « Evaluating situation awareness: an integrative review » (Sabrina et al., 2018)
Not provided
The best practices of the article: Situation awareness information requirements for maritime navigation: A goal directed task analysis (Sharma et al., 2019)
A total of 7 participants were interviewed (Mean age=27.9, SD=4.4). The interviews were semi-structured with the purpose to elicit expert knowledge as per the methodology outlined by Endsley and Jones (2012). Prior to the interviews, a notification message was sent to Norwegian Center for Research Data (NSD), informing the nature of the study. The participants were recruited by the professional contacts of the research group. A consent form was given to the participants informing them about nature of the study and their right to withdraw at any time during the process. Most of the interviews were conducted Face-to-Face, however due to certain limitations on the participants' side, two of the interviews were conducted on Skype™. The average length of the interviews was 34 min, with the shortest interview of 25 min and the longest of 52 min. The participants on an average possessed 4.2 years of experience working at sea. This denotes the total sea time. The participants were in average a decade into their sea going careers accounting their down time. Along with collecting physical notes, the interviews were audio-recorded and transcribed verbatim

The best practices of Analysis of the article: Assessing Distraction Potential of Augmented Reality Head-Up Displays for Vehicle Drivers (Hyungil et al., 2019)
Not provided
The best practices of Analysis of the article: A Systematic Review and Meta-Analysis of Direct Objective Measures of Situation Awareness: A Comparison of SAGAT and SPAM (Endsley, 2019)
Not provided
The best practices of the article: « Situation Awareness: Does it Change with Age? » (Bolstad et al., 2002)
The GDTAs were conducted through one-on-one interviews with brigade officers who either currently held each position or had performed the job in the recent past. The interviews were held at the **U.S.** Army Command and General Staff College at Ft. Leavenworth, Kansas and the **U.S.** Army War College in Carlisle, PA. **A** minimum of three officers were interviewed for each position. After several interviews, draft goal hierarchies complete with SA requirements were constructed. These goal hierarchies were then further refined and brigade officers were asked to evaluate and make corrections or additions **as** needed. Subsequently, the goal hierarchies were analyzed to identify shared information requirements.
The best practices of the article: Situation Awareness Requirements for a Critical Infrastructure Monitoring Operator (Rummukainen et al., 2015)
Not provided
The best practices of the article: Goal Directed Design of Rewards and Training Featur (Schwerd et al., 2020)
It is based on non-structured interviews with subject domain experts and determines a tree-like goal structure independent of technology and operator manual activity. Figure 2 shows an exemplary structure of a GDTA. At the top level, there are general goals that drive the operator. Each goal at the high level is subsequently broken down into sub-goals until they reach a point, where the operator must take a decision to pursue his objective. At this point, all dynamic information relevant to this decision is linked to the branch of the GDTA

The best practices of the article: Development of a Situation Awareness Assessment Tool for Rail Signalers (Thomas-Friedrich et al., 2018)
Not provided
The best practices of the article: Situation Awareness in the Power Transmission and Distribution Industry (Connor et al., 2007)
Not provided
The best practices of the article: Team and Shared Situation Awareness in Disaster Action Teams (Cuevas et al., 2011)
a Goal-Directed Task Analysis, a unique form of cognitive task analysis that involves conducting extensive knowledge elicitation sessions with domain subject matter experts (SMEs)
The best practices of the article: Contextual inquiry in signal boxes of a railway organization (Van Kerckhoven, 2010)
a Goal-Directed Task Analysis, a unique form of cognitive task analysis that involves conducting extensive knowledge elicitation sessions with domain subject matter experts (SMEs)
The best practices of the article: "Incorporating the Human Analyst into the Data Fusion Process by Modeling Situation Awareness Using Fuzzy Cognitive Maps" (Jones et al., 2009)
Not provided
The best practices of the article: (Van Kerckhoven, 2010)
Our research focused on the information needs of the sector manager: • What are the goals a sector manager is trying to achieve? • Which decisions need to be made for attaining these goals? • What information would a sector manager *ideally* need to know for making these decisions? These questions couldn't be answered directly by signallers, but had to be elicited via interviews and observations during real-time operations. The information gathered was organized into a hierarchy of goals, sub goals, decisions and situation awareness requirements.

The best practices of the article: The effect of 2-dimensional and 3-dimensional perspective view displays on situation awareness during command and control (van der Meulen et al., 2015)
Not provided
The best practices of the article: **S**ystem engineering to support the faa's nextgen airspace security capability *(Bolczak, et al., 2009)*
We conducted interviews with an expert bio pharmacologist at CELISCA. The expert was provided with a general model of a goal tree for a GDTA, like that shown in Figure 2. She was provided with an explanation of how information or SA requirements were to be organized at three different levels, including perceptual knowledge requirements (Level 1), requirements for relating perceived system states to task goals (Level 2), and requirements for projecting future system states (Level 3). An analyst subsequently posed questions to the biopharmacologist to motivate breakdown of HTS process goals, tasks and identification of SA requirements at each level. Example questions included: • What is the purpose of each major task to the present goal? (Why do you perform the task?) • Is your concept of how this task is to be performed consistent with the standard operating procedure? (If not, how is it different?) • What are the critical decisions you must make in completing the task? • What pieces of information do you require to address each critical decision as part of the task? • When do you need each piece of information during the task procedure (at what stages)? • How are the various pieces of information related to each other?
The best practices of the article: User, Robot and Automation Evaluations in High-Throughput Biological Screening Processes (Segall et al., 2006)
Not provided
The best practices of the article: Applying SA-Oriented Design to the Integrative Collaborative Control of Multiple Unmanned Vehicle Systems (Connor et al., 2008)
Not provided
The best practices of the article: Situational awareness in public health preparedness settings (Merhaji et al., 2005)
Not provided

The best practices of the article: Team Situation Awareness in Aviation Maintenance *(Endsley et al., 1996)*
Not provided
The best practices of the article: Human-robot interaction design: understanding user needs and requirements (Adams et al., 2005)
Multiple interviews will be conducted, thus resulting in revisions to the Goal-Decision-SA requirement structure. This structure will be the basis for future interviews and exercise observations. Observation of actual search and rescue training exercises will provide critical input and verification. Multiple training sessions will be observed; and the Goal-Decision-SA requirement structure will be updated after each session to provide direction for observations and interviews during future exercises.
The best practices of the article: Modeling Situation Awareness for Army Infantry Platoon Leaders Using Fuzzy Cognitive Mapping Techniques (Jones et al., 2010)
Not provided
The best practices of the article: Mixed Method Approach to Identify Analytic Questions to be Visualized for Military Cyber Incident Handlers (Buchanan et al., 2016)
Not provided

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