DETERMINING USER REQUIREMENTS OF FIRST-OF-A-KIND INTERACTIVE SYSTEMS: AN IMPLEMENTATION OF COGNITIVE ANALYSIS ON HUMAN ROBOT INTERACTION

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ABSTRACT

DETERMINING USER REQUIREMENTS OF FIRST-OF-A-KIND INTERACTIVE SYSTEMS: AN IMPLEMENTATION OF COGNITIVE ANALYSIS ON HUMAN ROBOT INTERACTION

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Although, user requirements are critical for the conformance of a system (or a product) design with the user, they may be appraised late in the development processes. Hence, resources and schedules may be planned with the limitations of system oriented requirements. Therefore, late discovered critical feedbacks from the users may not be reflected to the requirements or the design. The focus of this thesis is how to determine the user requirements of first-of-a-kind interactive systems, early in the development process. First-of-a-kind interactive systems differentiate from others for not having experienced users and subject matter experts. Cognitive analysis techniques are investigated with the aim to discover and integrate user requirements early in the development processes of first-of-a-kind systems. Hybrid Cognitive Task Analysis, one of the cognitive analysis techniques, is carried out for the determination of user requirements of a system in the Human Robot Interaction area. Therefore, while exemplifying the methodology, its competency and correspondence with the domain is observed.

Keywords: user requirements, first-of-a-kind systems, cognitive analysis techniques, human robot interaction

ÖZ

TÜRÜNÜN İLK ÖRNEĞİ ETKİLEŞİMLİ SİSTEMLERDE KULLANICI GEREKSİNİMLERİNİN BELİRLENMESİ: İNSAN ROBOT ETKİLEŞİMİ ÜZERİNE BİR BİLİŞSEL ANALİZ UYGULAMASI

Açıkgöz Kopanoğlu, Teksin
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Ürün geliştirme sürecinde, kullanıcı gerekleri, tasarlanan ürün ya da sistemin kullanıcıyla uyumu için kritik olmasına rağmen, geç değerlendirilebilmektedir. Bu nedenle, kaynaklar ve iş takvimleri sistem-odaklı gereksinimlerin limitleri dâhilinde planlanmaktadır. Sonuç olarak, geç tespit edilen kritik kullanıcı geribildirimleri, gereksinimlere ve tasarıma yansıtılamayabilmektedir. Bu tez, türünün ilk örneği etkileşimli sistemlerde kullanıcı gereksinimlerinin ürün geliştirme sürecinin erken aşamalarında nasıl belirlenebileceğine odaklanmaktadır. Türünün ilk örneği etkileşimli sistemlerin kullanıcı gereklerini belirlemek diğer sistemlere göre farklıdır; çünkü, bunların tasarım sürecine katkı sağlayabilecek deneyimli veya konunun uzmanı kullanıcıları bulunmamaktadır. Türünün ilk örneği etkileşimli sistemlerin kullanıcı gereklerini sistem geliştirme sürecinin erken aşamalarında belirleyebilmek amacıyla, bilişsel analiz yöntemleri araştırılmıştır. Bilişsel analiz yöntemlerinden Hibrid Bilişsel Görev Analizi, İnsan Robot Etkileşimi alanında bir sistemin kullanıcı gereksinimlerini belirlemek için uygulanmış, böylece yöntem örneklendirilirken yetkinliği ve belirtilen bağlama uygunluğu gözlemlenmiştir.

Anahtar Kelimeler: kullanıcı gereksinimleri, türünün ilk örneği etkileşimli sistemler, bilişsel analiz yöntemi, insan robot etkileşimi

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LIST OF ABBREVIATION

CTA:	Cognitive Task Analysis
CWA:	Cognitive Work Analysis
GDTA:	Goal Directed Task Analysis
GUI:	Graphical User Interface
HCI:	Human Computer Interaction
HMI:	Human Machine Interaction
HRI:	Human Robot Interaction
MAGIC:	Multi Autonomous Ground-Robotic International Challenge
OOI:	Object of Interest
POI:	Point of Interest
SA:	Situation Awareness
SME:	Subject Matter Expert
UAV:	Unmanned Air Vehicle
UCD:	User-Centered Design
UGV:	Unmanned Ground Vehicle

CHAPTER 1

INTRODUCTION

The increasingly faster advancements in technology and the complexity faced by humans usually show parallel attitudes. Sometimes complexity is considered as an inevitable consequence of advanced technology the system inherits. Higgins and Shanklin (1992) argue that “technological sophistication of the products is often ahead of the technological sophistication of the people who are meant to use them” (p.6). Obviously, the complexity in human interactions is not an outcome of technology; but it is a consequence of the design approach placing the user in the periphery of the design process. The main reason of complexity is that the system development approach not considering the user of the system and the context of its usage. In this approach, designers have tendency to rely on the information provided by sophisticated electronics and computer codes, as is and without considering the users. Therefore, the complexity of the inner system is directly reflected to the human interaction. Hence, the user who is not necessarily mastered in the related technology is frustrated by that interaction. In order to support the user’s conformity with the system, no matter how complex the system behind is, the user interface is to be kept away from that complexity and designed to fit the needs, preferences and capabilities of the users. In order to use the system, obviously, the user neither needs, nor has to learn or know as much as the designer of the system.

For both the user and the designer, the user’s physical conformity with the product/system has always been important. However, since the introduction of interactive systems, which are systems that respond to user interaction, physical conformity has become insufficient. Beyond physical effort, interactive systems require the user’s cognitive processes. Thus, for interactive systems, the focus shifted to cognitive aspects; which is what is going on in the human mind while interacting with the systems.

Norman (1993) summarizes the drastic impact of technology on human cognition as “technology can make us smart” and “technology can make us dumb” (p.3). Computers give the opportunity to extend human capabilities by performing complex analysis and calculations in shorter times. However, if these tools are not well suited to human cognition, even after a period of time with intense effort on understanding and learning the tool, users may still make frustrating errors which may lead to user’s rejection of the system. Norman (1993) indicates the reason of failure as the system design approach, which expects the human to act like a machine. Man-made machines make expected actions in an efficient way; they do not lose attention or feel dissatisfaction. On the other hand, human beings are unique, complex and unexpected; their behavior depends on a variety of dimensions from experience to social relationships (Norman, 1993). This solid difference between man and machine, makes designing their interaction, so called human machine interaction, challenging.

The machines that are evolved to operate in preprogrammed ways which may be partly autonomous are called robots. Ever since robots came into life from science fiction movies, they have been used in various areas to assist the human. Some of these areas are production, search and rescue, entertainment, military, space, healthcare and transportation. The areas of Human Machine/Computer Interaction (HMI/HCI) set the basics for the Human Robot Interaction (HRI). Yanco and Drury (2002) assess HRI area as a subset of the HCI area. However, HRI differs from HCI in several ways: different roles the user plays in HRI, environmental conditions of the robots, number of robots the user interacts with, physical and dynamic natures of the robots and the autonomy level of the robots (Scholtz, 2003).

Even though the ultimate goal of robotics (the branch of science studying robots) is developing fully autonomous robots that do not require human interaction, full autonomy is discussed to be impossible (Lin, Bekey & Abney, 2008). Thus, as Kelley’s

(1968) early but still valid argument suggests, robots are not substitutes for the human, and moreover they make the human role much more cognitive. HRI is one of the critical areas where designing for the fit between human cognition and the system is both significant and challenging.

1.1 Background of the Study

Designing for the fit between the user and the system is a significant goal; and the design process is an effective factor towards this goal. The design philosophy, known as User-Centered Design (UCD), integrates the user to the entire design process as an attempt to design for the fit between the user and the system. As specified in ISO 13407 (Human-centered design processes for interactive systems, 1999), UCD process covers four steps:

(1)” understand and (2) specify the context of use,

(3) specify user and organizational requirements, and produce design solutions,

(4) evaluate designs against requirements”

Even though all four steps are inevitable, it is widely accepted that understanding user requirements is the most critical step for the success of the whole system (Taylor, 2000). The aim of user requirement analysis in UCD processes is to make the design decisions obvious, by explaining the design problem and what the system does. As quoted in Sutcliffe (2002, p.2), Boehm (1981) summarizes the importance of initiating the system development process through well defined requirements as follows: beyond “designing the thing right”, requirements enable the designer to “[design] the right thing”. No matter how successful the design is, if the requirements are already ill-defined, it is not possible to end up with a successful design. The “tree swing” illustrations (Figure 1) make a humorous look at the outcomes of misinterpretation of the user needs; in other words ‘designing the thing wrong’.

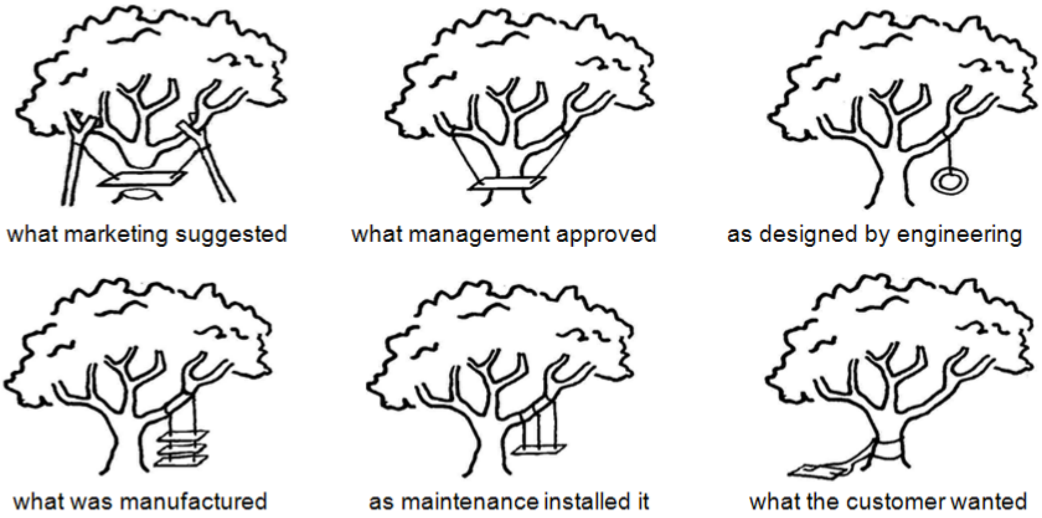


Figure 1 Misinterpretation of User Needs (Chapman, 1995)

In order to “design the right thing” before initiating the design process, it is compulsory to define the design requirements well. Well defined requirements are described as achievable, verifiable, unambiguous, complete, correct, traceable and consistent (IEEE STD 830, 1998; Bahill & Dean, 2009; Leonard, 1999). Well defined requirements may guide the design process and decrease the usability problems that may be found in the evaluation step.

Besides the theoretical background of the requirement analysis process, its implementations in industrial practices have also been studied intensely. For instance, the study by Mao, Vredenburg, Smith and Carey (2005) shows that, even though requirement analysis is considered to be one of the most important steps in the design process, it is not carried out widely in practice. Wharton and Lewis (1994) raise the question “How can the theoretical ideas of the researcher aid a practitioner who is always short of time, and for whom usability is only one of many important design and development goals, not all of which can be met?” (p.341). In industrial practices, requirement analysis methodologies can be by-passed because they require excessive time and money (Mao et al., 2005). Hence, in order to trace the benefits of the requirement analysis methodology, its applicability in the design practice is also quite significant, besides its quality. Even within tense design constraints like tight schedules and resources, design requirements should not be limited with the designer's vision.

From the industrial designer's point of view, design requirements are usually seen to be ready-made recipes. Industrial designers are often included in to the system development process only after the design requirements are determined. Even in industrial design education, as investigated by Wormald (2010), students traditionally start with design briefs. Design briefs explain major constraints and goals of a project, and later become design requirements. Similarly, in professional life, either the system engineer of a company or directly the stakeholders are supposed to provide the design requirements to the industrial designer. Stakeholders are executives defining and financing the design project. However, they are not always the end-users; and hence, they may not be capable of comprehending the needs of the end-users. Therefore, the reliability of the requirements provided by the stakeholders is subject to discussion. For instance, Coble et al., (1997) mention that the systems developed through the requirements of stakeholders not always end up with a really usable system. Robertson (2001) supports this view by underlining the drawbacks of gathering requirements from the stakeholder. Robertson (2001) says that "the reason for the late discovery of requirements is usually because we have not been able to inspire the stakeholders to think past preconceptions and communicate what they want" and he proposes some techniques to 'trawl' requirements from stakeholders (p.406).

On the other hand, the requirements prepared within a company without a user-centered approach cannot ensure to include correct and complete user requirements. Hence, the industrial designer usually takes responsibility to capture user requirements, with or without specific techniques, and to design in order to fulfill them simultaneously. The mentioned system development process, showing the industrial designer's or interaction designer's (depending on the domain) role within a design team, is illustrated in Figure 2.

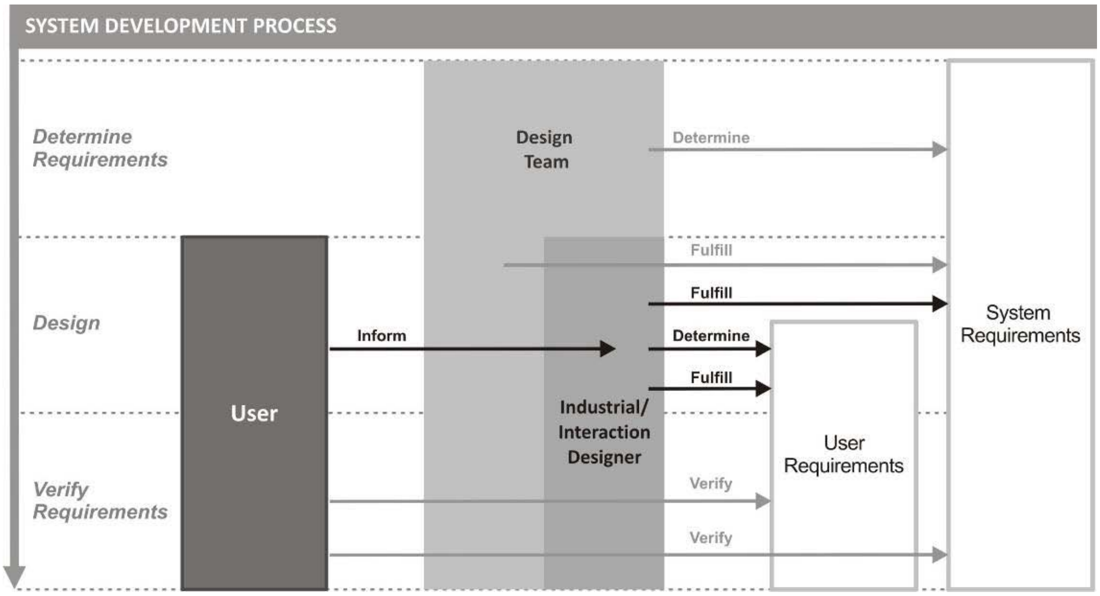


Figure 2 System Development Process through System Requirements

In this approach, system requirements and user requirements are separate inputs of the design process, and their contradictions and intersections are not defined. Moreover, user requirements are integrated into the system development process, where the system is already described and constrained with system requirements determined through system-technology centered design approaches. Hence, in this development process, the user's contribution is limited as being an attempt towards "designing the thing right". This development process may end up being a well designed solution that is ill defined from the very beginning. Even though design requirements can be adapted according to novel variables discovered during the development process, these adaptations may be costly in terms of resources and schedules. Sutcliffe (2002) shows that as the process draws near the end, the costs of an ill defined requirement increase drastically. Furthermore, even drastic modifications may be required because of the requirements that are linked to others. Therefore, it is important to define the requirements as early as possible in the development process.

Responsibility of an industrial designer is defined as developing products and systems to satisfy both design requirements and user needs. Lindgaard et. al (2006, p.51) argue that “the combination of requirements engineering and user needs analysis activities should improve both the process and the outcome of requirements capture.” Integrating those two, user requirements and system requirements, ensures a very early focus on users; and hence, enables the designer to “[design] the right thing”.

The requirements that are determined for the conformance of the system with the user, including user needs, preferences, capabilities and usability issues; are called *user requirements*. System development process through user requirements is drawn in Figure 3.

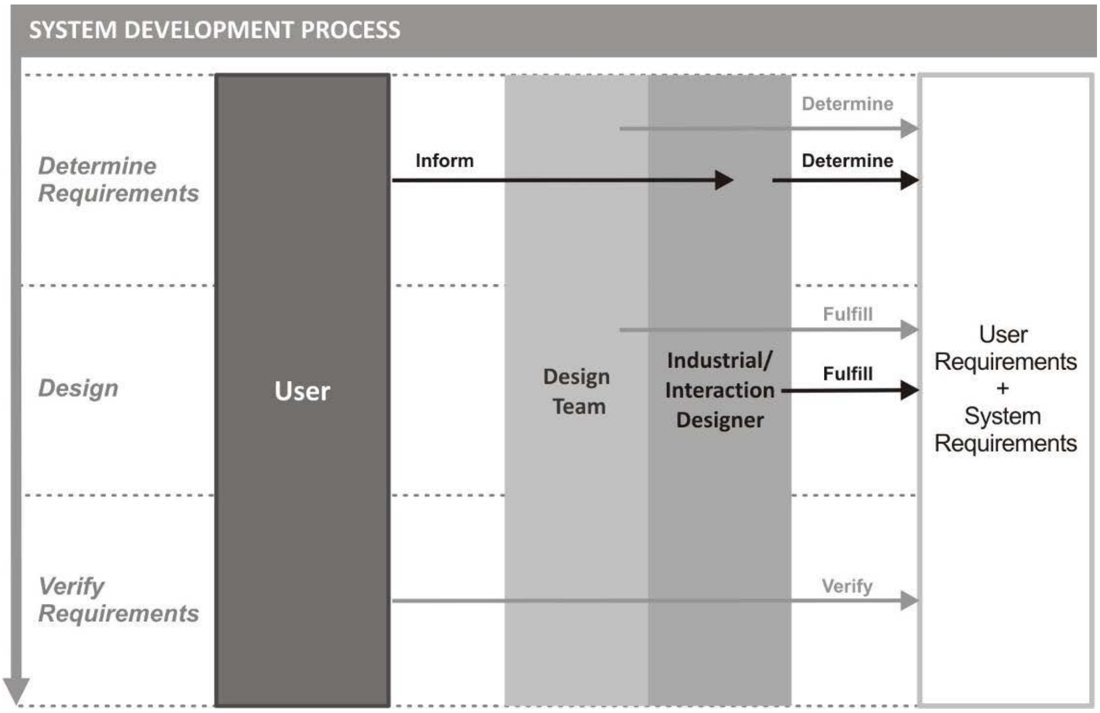


Figure 3 System Development Process through User Requirements

One of the main focuses of industrial design is transforming requirements or design problems into products or systems. International Council of Societies of Industrial Design (ICSID) defines industrial design as follows: “Design is a creative activity whose aim is to establish the multi-faceted qualities of objects, processes, services and their systems in whole life cycles” (“ICSID: Definition of Design”, n.d.). However, to fulfill this aim, defining those requirements well, in other words ‘multi-faceted qualities', is essential. Moreover, some sources directly refer to the industrial designer's role, within the requirement determination phase of the system development process. For instance, Tovey (1997) cites 'user requirements' as both represented and fulfilled by the industrial designer, and describes industrial designer's responsibilities as follows:

- "**to represent** the market and **user requirement** in determining the ergonomics and appearance of the product.

- to **integrate market, user and engineering requirements** into a whole design solution" (p.9)

Similarly, Industrial Designers Society of America (IDSA) mentions 'developing specification' and defines industrial design as follows:

> …the professional service of creating and developing concepts and **specifications** that optimize the function, value and appearance of products and systems for the mutual benefit of both user and manufacturer ("IDSA: What is industrial design?" 2010)

Wormald (2010) underlines the industrial designer's contribution to determine design briefs. He discusses that in the future, industrial designers will need certain abilities and knowledge; in order to take part in the development processes even before design briefs are developed.

1.2 Problem Definition

As mentioned, adding user requirements to the other requirements of the project is quite critical to prevent redesigns and conflicts. UCD focuses on the active involvement of users, also in the requirements determination phase. Indeed, in specifying user requirements, applying empirical analysis with Subject Matter Experts (SMEs) and experienced users is one of the important techniques. SME or in other words domain expert is a "person with special knowledge or skills in a particular area; a person extremely familiar with a given group of users and their work habits (because they belong to the group)" ("Usability First-Glossary: Domain Expert", n.d.). Especially for the development of incremental improvements over existing products, observing and questioning the use of similar products is a widely applied methodology. However, it is not always possible to access those experienced users, especially if the system at hand is a first-of-a-kind system which is the focus of this study.

The term ‘first-of-a-kind’ is used to refer to the level of innovativeness of the interactive system and emphasize the fact of being the ‘first’. Instead of comparable terminology such as ‘revolutionary’, ‘discontinuous’, ‘pioneering’, ‘boundary expanding’, ‘breakthrough’ and ‘radical’; ‘first-of-a-kind’ is chosen as that is the dominant terminology in Human Robot Interaction literature (Humphrey & Adams, 2010; Lintern, 2005; Naikar & Pearce, 2003; Naikar, Moylan, Pearce, 2006; Roth & Mumaw, 1995; Roth, Lin, Kerch, Kenney & Sugibayashi, 2001; etc.)

Newman and Lamming (1995) underline the difficulty in determining design requirements of first-of-a-kind interactive systems as follows:

> Many of the complexities surrounding the requirements process arise because interactive systems tend to involve novel design ideas. When a new system is developed there may not be any other system quite like it, and so the functional requirements must be defined largely from first principles. (p.158)

In first-of-a-kind system development, there are no SMEs, experienced users or examples about usage of similar products to collect data from (Dearden and Howard, 1998). Moreover, in the early development phases of first-of-a-kind systems, empirical techniques with actual users can not be applied as prototypes are not available. However, if user research is integrated after the development of prototypes, and decisions are made accordingly, it may be too late to modify the project timeline and resource plan. Especially in complex, dynamic interactive systems where cognitive loads of the users are relatively high, investigating user requirements early in the development process is critical. Hence, before the development of the first prototypes, in the requirements analysis phase, an understanding of the user and his cognitive requirements is necessary. First-of-a-kind system development process through user requirements is drawn in Figure 4. In

Chapter 4 an implementation on the requirement determination phase of this first-of-a-kind system development process is undertaken and explained.

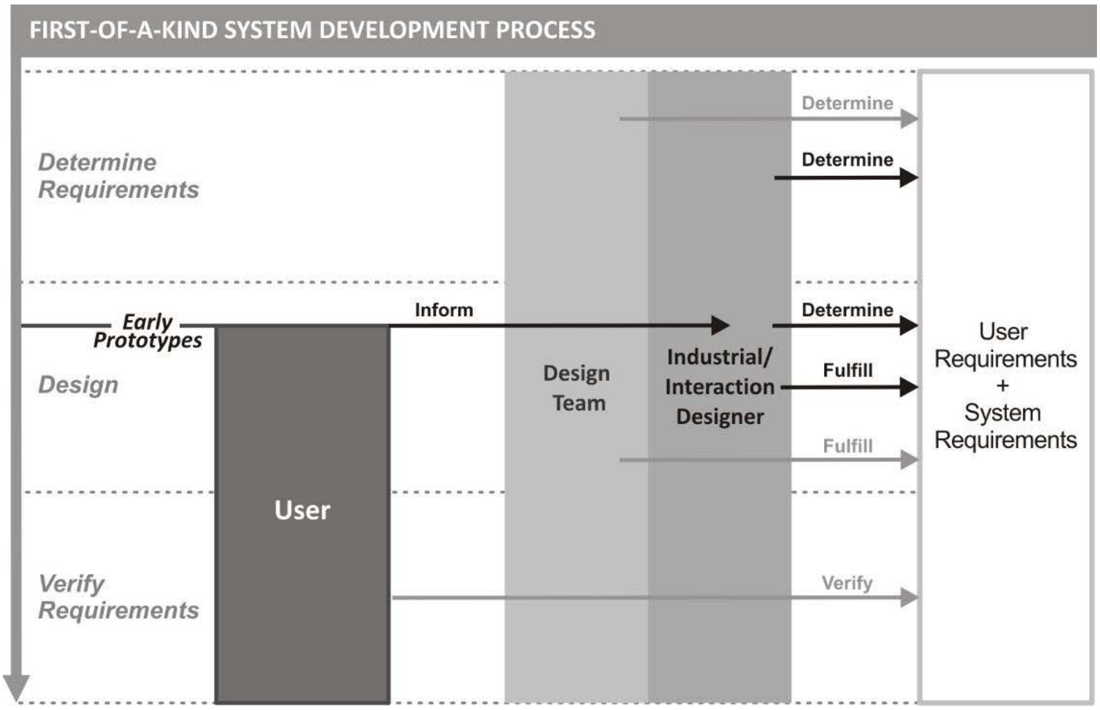


Figure 4 First-of-a-Kind System Development Process through User Requirements

In system development processes, if user requirements are not investigated, the first prototypes and concepts of first-of-a-kind systems are usually developed with the limited visions of the designers and their understanding of the users. User requirements aid the industrial/interaction designer during the design process and may prevent redesigns.

User requirements define experiences, functions and qualities provided by the system; according to the needs, preferences and capabilities of the target users. As Newman and Lamming (1995) explain, the decisions made in requirements determination phase are mostly design decisions. Hence, how those decisions are made is critical for the success of the design.

Spool (2002) describes the traditional design process with a bridge metaphor:

> *The bridge is build quickly and without any training, later a car full of people is driven by that bridge and it plunges into the water, then the observed problems are fixed and another car is driven through the bridge, the loop continues until the car does not plunge.*

This metaphoric example is an optimistic one in which at least the bridge is tested before it is opened for the public use (Spool, 2002). This example underlines the inefficiency of the ‘design-evaluate-redesign’ loop. This iterative design process and before launch testing are very beneficial and mostly indispensable. However, if the design is verified before and during the design process, redesigns may be prevented or limited with incremental improvements. Of course, for the bridge metaphor, techniques and simulations are used while building, in order to foresee the behaviors of the materials within specific conditions. Similarly investigating the user’s responses, behaviors and perceptions before and during the design process is significant. However, neither anticipating nor simply asking the users is enough to determine user requirements. Especially in complex and dynamic interactive systems, analyzing the cognitive demands of the users is critical in order to determine user requirements.

There are numerous techniques and methods to aid the designer in determining user requirements and discovering the user’s cognitive demands. Mainly, there are two types of methods: empirically by testing the prototype with the actual users and analytically by using specific techniques. Even though the information from the actual users is irreversible, in some cases it cannot be gathered. For instance, parting from development of incremental innovations, in first-of-a-kind interactive systems there are no experienced users, similar systems or SMEs. The information SMEs present is critical especially for systems that require professional training and experience from the users. However, as in the given case of first-of-a-kind interactive systems, it is not always possible to access SMEs.

1.3 Aim and Scope of the Study

This study aims to explore the process of determining user requirements of first-of-a-kind systems, as a contribution to the field of industrial design. In this study, the term ‘first-of-a-kind interactive system’ refers to the interactive systems that introduce novel human interactions; without former examples, experienced users or SMEs. So the main question of the study is:

- How can user requirements of first-of-a-kind interactive systems be determined?

This study aims to answer also the following sub questions in order to elaborate the main question:

- What are the constraints of first-of-a-kind interactive system development and how can those be overcome?
- What are the appropriate approaches for requirement determination of first-of-a-kind interactive systems?
- What are the dimensions of Human Robot Interaction (HRI) as a first-of-a-kind interactive system?

An implementation of the user requirement determination was thought to be beneficial, in order to investigate the mentioned research questions, while exemplifying and observing user requirement determination process more clearly. Hence, in the Fourth Chapter, the methodology of user requirement analysis is explained deeply and its implementation on a first-of-a-kind interactive system development project, in the field of Human Robot Interaction (HRI) is documented. The challenge in that HRI project is maintaining users’ Situation Awareness (SA) and supporting their decision making while supervising multiple autonomous robots.

1.4 Structure of the Thesis

In the Second and Third Chapters, the outcomes of the conveyed literature review are presented. The Second Chapter starts with elaborating the key concept of this thesis, first-of-a-kind interactive systems. Later, Human Robot Interaction (HRI) is explained to set the background for the implementation that is presented in Chapter 4.

Then, in the Third Chapter, the requirement determination phases of user-centered design processes, as well as the approaches and techniques for determining these requirements are investigated. Finally, cognitive analysis techniques and among these techniques the ones that are appropriate for first-of-a-kind interactive systems’ requirement determination are described.

In order to support the theoretical discussions, a cognitive analysis implementation is presented in Chapter 4. The implementation is carried out for a competition called Multi Autonomous Ground-Robotic International Challenge (MAGIC) 2010 within Human Robot Interaction area. The aim of the study, the domain of the implementation study and the methodology are described. The chapter ends with explaining the limitations of the study and presenting the corresponding discussions about the implementation.

In the last Chapter, concluding remarks synthesizing the discussions in the literature and the presented implementation are delivered. The thesis is concluded with conveying suggestions for further research.

CHAPTER 2

FIRST-OF-A-KIND INTERACTIVE SYSTEMS AND HUMAN ROBOT INTERACTION

In order to elaborate the proposed research questions, this Chapter starts with the exploration of key concepts. In the first section, first-of-a-kind interactive system is defined, within the levels of innovativeness. Later, the design approaches are explained in order to set the background for requirement determination within those design approaches. At the end of the section, constraints of first-of-a-kind system development are explained. In the second section, Human Robot Interaction (HRI) as an interactive system has been investigated to set the key concepts for implementation in the following chapter.

METU, Bilkent University and Aselsan Inc. libraries and with direct access or through search engines like: METU Library online search and Google Scholar, varying electronic databases such as ACM Digital Library, IEEEXplore, EbscoHost, Elsevier, Wiley Inter Science, Science Direct, Taylor & Francis Online Journals and Ebrary are scanned for keywords including: user-centered design, usability, interaction design, first-of-a-kind, interactive systems, human robot interaction, unmanned ground vehicle, robot, situation awareness, human computer interaction, graphical user interface and so on.

2.1 First-of-a-Kind Interactive Systems

Prior to the introduction of systems which are able to process the inputs from people and respond to them, interaction could only occur between living creatures. Today, interaction can refer to a variety of human machine interactions, from turning on a kettle to aviating a plane.

Ha and James (1998) describe interactivity as a respond to communication needs between the audience and the communicator. Similarly, Newman and Lamming

(1995) mention the two way communication between user and the computer, and explain interactivity through user interface as follows:

> The user takes actions such as pressing buttons, pointing with a mouse or typing in text. The system reacts accordingly, perhaps by displaying information, perhaps by activating machinery or performing some other useful service, perhaps just by waiting for user's next action. All of this takes place via the system's user interface, the part of the system that provides access to the computer's internal resources.-(p.6)

The interface, users interact and access to the interactive system, represents the system for the users. Researchers have proved that, the users are usually not interested in how the system works, but want to know how they can perform their goals (Guida & Lamperti, 2000; Norman, 1986). The user interface of a system is the showcase of the system. Users decide if they want to buy it, if they like it or if it is simply good or bad by judging the system's user interface. Fischer (1989) claims that on the system failure or success, the communication capabilities and the interface of the systems are much more influential, than its processing speed and problem solving capabilities. Thus, the design of human system interaction is significant for the whole success of the system.

As mentioned before, within the interactive systems, this thesis is focused on first-of-a-kind interactive systems. In order to investigate what first-of-a-kind system implies within the innovation domain, the level of innovativeness is explained in the following section.

2.1.1 The Levels of Innovativeness

Dominantly, two levels of innovation are mentioned in the literature:

- Highly innovative products called: 'revolutionary', 'discontinuous', 'pioneering', 'game changing', 'boundary expanding', 'breakthrough', 'radical' or 'first-of-a-kind'
- Less innovative products developed by modifications on an existing product called: 'evolutionary', 'continuous' or 'incremental innovation' (Ali, Kalwani & Kovenock, 1993; Kiousis, 2002; Norman, 2010; Veryzer, 1998).

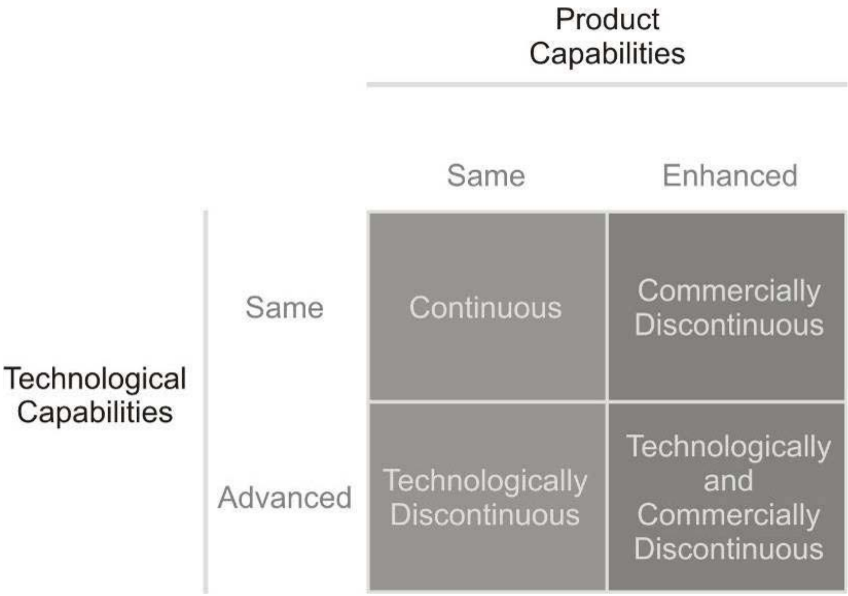
This categorization focuses on the level of technological novelty of the products. However, numerous studies indicate that a multidimensional scale is necessary to understand the innovativeness (Cooper 1979; Dahlin & Behrens 2005; Garcia & Calantone 2002; Green, Gavin & Aiman-Smith 1995; Lettl, Herstatt & Gemuenden 2006b; Soulder & Song 1997; Veryzer 1998).

There are many studies on the level of innovativeness promoting the multidimensional approach and some of those mention the factor of 'newness to the user'. For instance, Garcia and Calantone (2002) explain product innovativeness in three levels which are "newness to industry", "newness to firm" and "newness to the customer" (p.124). In an early study, Cooper (1979) lists the variables affecting the system's level of innovation as: "new to market", "unique features for customer", "superior to competing products in meeting customer's needs", "let customer reduce his costs", "product did unique task for customer", "product higher quality than competitor's" (p.97). Similarly, Soulder and Song (1997) explain the components of innovativeness as "product having unique features", "product unlike any other", "product requiring users to change their conventional modes of operating" (p.25).

On the other hand, Veryzer (1998) distinguishes technological/product capabilities and draws an innovativeness categorization based on those two:

- 'Technological Capability' implies to what extent the technology brings new ways to function products and expand technological capabilities,
- 'Product Capabilities' refer to the perceived and experienced novelty by users (Figure 5).

Types of innovation matrix adapted from Veryzer (1998) includes 'continuous', 'commercially discontinues', 'technologically discontinues' and 'commercially and technologically discontinues' categorizations (Figure 5).



Technological Capabilities \ Product Capabilities	Same	Enhanced
Same	Continuous	Commercially Discontinuous
Advanced	Technologically Discontinuous	Technologically and Commercially Discontinuous

Figure 5 “Types of product innovation” (adapted from Veryzer, 1998, p.307)

‘Continuous innovation’ implies products and systems applying both the available ‘Product Capabilities’ and ‘Technological Capabilities’ (Veryzer, 1998). ‘Technologically discontinuous’ category includes products with novel technologies that do not change the product’s interaction with the human. For example, after the launch of wireless remote controls, while a great deal of technological advancement has followed in televisions, only the media quality and form of the television has evolved, but the user experience of watching television has not changed drastically.

Thus, users not always conduct innovative experiences with products involving advanced and innovative technologies. Even by utilizing the same technological capabilities, enhanced product capabilities can be gained. For instance, Walkman®, the portable cassette player by Sony, launched in 1979, did not introduce novel technologies but a novel user experience. Walkman® changed the way of listening to music: carrying the portable music player around and listening to music with earphones while being involved with other activities (Du Gay, Hall, Janes, Mackay & Negus, 1996). Similarly, 20 years later, iPod®, a portable media player by Apple launched in 2001, introduced novel user interactions by applying already available (MP3) technology.

By considering all the mentioned studies it can be claimed that experienced innovativeness by the users includes products and systems which:

- Meet new customer needs (Cooper, 1979; Garcia & Calantone 2002)
- Utilize new experienced features and benefits (Cooper, 1979; Garcia & Calantone 2002; Veryzer, 1998).
- Introduce new ways of uses (Cooper, 1979; Garcia & Calantone 2002; Soulder & Song, 1997).

As mentioned before, instead of other terminology citing to the novelty of the system, the term ‘first-of-a-kind’ has been chosen in order to refer to the level of innovation, and underline the fact of being ‘first’ in a group of products or systems. After constructing the key terms for the process of determining user requirements of first-of-a-kind interactive systems, a requirement determination methodology is followed as an implementation in Chapter 4. Another reason for using the term ‘first-of-a-kind’ is the common use of the term in this implementation area which is Human Robot Interaction (Humphrey & Adams, 2010; Lintern, 2005; Naikar & Pearce, 2003; Naikar et al., 2006; Roth & Mumaw, 1995 etc.).

2.1.2 Design Approaches

Requirements analysis methodologies differ according to the approach held during the system development processes. Hence, the design approach is critical in order to investigate user requirements of first-of-a-kind interactive systems.

Design approaches are described in two main categories: System-Technology Centered Design and User-Centered Design (UCD). Even in System-Technology Centered Design approaches, the users of the system have always been important. However, in System-Technology Centered Design, the way the user is integrated into the design process differs from the UCD. In System-Technology Centered

Design, satisfying user needs is in the periphery, whereas fitting the system to the user is primary all through the design process in UCD.

a) System-Technology Centered Design

The very first studies on users were to decrease the errors caused by their misunderstanding of the system. For instance, Nagel's (1988) studies argue that a great percentile of accidents in aviation is found to be caused by 'human error'. The guilt was defined as the error of the human. So, first attempts were on selecting the right human who are less likely to make error and training them to enhance their safety and performance (Koonce, 1984). Massanari (2010) criticizes the approach in which the user is regarded as unpredictable and "stupid", so that, even in a well designed system, the user is supposed to make errors. 'The human error approach' is one of the system-technology centered design approaches in which design process is destined to overcome specific human limitations. Nevertheless, if the design process is not focused on the fit between the system and the user, the design may not even ensure reduced human error. As quoted in Woods and Roesler (2008), Cordesman and Wager (1996) state that even though the design of many systems aims to "ease the burden of the operator, reduce fatigue, and simplify the tasks involved in operations" (p.200), rather those increase the workload of the operator. Cordesman and Wager (1996) continue as follows:

> Almost without exception, technology did not meet the goal of encumbering the personnel operating the equipment… Systems often required exceptional human expertise, commitment, and endurance… As a result, virtually every advance in ergonomics was exploited to ask personnel to do more, do it faster and do it in more complex ways. One very real lesson is that new tactics and technology simply result in altering the pattern of human stress to achieve a new intensity and tempo of operations. (Cordesman and Wager, 1996 as quoted in Woods & Roesler, 2008, p.200)

Another system-technology centered design approach is not considering the target user group and designing for designers themselves. Hudson (2009) defines building empathy with the user as a basic and important system design technique. However, empathy should not be confused with the "assumption by technological creators that they themselves are prototypical users" (Massanari, 2010, p.404). Obviously, in order to design a system which satisfies user requirements, the designer, who is quoted as "the technological creator" by Massanari (2010, p.404), should be aware of the differences of the end-user from himself. The user does not necessarily like to be challenged to reach a menu, write abstract codes or read the manuals as the software engineer does.

Hoffman, Feltovich, Ford, Woods, Klein and Feltovich (2002) explain the process and consequences of System-Technology centered design as follows:

> In Technology Centered Design, system developers specify the requirements for machines, then implement or prototype the requirements, and finally produce devices and software. Then they go away, leaving users to cope with what they have built. (p.73)

In order to enhance system performance and user satisfaction, a development process only focused on technology development and "leaving users to cope with" philosophy is obviously insufficient. User-Centered Design (UCD) is a design approach and a group of methods focusing on the user involvement and iterative multidisciplinary system development processes (ISO 13407).

b) User-Centered Design (UCD)

There have been attempts to integrate user information to the design process, such as Gould and Lewis, (1983, p.300) who set three principles of design as "early focus on users and tasks, empirical measurement and iterative design". Still the actual term 'User-Centered Design' (UCD) was first mentioned by Norman and Draper (1986) in their book called "User-Centered System Design". Norman (1986) explains UCD as:

> User-centered design emphasizes that the purpose of the system is to serve the user, not to use a specific technology, not to be an elegant piece of programming. The needs of the users should dominate the design of the interface, and the needs of the interface should dominate the design of the rest of the system. (p.61)

Some of the benefits of UCD process to the final system design are increasing performance, user satisfaction and company reputation, while decreasing errors, training times and human support (Maguire, 2001). Similarly, Veryzer, & de Mozota (2005) propose impacts of including UCD into the new product development process, both on the process: “a more collaborative new product development effort”, “a positive effect on idea generation”, and on the final product: “a superior product or service”, a product that is “more readily adopted by users due to better product appropriateness” (pp. 135-138).

Following the book named “User-Centered Design” edited by Norman and Draper (1986), the UCD definition has expanded with dimensions like: “early focus on users”, “continuous iterations and prototyping”, “multidisciplinary team” and “active involvement of users” (Gulliksen et al., 2003; Kujala, 2003; Maguire, 2001; Shackel & Richardson, 1991).

In the literature, there are varying acronyms on the same design concerns mentioned (Figure 6); Hoffman et al. (2002) discuss-their relationships and conclude that “They are all rooted in the same soil. All drink the same water. All reach toward the same light”(p.78).

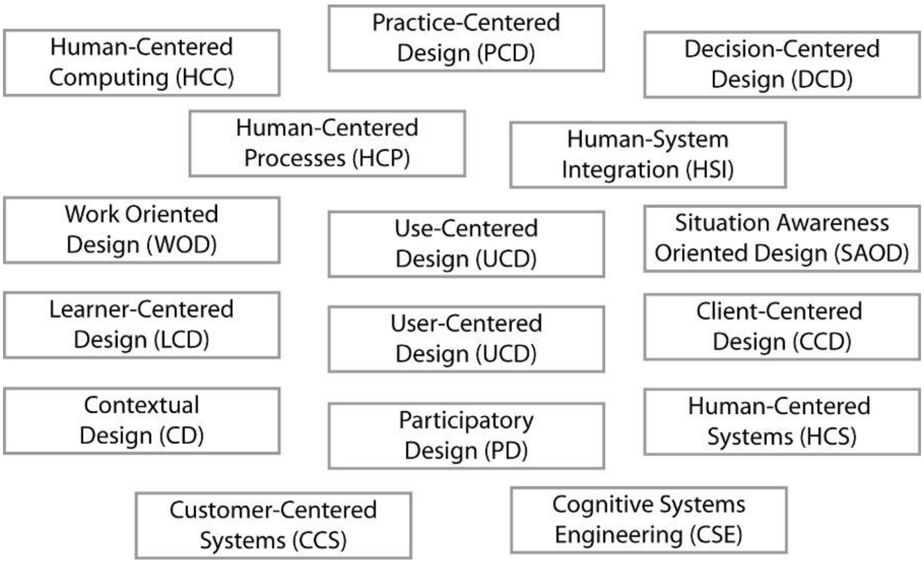


Figure 6 “The acronym soup of terms that have been offered to designate ‘the’ new approach to cognitive engineering” (adapted from Hoffman et al., 2002, p.73)

One of the acronyms is ‘Participatory design’ which is a phenomenon originated from Scandinavia, pointing out the “active involvement of users” dimension of UCD. In ‘Participatory design’ the intended users of the system attend the design process as peers (Schuler & Namioka, 1993). ‘Usability testing’ is a significant evaluation methodology in UCD, in which critical usability dimensions like “effectiveness, efficiency and user satisfaction” of a prototype or the final product/system is empirically measured, in a specified context of use (Bevan, 1995b; ISO/IEC 25062, 2006). Moreover, discussions like: “attractive things work better”, “why we love (or hate) everyday things” bring forward the hedonic product qualities and “emotional design” (Khalid & Helander 2006; Norman, 2004). Recently, fields like ‘interaction design’ and ‘experience design’ have emerged (Buxton, 2007; Schifferstein & Hekkert 2008; Sharp, Rogers & Preece, 2006; Moggridge, 2007, Xia & Li 2009).

All those approaches are in the same boundaries with different focuses; obviously they share the aim to design for the fit between the user and the system and in order to achieve user satisfaction. This thesis benefits from UCD approaches in order to depict the first-of-a-kind interactive system development process. Within the system development processes this thesis focuses on the requirement determination phase.

Up today, incremental innovations and first-of-a-kind systems bring different dimensions and drawbacks to UCD, which are elaborated in the following section.

2.1.3 Constraints of First-of-a-Kind Interactive System Design

Designer’s priorities and concerns for the systems presenting incremental innovations and first-of-a-kind innovations are different. Market success of the incremental innovation highly depends upon the difference it has among its equivalents. Therefore, UCD concerns such as user satisfaction, ease of use, and usability are essentials in order to get a market share. On the other hand, the designer of the first-of-a-kind system aims to market the product with its most distinguishing characteristic which is being first. Without any doubt, because of the ambiguities the first-of-a-kind system development present, developing a system which functions properly is the priority. Hence, the first-of-a-kind system designer may have the illusion of putting user requirements in the periphery of the system development, as satisfying user requirements is not an argument if the system does not work.

Moreover, the designers having the priority of building the ‘first’ with advance technology usually have remarkable resistance for UCD. Results of the Rosenbaum, Rohn and Humburg’s (2000) study show that the usability professionals consider the “resistance to user-centered design/usability” as the second important obstacle (26.0%) on the way to user-centered design, after “research constrains” (28.6%) (p.340). Resistance to UCD is a critical obstacle and its influence is greater in first-of-a-kind interactive system design.

Furthermore, as first-of-a-kind systems bring a kind of a novel feature, the new cognitive demands that novelty introduces to the users are usually undiscovered. In 1989, Weiner studied with airline crews on relatively automated and advanced aircrafts; and he claimed that ‘novel’ systems usually reduce the user’s physical workload, while increasing his cognitive workload. Even though what the “novel system” implies changed drastically in a decade, the argument remained similar:

> Poor use of technology can result in systems that are difficult to learn or use, can create additional workload for system users, or in the extreme, can result in systems that are more likely to lead to catastrophic errors. (Roth, Patterson, Mumaw; 2002, p.2)

For instance, washing machines decreased the physical effort necessary for washing clothes, while their digital interfaces make the user think about new variables such as temperature, duration, speed and water consumption. Obviously, in all kinds of systems, designing for user capabilities is a basic concern; still the reasons and consequences of these attempts differ according to the context of the system. In a casual activity like washing clothes, user frustration is the worst consequence of the poor use of the digital interface technology, which can lead to market failure. On the other hand, some professionals, whose jobs are to monitor, sort and control constantly changing real time data in a limited time, might not have second chances to make the right decisions. Hence, investigating those professional users' cognitive workloads is more fundamental for the system development.

Interactive systems include both physical and cognitive interactions with the users. However, with the introduction of computer mediated systems, the fit between human cognition and the system is emphasized more. Beyond the electromechanical interactive systems, computer mediated interactive systems introduce novel challenges to design. Smith (2007) in the book called "Designing Interactions" explains the differences between electromechanical and computer mediated interactive systems in terms of the human interaction they present.

> An electromechanical object, a radio say, links its physical mechanical components to its electronic elements in a fairly direct way. When we turn the dial, our fingertips and muscles can almost feel the stations being scanned. With computers, however, the distance between, on one hand, keystrokes and screen image, and, on the other, what's happening inside the computer, is usually much less direct. Our physical world and the computer's virtual world seem miles apart. (p.XV)

Developing the computer mediated systems, which build the desired mental representation in the users' minds, is critical in the interactive system design. Zhang and Norman (1994) formulate the mental model in the user's mind as "internal representation" and the product/system as "external representations" and claim that the cognitive workload of the user depends on this so called "distributed representation" (p.4). An understanding of what is happening in the user's mind, the human cognition, is crucial in order to design a system evoking the expected representations in the user's mind.

In order to cope with the new cognitive demands that first-of-a-kind systems introduce, cognitive capabilities of the user should be considered all through the design process. Even though, many researchers agreed on the necessity of focusing on the fit between the system and cognitive capabilities of the user, still "… system developers are heavily biased towards engineering the new technologies with little regard given to specifying the cognitive demands associated with the new technologies" (Naikar & Pearce, 2003, p.1928).

Although it is widely accepted that new technologies bring higher cognitive demands and the user research is the key to cope with that; System-Technology Centered Design approaches have always been more dominant comparing to User-Centered Design (UCD) approaches, especially in first-of-a-kind system development. Even Donald Norman (2010), one of the founders of User-Centered Design UCD, argued that "design research is great when it comes to improving existing product categories, but essentially useless when it comes to breakthroughs" (p.38). Opposite to the studies claiming the benefits of exploring user needs for innovative products (Lettl, Herstatt & Gemuenden, 2006a), Norman argues that none of the technological breakthroughs happened to satisfy a need (2010). He adds that the system the technologist invented may become complex and frustrating. But still, only after the invention, not during the design process; user research is beneficial to improve the system (Norman, 2010).

One of the arguments supporting Norman's (2010) debate is the solid obstacle to conduct user research in the early phases of the first-of-a-kind system development process, which is the lack of SMEs and experienced users.

Furthermore, in the marketing literature, the contribution of users in the first-of-a-kind system development is extensively discussed (Cooper & Kleinschmidt, 2007; Griffin & Page, 1993; Lettl et al., 2006a; Lynn, Morone & Paulson, 1996; Veryzer, 1998). Lettl et al. (2006a) portray users as "a source of market related knowledge" in order to resolve high market uncertainties of first-of-a-kind systems (p.26). Nevertheless, from the user's side, they mention some obstacles to involve users in first-of-a-kind system development process. They define those obstacles as the user's inability to convey proper information, and his lack of motivation in this process. They mention several reasons like the user being attached to the current context of use, user’s worry of the obsolescence of current knowledge (Sheth, 1981), user’s inability to generate novel ideas, user’s inability to evaluate without reference to similar systems and user being burdened by the complexities first-of-a-kind system introduces (Lettl et al., 2006a). Hence, Lettl et al., (2006a) place market related user research as a challenging but important contribution for first-of-a-kind system development.

It is noteworthy that, a decade before Lettl et al.’s study (2006a), Lynn et al. (1996) argued that user research was not appropriate for first-of-a-kind system development processes. Lynn et al. (1996) in their study on successful innovations, interviewed 78 people in and out of the companies and concluded that marketing research techniques, including user research: are often disregarded, maintaining limited benefits and even display inaccurate and misleading information. One of the participants of the study, who run a striking first-of-a-kind system development process, states:

> It did not get any help from the customer, who didn't realize, until they really saw the clinical evidence and technical papers that started coming out, just how important this was going to be. (p.15)

Lynn et al. (1996) conclude that because of the uncertainties first-of-a-kind system design involves the process is experimental, in which probing and redesigns gathered from the experience from those probes are crucial. Consequently, in marketing research, marketing related user research is described as challenging or even misleading in first-of-a-kind system development, especially in the early phases of the development process when prototypes are not available (Lynn et al., 1996; Veryzer, 1998).

Roth et al., (2001) claim that studies with actual users may limit and even mislead the first-of-a-kind system development process, as users have tendency to rely on their previous experiences and available technology within their limitations. Similarly, Maguire and Bevan (2002) claim that both users and designers have difficulties in being innovative as they prefer to think the current and traditional systems.

To sum up, the main constraints of user-centered first-of-a-kind interactive system development are as follows:

- Priorities and concerns of the first-of-a-kind interactive system designers (Naikar & Pearce 2003)
- Resistance to UCD by first-of-a-kind interactive system designers (Rosenbaum et al., 2000)
- Undiscovered cognitive demands of first-of-a-kind interactive systems (Weiner, 1989; Roth et al, 2002)
- The lack of experienced users and SMEs, in the early phases of first-of-a-kind interactive system development (Dearden & Howard, 1998)
- The lack of prototypes and similar products, in the early phases of first-of-a-kind interactive system development processes (Lynn et al., 1996; Lettl et al., 2006a; Lettl et al., 2006b; Veryzer, 1998; Newman & Lamming, 1995)
- Users limiting the first-of-a-kind system design, as they have tendency to rely on previous experiences and existing technologies (Lynn et al., 1996; Maguire & Bevan, 2002; Norman, 2010; Roth et al., 2001)

Obviously, Human Robot Interaction (HRI) is a significant first-of-a-kind system development area. Robots and their interaction with humans have been discussed not more than four or five decades and the area is subject to fresh opportunities and inventions. As Dautenhahn (2007) states, the field of Human Robot Interaction is “still in its infancy” (p.103).

In the Fourth Chapter, an implementation exemplifying the requirements determination of a first-of-a-kind interactive system in the HRI area is explained. Hence, following section investigates HRI and its dimensions in detail as a first-of-a-kind interactive system.

2.2 Human Robot Interaction (HRI) in First-of-a-Kind Interactive Systems

Robot Institute of America defines the robot in 1980 as “a reprogrammable, multifunctional manipulator designed to move material, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks” (quoted in Sciavicco & Siciliano, 2000, p.4). The word ‘Robot’ was first introduced by the Czech writer Karel Čapek in his play “Rossum's Universal Robots” published in 1920. ‘Robota’ in Czech means worker. The term ‘Robot’ is widely used for electro-mechanical machines or vehicles guided by computer programs. However, the term ‘unmanned vehicle’ is more common in military applications. The word ‘unmanned’ implies that there are not any onboard human on the vehicle. Paradoxical with their names, extensive human involvement is required for guiding or supervising those ‘unmanned vehicles’. Unmanned vehicles varies such as unmanned ground/aerial/underwater vehicles (UGV/UAV/UUV) depending upon the working environment.

Robots working autonomously, responding to human and showing emotional reactions have been parts of science fiction movies since 1920s. Nowadays, robots are fitting into our daily life slowly but with measured steps. In the HRI 2010 conference, Freier, Asada, Hinds, Sagerer and Trafton (2010) explain the state of robots and their foresights about them as follows:

> Robots are becoming part of people's everyday social lives - and will increasingly become so. In future years, robots may become caretaking assistants for the elderly or academic tutors for our children, or medical assistants, day care assistants, or psychological counselors. Robots may become our co-workers in factories and offices, or maids in our homes. They may become our friends. As we move to create our future with robots, hard problems in [Human Robot Interaction] HRI exist, both technically and socially. (p.11)

In various fields, production, search and rescue, entertainment, military, space, healthcare and transportation, robots are developed as assistants or substitutes for human labor. Humanoid Asimo® designed by Honda® in 2000 is helping people especially elderly (Figure 7a), Trilobite™ by Electrolux® in 2001 is a fully automatic domestic vacuum cleaner (Figure 7b), PARO® is a therapeutic robot developed by AIST® in 2003 treating patients (Figure 7c), the Caliber® designed by ICOR® in 2006 has a risky duty as a bomb disposal (Figure 7d); these are only some of the examples showing the different implementations of robot technologies.

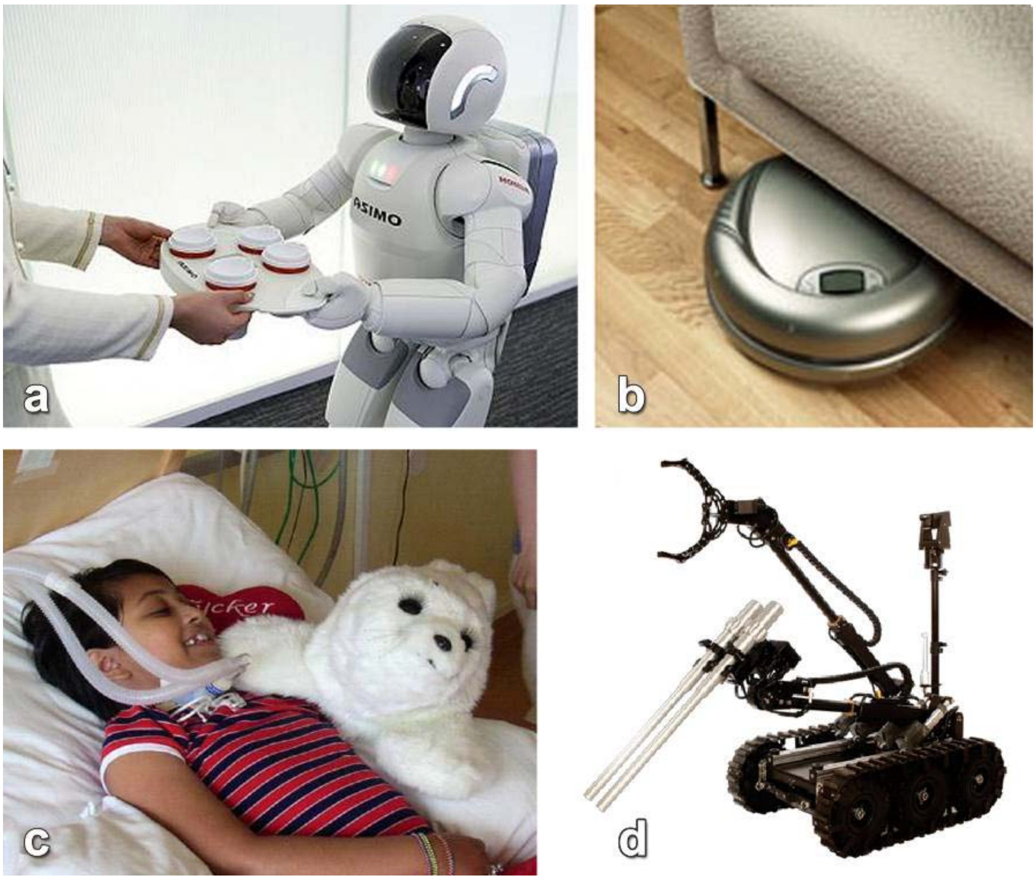


Figure 7 a) Humanoid Asimo® (Honda® 2000), b) Robotic Vacuum Cleaner Trilobite® (Electrolux® 2001), c) Therapeutic robot PARO® (AIST®, 2003), d) Bomb disposal robot Caliber® (ICOR Technologies® 2006)

Mainly, robots are operated in tasks which are difficult and unsafe for human, which require repetitive continuous actions, and complicated calculations of huge data. The ultimate goal of robotics is developing fully autonomous robots. Autonomy is partly fulfilled for some task specific matters, but still robots require human supervision or programming. Lin et al. (2008) claim that human intervention is necessary for robots, at least in the preprogramming levels:

> While it is true that programs need to be created by some programmer, even programs written by other programs, there will always be some external, human cause for whatever actions machine exhibit; so artificial autonomy would be impossible if no person can play a role in the causal chain, especially at the programming level (p.105)

Cognitive human capabilities like intelligence, reasoning, adapting, synthesizing are still quite difficult to be performed by robots. In an early attempt, Kelley in 1968, argued that autonomous systems would not be substitutes for human; those systems would even make the role of human more cognitive. His early hypothesis has not been disproved yet.

As mentioned, robots interactions with humans are described as inevitable. Surprisingly, this interaction between humans and robots has been a topic for a long time, even before robots are developed. As quoted in Isaac Asimov (1968), in his novel “I, Robot” dated 1941, states the “Three Laws of Robotics” basically for the safety of human in the robot interaction. Nowadays, in Human Robot Interaction (HRI), beyond the security of the human, sustaining a more intuitive interaction between human and robot has been investigated (Atienza & Zelinsky, 2005; Voyles & Khosla, 1995).

HRI is a multidisciplinary field at the intersection of areas like robotics, artificial intelligence, engineering, computer sciences, social sciences, human engineering, and human-computer interaction (Dautenhahn, 2007). Ancestors of the field of HRI can be defined as Human Machine Interaction (HMI) and Human Computer Interaction (HCI). However, robots bring forward new dimensions, making HRI different from HCI and HMI. Scholtz (2003) lists the differences of HRI as follows:

- Operator may play different roles like supervisor, operator, bystander and teammate, which requires different human interactions.
- Mobile robots build a “world model” from the real world with limited sensors and algorithms. The modeled world version is the main tool for the user to comprehend the state and environment of the robot.

- Robots have a dynamic nature. Sensors of robots may fail and the user may continue the operation with missing sensory information.

- Environmental conditions where robots perform their tasks can be dynamic, harsh, noisy and so on.

- The number of robots a single user operates can be more than one. Increasing the number of robots a user supervises, without increasing the cognitive workload of the user is one of the main goals of HRI.

- In the autonomous mode of the robots, users are responsible for monitoring the actions of the robots and interrupt the autonomy when necessary, which emphasizes the importance of maintaining “situation awareness” of the user (pp.1-2).

One of the critical factors affecting users’ decision making in human robot interaction is attention, because human beings can only pay attention to certain amount of information instantly. Simon (1971) in his farsighted article refers to his observations:

> What information consumes is rather obvious: it consumes the attention of its recipients. Hence a wealth of information creates a poverty of attention, and a need to allocate that attention efficiently among the overabundance of information sources that might consume it. (pp.40-41)

Hence, attention is one of the significant cognitive limitations causing the mismatch between human and the system. Endsley (2003) studies the reasons of cognitive mismatching between human and the system. She states that in majority of cases “people do not make bad decisions or execute their actions poorly; they misunderstand the situation.”(p.12). She also depicted that %88 of human error was found to be the result of problems with Situation Awareness (SA) (Endsley, 1995). Endsley (2003) defines SA as “being aware of what is happening and understanding what that information means to you now and in the future.” Especially in goal oriented complex and dynamic operational situations SA has been studied as a significant measure of system performance (Redish, 2007). SA in HRI is further elaborated in the following section.

2.2.1 Situation Awareness (SA) and Human Robot Interaction (HRI)

Murphy and Burke (2005) assert that, understanding the robot's state and its environment, in other words building 'Situation Awareness' (SA), takes much more time than navigating the robot. Results of their field studies with 33 operators show that "the robot is stationary half the time, as operators try to understand what is going on around them by communicating about the task, system and environment" (p.4).

The terms 'Situational Awareness' and 'Situation Awareness' are used synonymously; the second one is more dominant in the literature. In this study the acronym SA will be used for the term 'Situation Awareness'. Endsley (2003) draws SA as the foundation of decision making and performance (Figure 8).

In User-Centered Design (UCD) literature, even though the specific term 'situational awareness' is not referred, its content has been frequently implied. Norman (1988) who has suggested the UCD approach draws some of key points of it, as follows:

- The possible actions should be easy to distinguish
- Current state of the system, alternative actions and results of the actions should be visible
- There should be natural mappings between actions and effects (p.188).

In other words, Norman (1988) suggests that for UCD, user should be aware of the situation and be aware of the consequences of his action. Norman (1988), without referring to the exact term, mentions SA as a prerequisite for UCD. Moreover Endsley (2003) also fits her SA theory on UCD approach. She describes SA as a key to UCD and writes the principles as follows:

- Design for user's goals and abilities
- Design according to user's way of processing information and making decision
- Design to keep user in control and aware of the state of the system (p.10)

Even though SA has been an important topic in aviation psychology for a couple of decades, the term SA has lately started to be referred in Usability literature. Redish

(2007), one of the leading authors in usability literature, brings forward a question: "How do we evaluate the usability of systems that are too complex for our typical usability testing protocols?" (p.102). What "complex systems" implies is quite critical to understand her concerns. She lists the characteristics of complex systems, which are obviously also valid for HRI:

- Information overload
- Cognitively burdensome data analysis and decision making
- Unreliable and incomplete information
- Critical time factors
- Professional users
- Usually data analysts and decision makers are not the same
- Visual representation of the data is critical (Redish, 2007)

She makes some additional suggestions for the usability evaluation of complex systems characterized above: conducting usability studies together with domain experts and developers, having multiple evaluators, running simulations, investigating "unattended data capture", making "**situation awareness measurements**" (Redish, 2007).

There have been several attempts to depict SA. One of those is drawn by Dennehy and Deighton (1997). They define SA as the "operational space within which personal and environmental factors affect performance" (Dennehy & Deighton, 1997, p.287). Their attempt to draw the "operational space" is shown in Figure 8; which summarizes the dimensions affecting SA of the operator in its context.

Their effort was primarily fitting the person to the environment thus characteristics of the "subjective person" is underlined, whereas equipment itself is described as "objective environment": a constant element of the environment. "Objective environment", as Dennehy and Deighton (1997) described, consists of some constant features that designers are not capable to change. Even though later in the literature focus shifted to designing system that fits the person, their "interactionist" model kept its significance as the model describing SA with its environment.

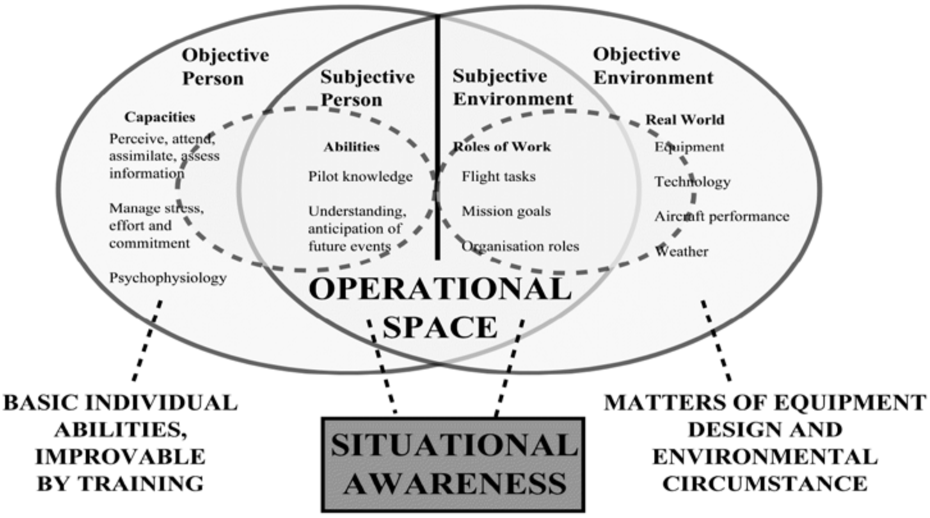


Figure 8 Interactionist Model of SA (Dennehy & Deighton, 1997, in Smith, 2003)

Salmon et al. (2007) summarize other SA models as presented in Figure 9. While Endsley (1995, p.36) defines SA as ‘situation assessment’ and distinguish SA as the ‘state of knowledge’, Smith and Hancock (1995) define it as “adaptive externally directed consciousness” (p.137) and Bedny and Meister (1999) construct their SA theory on the ‘Activity Theory’.

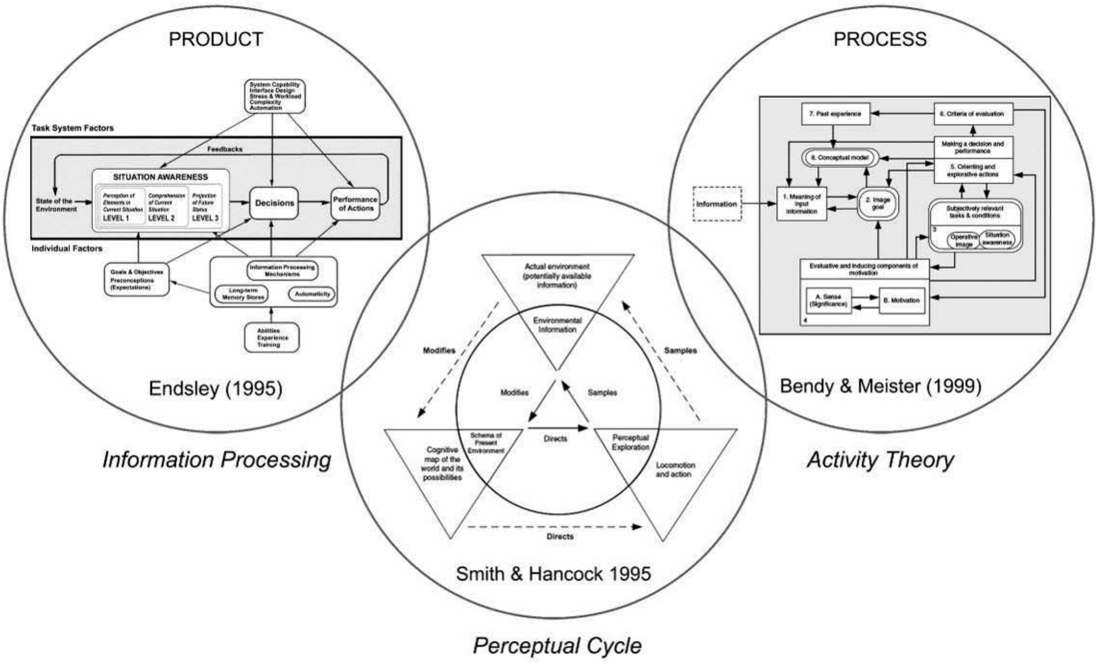


Figure 9 “Situation Awareness Models” (adapted from Salmon et al., 2007, p.410)

Salmon et al., (2007) state that all those theories have different useful characteristics. Smith and Hancock's (1995) theory is strong in explaining the dynamics of SA and Bedny and Meister's (1999) theory is significant as it explains user's internal cognitive activities while maintaining SA. However, those two theories have not been supported by empirical evidences. On the other hand, even though Endsley's (1995) theory is criticized for being simple (Bendy & Meister, 1999), not compatible with the dynamic nature of SA (Salmon et al., 2007) and defined over ill defined constructs like mental models (Smith & Hancock, 1995); still it is the dominant theory in literature. Because, Endsley's (1995) theory is easily applicable in practice as it presents measurable constructs, helps to gather inputs for the design process and provides empirical evidences.

Endsley (1988) defines SA as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future". As shown in the Figure 10, Endsley (1988) specifies three levels of SA: perception, comprehension, projection.

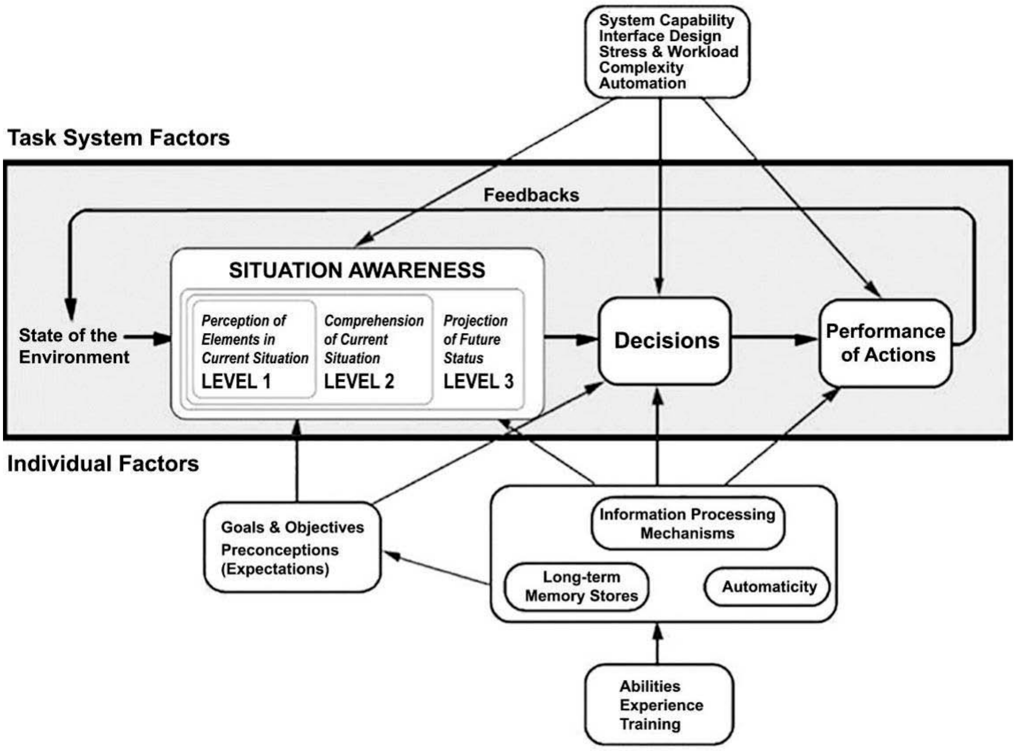


Figure 10 "Model of SA in dynamic decision making" (Endsley 1995, p35)

The concept of SA was born in military, especially in aviation ergonomics to explain the dimensions affecting the cognitive performance of the crew. Later it has attracted attention from varying fields as being foundation of decision making and performance (Figure 11).

Figure 11 “Situation awareness drives decision making and performance” (Endsley, 2003, p.12)

The concept of SA is applied to: air traffic control, education, medicine, driving, train dispatching, advanced manufacturing systems, maintenance, power plant operation and weather forecasting. It has even been applied to non work related activities like: sports, self protection and acting (Endsley, 2003). HRI is one of the critical areas where maintaining SA is very critical. The dimensions of HRI are explained in the following section.

2.2.2 Dimensions of Human Robot Interaction (HRI)

There have been various attempts to draw the dimensions of HRI in the literature. For instance, Scholtz (2003) distinguishes the following HRI dimensions: the roles of the human in the interaction, limited perceived environment through sensors and cameras of the robot, environmental conditions of robots, number of robots a human interacts with, and the level of autonomy. Similarly, Yanco and Drury (2002) draw the dimensions of HRI: the level of autonomy, number of human-robot ratio, shared interaction level among teams, decision support tools, criticality, “time-space taxonomy” and the robot team composition.

Additional dimensions of HRI are investigated in the literature, such as social and emotional dimensions, which are quite critical where robots make proximate interaction with both their trained users and uninformed people. Murphy and Burke (2005) mention the social interaction dimension of HRI, in search and rescue tasks, in which robots conduct proximate interactions with both the rescuers and the victims. Similarly, Mutlu and Forlizzi (2008) make "an ethnographic study of an autonomous hospital delivery robot", and show that "aspects of workflow, and social/emotional, political, and environmental context influenced how workers at a hospital used, perceived, and interacted with the robot" (p.293).

As the focus of the implementation explained in the Fourth Chapter is *remote supervisory multiple robot interaction* through graphical user interfaces, in order to explain the broad range of HRI types and the position of *remote supervisory multiple robot interaction* within this range, the following dimensions are explained in detail:

> **Location and Role of the User:** "Time/space taxonomy" (Scholtz, 2003; Yanco & Drury, 2002)
>
> **Autonomy Levels of the Robot:** (Scholtz, 2003; Yanco & Drury, 2002)
>
> **Team Structure:** "Ratio of people to robots", "Level of shared interaction among teams" and "Composition of Robot Teams" (Scholtz, 2003; Yanco & Drury, 2002)

a) Location and Role of the User

There are several attempts to classify user roles in HRI. For instance, Scholtz (2003) distinguishes five types of HRI with different user groups and requirements: supervisor interaction, operator interaction, mechanic interaction, peer interaction, bystander role. His categorization focuses on the responsibility of the user in that specified role within HRI.

HRI can mainly be categorized into two, based on the locations of human and robot, as remote and proximate interaction.

Remote HRI: Operating robots that are not in the vision of the user requires additional concerns such as user's awareness of the position and surroundings of the robot. In remote operations user relies on the vision gathered from the cameras and sensors on the robot. These are displayed to the user usually through Graphical User Interfaces (GUI). This conversion brings some difficulties for the user. Drury, Hestand, Yanco and Scholtz (2004) underlined that operator's awareness of the position of the robot and its environment cause most of the HRI problems. In remote HRI human can have varying interaction roles, depending on the autonomy levels of the robot:

- **Operator interaction:** controlling and monitoring actions
- **Supervisor Interaction:** controlling and monitoring long term task planning
- **Peer Interaction:** controlling end goals (Scholtz, 2003).

Proximate HRI: In proximate HRI, user controls the robot from a proximate distance. User can be located inside the robot as a user, or work with the human together. For instance, an agriculture robot developed by Shigeki Toyama is a robot suit designed to help elderly agriculture workers through tough works (Figure 12a).

In proximate interaction human and robot are at the same location so human is capable of perceiving the shared environment, free from robot's sensors and cameras. In some of the cases user may control robots, from a proximate distance through portable devices, while seeing the robot (Figure 12b).

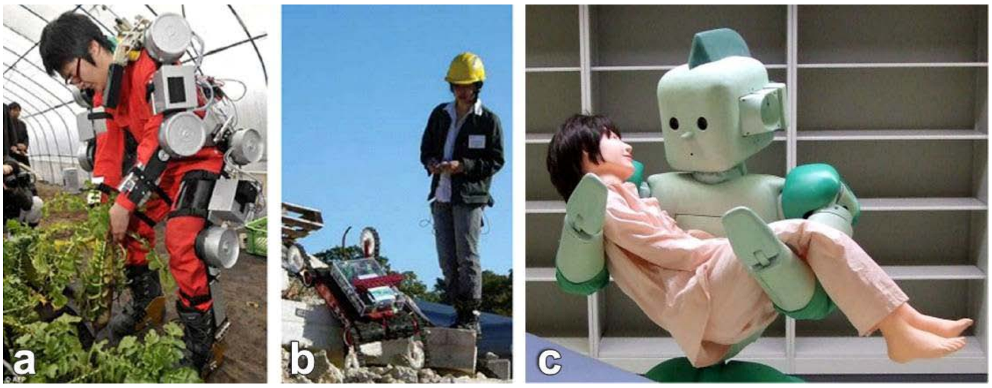


Figure 12 a) Agriculture Robot by Shigeki Toyama to Help Elderly Agriculture Workers, b) Proximate Robot Teleoperation for Search and Rescue, c) RI-MAN® Developed by RIKEN to Care Patients

Robots do not always interact with their expert users but sometimes with untrained people. Social and emotional HRI studies usually carry out for tasks requiring interaction with uninformed humans or cases where robots are made to serve and help people. For instance, RI-MAN® (Figure 12c) developed by RIKEN in 2006, cares patients, and hence requires proximate interaction with untrained people. Human can also have secondary roles in the proximate HRI; for instance, the role of a mechanic working on the hardware of the robot and testing the outcomes of the modifications is a secondary role in proximate HRI.

b) Autonomy Levels of the Robot

User's role in remote HRI can be different according to the robot's level of automation. HRI requiring 'real time direct human manipulation' is referred as 'teleoperation'. In supervisory control, robot has the ability to behave according to the pre-loaded data, usually asking for permission in changing environments. While the user in supervisory control, simultaneously follows robot's actions and is able to interrupt, and take the control when needed. Peer to peer collaboration is the highest robot autonomy level where robot and human are sharing responsibility. The autonomy levels from direct control to dynamic autonomy are given in Figure 13.

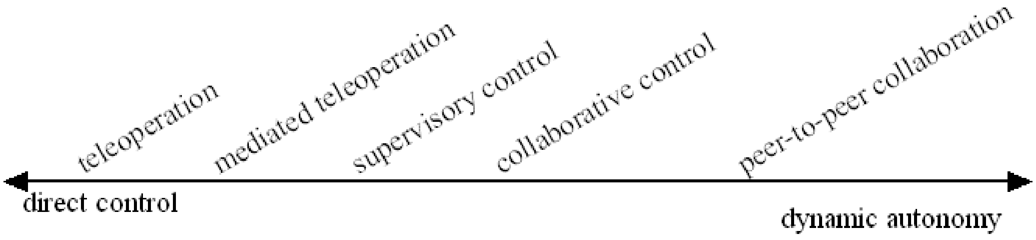


Figure 13 Types of HRI in Terms of Robot Autonomy Level (Goodrich & Schultz, 2007)

Increasing robot autonomy has been a significant concern in HRI to decrease user's workload. However, Endsley (2003) states that "… keeping the user in control is fundamental to good SA" (p.12). On the other hand, partly giving the control to the robot, in other words automation is served as a solution to reduce the 'human error'. Even though automation aims to reduce workload and the need for SA of the user; if it is not designed properly it can increase the reaction time and cause loss of attention (Endsley, 2003). Adams (2007) draws this relationship between user SA and robot SA according to the levels of autonomy (Figure 14).

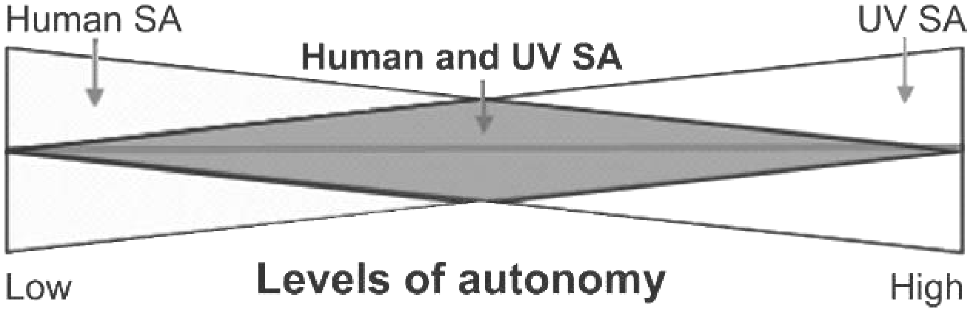


Figure 14 Allocations of Human SA and Unmanned Vehicle(UV) SA According to the Levels of Autonomy. (Adams, 2007)

Endsley (2003) claims that SA in automated systems is as important as in manual controls; she adds that, it is not enough to only display the automaticity mode, the information about how the goals are performed by the machine should also be presented. Thus, the user would be kept in the loop and he would be able to take control back when necessary (Endsley, 2003).

c) Team Structure and Situation Awareness

HRI not always occurs between one human and one robot. As in the implementation presented in the Fourth Chapter a single user might be charged for supervising multiple robots. The number and combination of humans and robots are significant for the design of the HRI.

There are suggested theories for team SA, where more than one user and robot is included. Salas, Prince, Baker and Shrestha (1995) argue that team SA is the team members' shared SA in a specified time. On the other hand, Endsley (2003) draws the importance of team members' responsibilities on their SA, still agreeing about overlaps in individual SA. A more comprehensive concept of team SA is called 'distributed SA'. Artman and Garbis (1998) define team SA as a "partly shared-partly distributed" construct; so, none of the team members has the overall SA.

Distributed SA theory claims that SA is distributed to the system as knowledge elements and team members do not have the same SA for the same situations but their SA overlaps and compensates each other (Stanton et al 2006). For all the team SA theories, communication is one of the fundamental elements. Level of communication between team members affects the overlaps of individual SA's and distribution of them.

The number of robots that can be controlled simultaneously by a single user is one of the investigations on human robot team structures. One of the main goals of HRI is increasing the number of robots a single user control, without increasing the workload of the user. Murphy and Burke (2010) claim that, for teleoperation, the formula for safe human-robot ratio is as follows:

$$\textbf{NUMBER OF USERS} = \textbf{THE NUMBER OF ROBOTS} + \textbf{THE NUMBER OF PAYLOADS} + \textbf{ONE USER FOR SAFETY}$$

From this equation, for instance, in order to safely tele-operate two robots each having a camera as a payload, five users are necessary. Murphy and Burke (2010) mention that by autonomy or semi-autonomy the ratio may be reduced, in other words robots may be supervised by less number of users. However, still they underline that autonomy may result in loosing attention because of user feeling out-of-the-loop.

While Murphy and Burke (2010) discuss the necessity of multi users controlling a single robot for the safety issues; there are studies focusing on the maximum number of robots that a single user can supervise. For instance, Trouvain, Schlick and Mevert (2003) measure the performances and mental workloads of the users serially supervising one, two or four robots. Their empirical study evidenced that, the mental workload of the user gradually increases with the increasing number of robots. Furthermore, the performance of the user supervising only one robot is the highest while supervising two or four robots do not change the performance drastically. However, Parasuraman, Galster, Squire, Furukawa and Miller (2005) investigated the single user supervising four or eight robots and argued that total performance decreased while interacting with eight robots.

Human Robot Interaction and its dimensions are explained in order to set the key dimensions of the domain for the implementation in the Fourth Chapter.

As discussed before, determining user requirements early in the design process is critical and first-of-a-kind system development presents specific constrains. In the following Chapter how to determine user requirements of first-of-a-kind interactive systems are discussed.

CHAPTER 3

DETERMINATION OF USER REQUIREMENTS

The following chapter starts with elaborating key concepts such as requirements and user requirements. After investigating the significance of requirements determination phase in user-centered system development processes, varying user-centered approaches for determining user requirements are explained. Finally, the methods for determining user requirements and especially for first-of-a-kind interactive systems are conveyed.

METU, Bilkent University and Aselsan Inc. libraries and with direct access or through search engines like: METU Library online search and Google Scholar, varying electronic databases such as ACM Digital Library, IEEEXplore, EbscoHost, Elsevier, Wiley Inter Science, Science Direct, Taylor & Francis Online Journals and Ebrary are scanned for keywords such as requirement determination/analysis/ writing, usability requirements, user-centered requirements, user requirements, quality requirements, cognitive task/work analysis, first-of-a-kind systems and Hybrid Cognitive Task Analysis.

3.1 Significance of Requirement Analysis in User-Centered Design Processes

Considering any industrial design process, requirement is a wide term embracing a variety of concepts from business requirements, process requirements to design requirements. Even the ‘design requirements’ is referred with different names in the literature such as ‘requirements’ (Robertson & Robertson, 1999), ‘system requirements’ (Bahill & Dean, 2009; Glinz, 2007), ‘information requirements’ (Davis, 1982), and ‘design requirements’ (Higgins, 2003). The term ‘requirement’ used in this thesis refers to the specifications, which explain the experiences, a designed product or system provide to its users.

Requirements' existence relies on two main cases; either the client/stakeholder demands certain specifications; or the design team takes a group of people into consideration, so called 'target users', and define their needs. In both cases, the design team regenerates those 'specifications', 'user needs' or 'design briefs' into design requirements, which guides the system development process. Bahill and Dean (2009) describe requirement as "… [the] statement that identifies a capability or function that is needed by a system in order to satisfy its customer's needs." (p. 209). Requirements depict what the system should perform, without explaining how it is done.

ISO 13407 (ISO, 1999) standard draws essential User-Centered Design (UCD) activities during the design process. As shown in Figure 15, after "understanding and specifying the context of use" phase, "specifying the user and organizational requirements" phase begins.

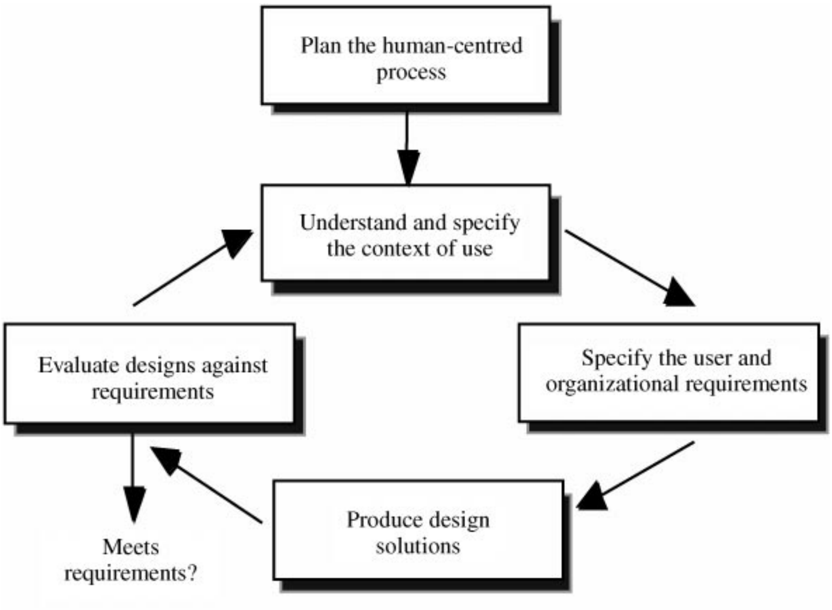


Figure 15 User-Centered Design Process (ISO, 1999)

Requirements should be explored before starting to design and construct a system. Discovering a design requirement during the design process could lead to expensive redesigns or market failure (Robertson & Robertson, 1999). In a survey done by Taylor (2000), 38 project managers are asked about the reasons of failure in information technologies. Those project managers most frequently mentioned "unclear objectives and requirements" as the reason of failure and vote the same factor as the most important one (p.25).

Predominantly in the literature, requirements are divided into two main categories:

- **Functional requirements**; what the system must do,
- **Non-functional requirements**; the properties and qualities the system must have (Bahill & Dean, 2009; Bevan, 2010; Robertson & Robertson, 1999 etc.).

Hochmüller (1997) preferred to use the term 'extra-functional' instead of 'non-functional', as the term 'non-functional' implies negative aspects. The term 'extra-functional' is originated by Shaw (1996). In order to underline its importance and assistance to build functional requirements, it is called extra-functional also in this thesis.

Contrary to definite and straightforward functional requirements, extra-functional requirements are usually described as ambiguous, difficult to elicit and difficult to measure (Hochmüller, 1997). Description and classification of extra-functional requirements show great variety in the literature. ISO 9126 Standard describes extra-functional requirements as product quality attributes and lists categories of extra-functional requirements as reliability, usability, efficiency, maintainability, and portability. In "Recommended Practice for Software Requirements Specifications" (IEEE STD 830, 1998) extra-functional requirements are classified as external interfaces, performance, quality attributes and design constraints.

The term 'user requirement' implies all kinds of requirements derived from the needs of users, preferences of the users, and the physical and cognitive capabilities of the users.

Within classifications of requirements, some user requirements are mentioned with terms such as 'user' (Maguire & Bevan, 2002), 'usability' (Glinz, 2007; Maguire & Bevan, 2002), 'quality in use' (Bevan, 1995a), 'human factors' (Allendoerfer, 2005) and "accuracy, security and performance" (Chung & Nixon, 1994, p.1) and those are placed into the non-functional or quality requirements category, so called extra-functional requirements. However, this division is unclear; placing user requirements in the extra-functional category may imply that the functions of the system design are not obtained from user requirements. Derived from Bevan's (1995a) 'quality of use' definition, Allendoerfer (2005) argues that "quality in use is a product of both functional and non-functional attributes" (p.1). Obviously, in order to develop a system conforming users, user requirements should directly shape both functional and extra-functional requirements, in other words functions and qualities of the system.

Sutcliffe (2002) explains the motivation of user requirement determination in the computer domain as "to reduce the high cost of misunderstanding between users and designers, so that computer systems are built to do what the users want, on time and at a reasonable cost" (p.4). The costs of an ill defined requirement increases drastically when the development process moves toward the end (Sutcliffe, 2002). Hence, understanding what user wants as early as possible in the system development process is critical for the whole success of the system.

For the system aiming to satisfy human needs, the main source of requirements is obviously human; with his needs, wants, cognitive capabilities and constraints. However, analyzing those is quite difficult, because they are driven by subtle factors like time, place, ethnography, culture, experience and emotion. In the literature, the challenges of user research in requirement determination phases are frequently mentioned. For instance, McConnell (1996) discusses that users could inhibit exploring requirements process and lead to change requirements even during the design process. Maguire and Bevan (2002) mention that both users and designers have tendency to think the current and traditional systems and they have difficulties in being innovative. Robertson (2001) claims that "the reason for the late discovery of requirements is usually because [of] they have not been able to inspire the stakeholders to think past preconceptions and communicate what they want" (p.406). He explains that, even though stakeholders tend to mention the requirements that they are “conscious” of, there are also “unconscious” and even “undreamed requirements” (p.406). Robertson (2001) claims that it is not possible to uncover all these requirements only by interviewing users; so, he suggests some techniques that he calls ‘trawling techniques’. Similarly, Davis (1982) states that to obtain correct and complete requirements, it is not enough to only ask potential users of the system what they want.

Therefore, techniques and methodologies are necessary to obtain the concealed requirements and there are various approaches for determining them. In the following section the approaches for the determination of user requirements are explained.

3.2 Approaches for the Determination of User Requirements

> Practitioners have great difficulties specifying usability requirements and often end up stating that **the system shall be easy to use** (Lauesen and Younessi, 1998, p.1).

The statement that Lauesen and Younessi (1998) specify in order to underline the difficulty of determining user requirements, **“the system shall be easy to use”,** is obviously an ill defined requirement as it is unverifiable, ambiguous, untraceable and incomplete. Because, bare adjectives describing the qualities of the system are not requirements, until how to measure or realize those are defined.

In order to write well defined requirements, described as achievable, verifiable, unambiguous, complete, correct, traceable and consistent (IEEE STD 830, 1998; Bahill & Dean, 2009; Leonard, 1999), there are several approaches proposed in the literature. The following approaches are mostly compiled from Allendoerfer (2005) and Lauesen & Younessi (1998)’s studies as those are the most comprehensive ones in the literature.

Lauesen and Younessi (1998) list six approaches for determining user requirements:

- Performance Based Requirements
- Defect Based Requirements
- Process Based Requirements
- Subjective Requirements
- Design Based Requirements
- Guideline Based Requirements

Allendoerfer (2005) remarks on those six and adds three more:

- Training Based Requirements
- Help Request Based Requirements
- Outcome Based Requirements

Each of those user-centered requirement determination approaches are explained in the following sections in a rearranged order in order to serve the goals of this thesis. At the end of the section, those are discussed in terms of their conformity with the first-of-a-kind system development. Additionally, an example for each approach is given in order to clarify the issue. The example is about a web-site application of a hypothetical online flight booking system; so, the given data is arbitrary.

1) Performance Based Requirements

To define performance based requirements, user profile is specified and then, that profile's success is statistically conditioned in terms of criteria like timing, accuracy or steps followed for specific tasks (Allendoerfer, 2005). Three kinds of information have to be collected in order to determine performance based requirements: user profile, critical tasks and performance objectives (Lauesen & Younessi, 1998).

a) Task: Task is the work to be performed in order to achieve the goals. Lauesen and Younessi (1998) explain that the task should be clear and meaningful in order to depict the purpose and it should explain its time limits.

b) User profile: User profile is representing the characteristics of users and/or potential users of the system, hence aiding the designer in making design decisions. User profiles should include characteristics like demographics, job, experience and so on. Some specific characteristics may also affect the performance of the user while performing specific tasks. Hence, additional factors may also be included such as “work experience”, “general computer experience”, “specific computer experience”, “experience with similar products” and “experience with this specific product” (Dumas & Redish, 1999, p.122).

c) Performance objectives: Performance objectives are statistically conditioned in terms of timing, accuracy, steps followed. Those should be inferred from the known performance objectives (Allendoerfer, 2005). In order to write realistic performance requirements, performances of the specific user profiles should be empirically observed and tested.

Example Task: *Book a one-way flight from İstanbul Atatürk Airport to Ankara Esenboğa Airport on 07.02.2011 in the morning*

- ***Users with computer experience, without online flight booking system experience*** *should be able to perform the task in* ***10 minutes or a maximum of 6 steps***
- ***Users experienced with online flight booking systems*** *should be able to perform the task in* ***5 minutes or a maximum of 3 steps***

This type of requirements, guide the designer about how the system will be verified; but do not explain the methodology exclusively. In order to set complete performance requirements of a system; variables, number of users and context should also be defined (Lauesen & Younessi, 1998).

Newman and Lamming (1995) underline that, performance requirements alone may not ensure a usable system, as follows:

> … speed of operation is often given highest priority because it has the greatest effect on efficiency and cost savings. However, if people never succeed in learning to use the system properly they will never achieve their intended speed of task performance, and if they make lots of errors they will spend valuable time correcting them. (p.153)

2) Outcome Based Requirements

Performance requirements cannot be applied to systems with complex unstructured tasks which include metrics like “problem solving, decision making, situation awareness, creativity” (Allendoerfer, 2005, p.4). In this approach the requirements are defined as the specific outcome of a system, and the methodology to evaluate that outcome is explained.

*The **situation awareness** of the system should be improved compared with the previous version, the evaluations should be made with the SAGAT methodology (Endsley et al. 2003)*

This methodology is applicable when performance metrics like accuracy and speed are not obtainable or not enough to evaluate the system. It requires previous comparable measurements of the outcomes, and a valid evaluation methodology.

3) Training Based Requirements

Training based requirements resemble performance based requirements. In training based requirements, additional to performance objectives, training objectives are defined in terms of time limits and experience levels. Reducing training times usually express an improvement in usability (Allendoerfer, 2005)

- *Users with computer experience, without online flight booking system experience should be able to perform the task in 10 minutes or a maximum of 6 steps **with a one-to-one training not exceeding 5 minutes or with the using help program not exceeding 10 minutes.***
- *Users experienced in online flight booking systems should be able to perform the task in 5 minutes or a maximum of 3 steps **without any training or using help program.***

Training times alter according to the user profile, context of the task and performance criteria. Where complex systems designed for professionals may require long training times, everyday systems in the use of a variety of user profiles are ideally do not require any training to accomplish main tasks. In this approach, similar to performance requirements, in which specifying performance criteria requires extensive research, specifying feasible training times is necessary to set training objectives.

4) Defect Based Requirements

In this approach requirements are determined by the limits of the numbers of the usability problems and their severity (Lauesen & Younessi, 1998). The usability defects may be classified such as task failure, severe problems and moderate problems.

- *Users with computer experience, without online flight booking system should be able to perform the task* ***at most 0.3 per user task failure/ at most 0.6 per user severe problems/ at most 4 moderate problems***
- *Users experienced in online flight booking systems should be able to perform the task in* ***at most 0.2 per user task failure/ at most 0.4 per user severe problems/ at most 2 moderate problems***

Defining the possible usability defects and their severity levels for the system is critical to determine realistic defect based requirements (Allendoerfer, 2005). In order to draw objectives about usability defects and their severity usability testing should be proceeded on similar products and prototypes.

If procedures are well defined, the defect based requirements can be verified with empirical user tests. However, this approach relies on an assumption: if users do not encounter any usability problems then the system is assumed to be efficient and satisfactory, no matter how difficult it was to operate the system, and how long it takes to learn and complete tasks and how frustrating it is to complete those.

5) Subjective Requirements (Satisfaction)

In this approach the requirements are defined as the subjective measures of user satisfaction.

90% of the users at their first try of the system should rate the system **pleasant.**

60% of the users at their first try of the system should rate the system **joyful.**

Subjective requirements do not give clues about how to design a system satisfying those requirements. Moreover, it is not possible to verify requirements during the design process on prototypes. Characteristics of prototypes can drastically affect the satisfaction measure compared with the final product. Subjective requirements are quite significant as those define how the satisfaction dimension of usability will be evaluated.

6) Help Request Based Requirements

Help request based requirements are a combination of training, defect, and satisfaction based requirements (Allendoerfer, 2005). In this approach requirements define the number of help requests from the users such as calls to help lines or applications to online help. Similar systems may be reference to define the critic number of help requests.

Users (not exceeding 1000 per month) of the online flight booking system shall **not make more than 10 help requests monthly.**

Help request requirements are helpful to compare systems with similar ones. Allendoerfer, (2005) claims that the main disadvantage of help request based requirements is that “it is dependent on users’ perceived quality of the available help and is affected by their attitudes regarding asking for help.”

7) Process Based Requirements

Setting correct limits of performance or defects may be inappropriate or very difficult for systems in which there are not available data about previous similar systems. In process based requirements, the process, not the system, is specified in terms of usability aspects (Lauesen & Younessi, 1998). Process based requirements are defined in terms of numbers and schedules of prototypes and usability tests to be followed in the development process.

> *In the system development process; iteratively **4 prototypes must be built and each of those must be empirically tested with at least 5 users,** experienced on online flight booking systems, in order to take their qualitative feedback on the usability of the prototype.*

Inspecting the development process is enough for verification of this type of requirements; still following the defined process does not guarantee high usability. Thus the specifications of prototypes and usability tests and their inspections are very critical on this approach. It is not possible to verify the usability of the final system by following a defined development process (Lauesen & Younessi, 1998) but that increases the possibility of the success (Allendoerfer, 2005).

Even the outcomes and tests are well defined; still the experience of the designer is a matter of success for this approach. Even though feedbacks from the tests may require more comprehensive solutions, designers have tendency to stick on the very first prototype and make minor differences in order to enhance the system (Lauesen & Younessi, 1998).

The number of prototypes and iterations is the only information to be gathered for this approach. However, there are not any formal methods to specify this number that should be foreseen depending on a variety of factors like: the complexity of system, experience of the development team and schedules of the development process.

8) Guideline Based Requirements

In guideline based requirements, a guideline or a specific standard is referenced as design specification. The advantage of guideline based requirements is that, they do not require any development costs and they are relatively easier to verify. However, the efficiency of that verification is discussed to be low. For instance, Jeffries, Miller, Wharton and Uyeda (1991) in their experiment, show that evaluating systems against guidelines is not very effective, because many severe usability defects are missed through that technique. Moreover, many guidelines include hundreds of factors to be inspected, where as only some of them are critical for a specific context. This makes the guideline based requirements difficult to verify (Allendoerfer, 2005). In order to make verification easier, instead of referring to the full guideline, referring to specific chapters or parts is more preferred.

> *Online flight booking system graphical user interface should follow* ***the NASA-LS-71130 (1997_10) Human-Computer Interface (HCI) Design Guide, section 2.4.***

Furthermore, guidelines are determined to specify a great variety of systems, and thus, present very general information. So, their ability to ensure usability is very limited. Guideline based requirements can only set the basics for a level of usability (Lauesen & Younessi, 1998) and may be useful with complementary approaches.

9) Design Based Requirements

Different from the previous approaches, which focus on the qualities of the system in terms of how to evaluate those in the final system; design based requirements explain the way system functions and the qualities it should have in a way guiding the designers about how to realize those in the final system. Design based requirements combine functional and extra-functional (quality) requirements (Lauesen & Younessi, 1998).

> *Online flight booking system home page should display the information listed in table x. Online flight booking system, date selection menus should be as in the Figure y.*

This is a radical approach for most system development methodologies, in which the roles of developers, the one defining requirements and the one designing accordingly, are strictly separated (Allendoerfer, 2005). In order to define design based requirements, the design should partly be performed in the requirements determination phase. Hence, the roles and responsibilities of the developers may overlap in order to determine design based requirements. Newman and Lamming (1995), in their book titled “Interactive System Design”, indicate the overlap between determining requirements and design phases as a characteristic of innovative interactive system development and they continue as follows:

> The decisions we make in drawing up requirements are, for the most part, design decisions. … They involve us in activities such as the study of users' needs, the choice of user interface styles and structures, and the use of analytical methods. … What we have achieved, during the requirements process, is a reduction of the original problem to something that can be designed by routine methods, within the available time and resource limits, and with manageable levels of risk. (p.159)

Design based requirements enable the designer to have user requirements in the early phases of the design process, which decreases the drawbacks and redesigns during the following design process. The design process is relatively easier in this approach, as the design based requirements give clues about how to satisfy those. Furthermore some of the activities traditionally done in the design process are carried out earlier in the requirements determination such as studies with users. The evaluation of the final design according to the requirements is also easier, when compared with approaches such as performance based requirements in which empirical testing is necessary. The final design can be verified simply by checking the design based requirements.

However, the success of design based requirements approach depends on the correctness and completeness of the determined user requirements. Determining requirements phase is the challenging part of the development process in this approach.

As Lauesen and Younessi (1998) explain, the information necessary for the fit between user and the system should be gathered in the requirements analysis phase. Especially in complex and dynamic interactive systems including the cognitive demands of the users to the user requirements is critical.

Summary

Performance, outcome, training, defect, help request and subjective requirement determination approaches require observations or tests of previous similar systems in order to define their objectives. Hence, those requirements approaches cannot be utilized in first-of-a-kind system development processes. Moreover, these types of requirements do not give clues to the designers on how to satisfy them. Before the development of a mature prototype, it is not possible to verify a concept design. If only during the design process, the prototypes are iteratively evaluated in terms of their conformity with those requirements, then the results may help the designer in the development process. The results of those evaluations provide extensive comparison and information about system's level according to specific measures; but still, provide little information on how to improve the system.

On the other hand, approaches like guideline and process based requirements do not require measurements from previous systems. However, as discussed earlier, their verification present limited information. Those approaches should be assisted with complementary approaches to ensure a level of usability.

Performance, outcome, training, defect, help request, subjective and guideline based approaches, all focus and define how the system will be verified. Those approaches are appropriate for stakeholders who desire betterments on previous systems about specific measured values, or who require specific performance values or outcomes to be measured and verified in the final system. Process based requirements may be set by stakeholders to inspect the design process. On the other hand, design based requirements are suitable to be generated by the design team to describe the functions and qualities of the design and provide inputs for the design.

Design based requirements do not necessitate comparison with similar products; and hence, are appropriate for first-of-a-kind system development. Design based approaches of requirement determination claimed to be beneficial in first-of-a-kind system development through analytical techniques (Roth et al., 2001; Nehme, Scott, Cummings & Furusho, 2006).

In the following section, techniques developed for determining user requirements are explained. After an overview of techniques, appropriate ones for first-of-a-kind interactive systems are investigated in detail.

2.3 Techniques for the Determination of User Requirements

Techniques for determining user requirements are usually described under the title of “usability evaluation”. While some tests are utilized to measure the functionality of the system and repair the ‘bugs’, usability evaluation aims to measure the systems’ usability that depends upon characteristics such as effectiveness, efficiency, productivity, safety and user satisfaction (Nielsen, 1993). Rubin, Chisnell and Spool (2008) define the truly usable beyond “the absence of frustration”, as follows:

> … when a product or service is truly usable, the user can do what he or she wants to do the way he or she expects to be able to do it, without hindrance, hesitation, or questions. (p.4)

There are two main approaches of usability evaluation:

- **Formative:** in the early phases of system development**,** forming the required information for the iterative design process. Describing what should the design do and also how should the design do those.
- **Summative:** at the end of the development process, evaluating the final design, if the design does what is intended to be done.

Formative usability evaluation is suitable to help designers in the requirements determination phase and through the design process. Another classification of usability evaluation may be made in terms of the technique followed:

- **Usability Testing (Empirical):** testing or getting subjective opinions of the actual users with prototypes or concepts

- **Usability Inspection (Analytical):** evaluating systems with established methods and techniques (eg. Blandford, Keith, Connell & Edwards, 2004, Nielsen, 1994).

Usability testing requires recruiting users and usually costs more than usability inspection methods in terms of resources and schedules (Nielsen, 1994). However, the unique information usability testing presents about the actual users can not be replaced by usability inspection methods. For instance, Nielsen (1993) explains the importance of usability testing, in computer domain, as follows:

> User testing with real users is the most fundamental usability method and is in some sense irreplaceable, since it provides direct information about how people use computers and what their exact problems are with the concrete interface being tested. (p.165)

Karat, Campbell, and Fiegel (1992), show that usability testing uncovered more usability problems than usability inspections. Nevertheless, it is also claimed that usability inspection methods discover many usability problem that are not noticed in usability testing, while the vice versa is also correct (Desurvire, Caplan & Toth, 2004). The combination of those two is obviously the best, for the design of a system fitting users. Moreover, in different phases of the system development process (requirement determination, the design process, verifying requirements) they may undertake different missions (Figure 16). Within the development processes usability testing and usability inspection methods complement each other and it is better to benefit from both (Hollingsed & Novick, 2007).

> There are some situations in which empirical investigation of practitioner performance in the existing environment is not sufficient in itself to characterize the requirements for effective support. A case in point is the design of first-of-a-kind systems that, when implemented, are intended to change dramatically the cognitive and collaborative activities entailed by the work environment. (Roth et al., 2001, p.113)

As mentioned before and shown in Figure 16, in the very early phases of first-of-a-kind interactive system development processes, before early prototypes and concepts are developed it may not be possible to conduct empirical studies with the actual users.

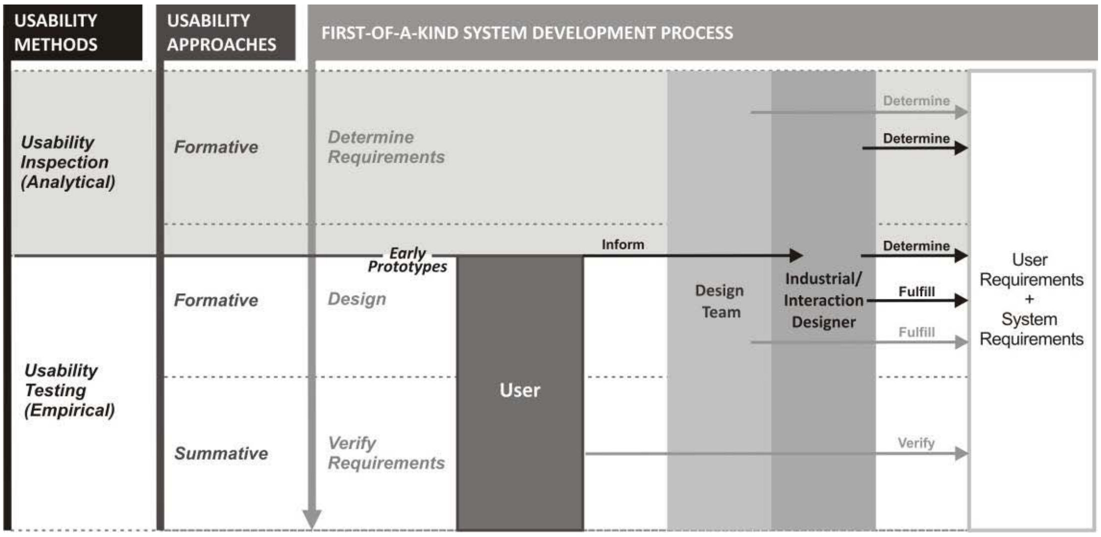


Figure 16 Usability Methods in First-of-a-Kind System Development Process

In the requirements determination and early phases of the first-of-a-kind system design, usability inspection methods are beneficial to set the user requirements and define how to realize those in the design process. Usability inspection methods decrease the problems found in the final design and reduce the severity of redesigns.

As Dautenhahn (2007) states that "there is no 'once-and-for-all' solution applicable across HRI." (p.103). Hence among a variety of techniques selecting the appropriate one according to the domain is critical. Greenberg and Buxton (2008) underline that if the usability methodology is not selected appropriate for the problem in the context, that usability testing can limit the design and even hinder it.

Within numerous usability techniques, cognitive analysis techniques are selected as they are frequently referred to be suitable for requirement determination and discovering cognitive demands in the early phases of the system development processes (Crandall, Klein & Hoffman, 2006; Naikar & Pearce, 2003; Nehme et al., 2006; Schraagen, Chipman, & Shalin, 2000). Cognitive analysis techniques are explained in the following section.

3.4 Cognitive Analysis Techniques

As mentioned before, understanding users' responses to their environments, how they think, understand, organize information and anticipate, shortly what is going on in their minds, is significant in order to design complex interactive systems which fits to users. Designing an information system without knowing its cognitive demands is similar to drawing eyes shut; in which designer could only imagine and guess the outcome. Cognitive analysis helps the designer to foresee the expected cognitive responses and processes to the system; so, at least, it enables the designer to see some parts of the perceived image while drawing.

There are mainly two streams of cognitive analysis techniques: Cognitive **Work** Analysis (CWA) and Cognitive **Task** Analysis (CTA). CWA and CTA share the same intention of discovering cognitive demands, but their approaches differ. While CWA focuses on the constraints in the working environment (Vicente, 1999), CTA focuses more on the tasks and what the users think while performing those tasks (Schraagen et al., 2000). Crandall et al. (2006) underline the complementary aspects of CTA and CWA as follows:

> Their [CWA] claim that cognitive work can be supported by studying the workplace independent of the decision makers seems as artificial as [CTA] studying decision makers without considering how the workplace affects their cognition. (p.250)

CWA and CTA share similar backgrounds, and referring to Roth (2008) both are evolved with the contributions of similar research areas: cognitive science, cognitive systems engineering, naturalistic decision-making and distributed cognition. There are also some techniques in the intersection of CWA and CTA; for instance, "decision ladder technique" developed by Rasmussen (1985) is common in both CWA and some of the CTA techniques such as Hybrid CTA.

Schraagen et al. (2000) define Cognitive Task Analysis (CTA) as "the extension of traditional task analysis techniques to yield information about the knowledge, thought processes, and goal structures that underlie observable task performance."(p.3). Crandall et al., (2006) list the benefits of integrating requirements determined by CTA to the system development as follows:

- Increase performance
- Reduce breakdowns
- Save time and funds by cutting down on design iterations
- Improve design quality (p.194)

Task analysis depends on decomposing tasks and ordering those into a sequence, whereas in Cognitive Task Analysis, the decomposed tasks are examined usually with Subject Matter Experts (SMEs) through semi structured interviews. Crandall et al. (2006) claim that Task Analysis, so called Behavioral Task Analysis is not appropriate for the users of Information Technology (IT) because "skilled IT users are not following steps" and it is needed "to go beyond task decompositions and understand the users' point of view-how they are viewing the work, how they are interpreting the task, how they are adopting or rejecting strategies and how they are modifying or abandoning standard procedures." (p.164).

The task, in the CTA, can refer to using a cell phone for elderly, or supervising multiple robots in real time dynamic situations for a user. Even though, the task may occur in varying contexts and is only limited with the possibilities of human activities, still for simple and defined tasks CTA may be unnecessary and time consuming. However, CTA is critical for complex tasks as Crandall et al. (2006) depict:

> When the tasks that people are doing are complex, it is not enough to simply observe people's actions and behaviors - what they do. It is also important to find out how they think and what they know, how they organize and structure information, and what they seek to understand better. (p.3) Cognitive Task Analysis becomes more valuable as the nature of the work becomes more conceptual than physical, when the tasks can't be boiled down to procedures and when experts clearly outperform novices." (p.167)

In the literature, cognitive analysis techniques are frequently referred to discover cognitive demands of the users in the early phases of the design process. Cognitive analysis techniques mostly rely on semi structured interviews with SMEs. As mentioned before, it is not always possible to access experienced users or SMEs, especially in the first-of-a-kind system development. Still, it can be claimed that, users in domain or users experienced in previous systems with similar functions may be interviewed for determining requirements. Roth et al. (2001) explain the reasons for not studying with those users:

> [In first-of-a-kind systems] traditional cognitive task analysis methods that rely on elicitation of expert knowledge and strategies are of limited value because much of the existent expertise is likely to reflect strategies and work-arounds intended to cope with limitations of the existing interfaces and technologies. (p.134)

Hence, instead of relying on the users' experiences with previous systems which is claimed to be limiting for the first-of-a-kind system design, some hybrid cognitive analysis techniques are developed to discover cognitive demands analytically, without empirical studies with actual users. Those methodologies try to compensate the lack of user studies with complementary techniques and are argued to be appropriate for first-of-a-kind system development (Naikar & Pearce, 2003; Roth et al., 2001). Cognitive analysis techniques are summarized in Table 1.

Table 1: Cognitive Analysis Methods

Applied Cognitive Task Analysis (ACTA)	ACTA is a streamlined method of CTA in which three series of semi-structured interviews with SMEs are conducted. From the first interviews a task diagram including a broad overview and difficult cognitive parts is drawn. Second set of interviews sets knowledge audit which investigate the expertise required for specific tasks. Finally through a specific scenario the cognitive processes of SMEs are examined. (Militello & Hutton, 1998).
Applied Cognitive Work Analysis (ACWA)	Methods such as “functional abstraction network, cognitive work requirements, and information/relationship requirements” are carried out to discover the “fundamental behavioral characteristics of the work domain in a principled manner to generate well-grounded decision support concepts for the cognitive demands facing the human-machine decision-making team.” (Elm, Potter & Gualtieri, 2003, p.380)

Table 1: Cognitive Analysis Methods (continued)

Cognitive Function Model	Cognitive function model consists of two steps; in the first step task decomposition, graphically presenting the role of the user in the system is drawn. In the second step, through the guidance of a computer application called “cognimeter”, the analyst and SMEs rate cognitive demands of the each node in the task decomposition. Hence the cognitively challenging nodes are identified. (Chrenk, Hutton, Klinger & Anastasi, 2001). In this method, the structure of the SME interview is guided through the computer application.
Cognitively Oriented Task Analysis (COTA)	COTA is utilized to explain “the expertise that supports overall job performance” and differentiates from others as it explain the “contents of knowledge rather than the processes of cognition” and focuses to the total job instead of tasks (pp.42-43). In this method, task decomposition, so called “plan-goal graph model” is drawn, and then through several protocols with SMEs the graph is refined. (DuBois & Shalin, 2000)
Critical Decision Method	Semi-structured interviews with SMEs are performed, to capture how experts make critical decisions in non-routine incidents. A non-routine incident is called back and cognitive probe questions are asked to SMEs. (Klein, 1996)
Decompose, Network And Assess (DNA) Method	DNA method focuses on expert knowledge, and helps the analyst to gather experts’ knowledge structures through a computer program. The knowledge gathered from the interviews with SMEs is decomposed, made networks in a hierarchy and those are assessed in terms of their reliability. (Shute & Torreano, 2002)
Function Based Cognitive Task Analysis	This method is categorized in cognitive work analysis. It starts with analyzing the demands of the domain so called work domain analysis, and later a functional goal-means representation is carried out to “guide the identification of human decision making requirements and supporting information needs” (Roth et al., 2001, p.114).
Hierarchical Task Analysis	Hierarchical Task Analysis is one of the leading task analysis techniques, which is applied within many cognitive task techniques. In this technique, goal and tasks are broken into sub steps in a hierarchy, including the timing. (Annett & Duncan, 1967; Stanton, 2006)
Hybrid Cognitive Task Analysis	Hybrid CTA aims to compensate the unavailability of SMEs in first-of-a-kind system development. It requires generating four steps: “1) scenario task overview, 2) event flow diagram, 3) situation awareness (SA) requirements, and 4) decision ladders for critical decisions” (Nehme et al., 2006)

Table 1: Cognitive Analysis Methods (continued)

Knowledge Analysis And Design System (KADS)	KADS is described as a methodology for the development of experts systems, so called “knowledge based systems”, in a structure way. Tasks are classified such as assessment, design, planning, and classification and utilized to build knowledge patterns. (Schreiber, Weilinga, & Breuker, 1993)
Precursor, Action, Result, Interpretation (PARI)	Cognitive and behavioral demands of troubleshooting are explored through structured interviews of users from varying experience levels. The interview structure is described in the name of the method. At each step, a precursor develops an action which produces a result, and the result is interpreted. (Hall, Gott, Pokorny, 1995)
Skill-Based Cognitive Task Analysis	This methodology analyze the performance in terms its cognitive aspects which is claimed to be utilized in an operational setting. It focuses on the skills and presents “a simplified hierarchy of cognitive skill types linking each type to several established CTA methods“.(Seamster, Redding & Kaempf, 2000, p.135)
Task Knowledge Structures (TKS)	TKS was developed “to model conceptual, declarative, and procedural knowledge concerned in executing work tasks“which can be used by the designers as inputs for the user interface design. (Johnson, Johnson & Hamilton, 2000, p.212).

As seen from the above table, most of the cognitive analysis techniques require access to experienced users, SMEs, existing systems, and documentations. However, in first-of-a-kind systems there are no similar systems and in the early phases of system development, it is not possible to access experienced users and SMEs. There have been some attempts to develop combined methodologies in order to serve the determination of user requirements of first-of-a-kind interactive systems. Taking advantage of a combination of varying cognitive analysis methodologies is suggested to understand the needs of the user and the limitations of the interface design better (Kaber et al., 2006; Adams et. al., 2009). Cognitive analysis techniques appropriate for determining user requirements of first-of-a-kind interactive systems are explained in detail, in the following section.

3.5 Cognitive Analysis for Determining User Requirements of First-of-a-kind Interactive Systems

There are mainly two approaches in the determination of first-of-a-kind system requirements. Some researchers benefit from SMEs' experiences in previous systems in the domain (Humphrey & Adams, 2010; Naikar & Pearce, 2003); while the others combine varying techniques and argue to be compensating the unavailability of SMEs (Nehme et al., 2006; Roth et al., 2001).

Humphrey and Adams (2010) apply a combination of Goal Directed Task Analysis (GDTA) and Cognitive Work Analysis (CWA) for a first-of-a-kind system. The system is an incident response system, which may include hundreds of people with varying responsibilities and training. GDTA build on Endsley's (1988) Situation Awareness (SA) theory (explained in detail in section 2.5.1). GDTA developed by Endsley (2003) consist of three steps: first (1) the goals and sub goals are defined; then (2) the corresponding major decisions are described; and finally (3) the information required to build all three levels (perception, comprehension, and projection) of situation awareness is identified. Humphrey and Adams (2010) discussed that GDTA was good for identifying general goals and SA requirements but was unable to discover timing of tasks especially simultaneous tasks; distinguish critical tasks; and identify constraints of the system. Humphrey and Adams (2010) claim that the efforts to combine CWA with the GDTA outcomes fulfill those missing information. Through this process, they benefit from the interviews with SMEs who have experience in the previous versions of the system. However, they argue that, SMEs had difficulty in understanding one of the methodologies in the CWA called "abstraction–decomposition space" as follows:

> During interview sessions in which the abstraction–decomposition space was present and 'how', 'why', 'part of' and 'composed of' questions were asked, very limited useful feedback was obtained. Our SMEs' struggled to understand the abstraction–decomposition spaces' dimensions/relationships. While many of our SMEs have very specialised training, some if which involves technology, they are not engineers or frequent users of advanced technology. The abstraction–decomposition space's combined dimensions

> simply did not represent how the SMEs think about their response activities and the relationships between the response activities (p.7).

Humphrey and Adams's (2010) observation shows that, in order to benefit from SMEs' experiences, the methodology should correspond with their training, experience in the related technology and the way they think about the activities.
The other study on first-of-a-kind system development is done by Naikar and Pearce (2003). Similar to Humphrey and Adams's (2010) study, Naikar and Pearce (2003) utilize interviews with SMEs as sources of data. Naikar and Pearce (2003)'s study is on the design of the team: its scope, composition and the work distribution within the team. They follow initial phases of CWA in order design the team of a first-of-a-kind complex system named Airborne Early Warning and Control.

On the other hand, Nehme et al. (2006) and Roth et al. (2001) study first-of-a-kind system development without the actual involvement of the users. Their study focus on the cognitive analysis for first-of-a-kind systems in which SMEs and experienced users can not be accessed.

Roth, et al. (2001) carry out a function based CTA technique, to design a group view display of a power plant which is a first-of-a-kind system. They did not utilized information from actual users during requirements determination through CTA. Distinguishing from other studies on first-of-a-kind system requirement determination, Roth et al. verified the outcomes of their study with a series of empirical evaluations. As a result of their empirical evaluation including both objective and subjective measures, they conclude that the system design through CTA lead a superior design.

The other study on the determination of first-of-a-kind system requirements without access to SMEs and experienced users is done by Nehme et al. (2006) in the HRI domain. Nehme et al. (2006) argue that the cognitive analysis methodologies based on semi structured interviews with SMEs cannot be applied to first-of-a-kind systems. He recommends a hybrid CTA methodology for the requirement determination of first-of-a-kind interactive systems. Their case study is on “supervisory control of multiple, heterogeneous unmanned vehicles” (p.1). Nehme et al. (2006) argue that Hybrid CTA enables designers to determine requirements of first-of-a-kind interactive systems and “compensates for the lack of SMEs” (p.5). Those claims are further discussed in section 4.5.

In the following Chapter an implementation of Hybrid CTA for determining user requirements of a first-of-a-kind interactive system design are explained, in order to assess the methodology in terms of its coherence with the domain and its effectiveness. The reasons for selecting Hybrid CTA for the implementation are explained in the following Chapter. Moreover, each phase of the Hybrid CTA methodology is explained in detail with examples from the implementation.

CHAPTER 4

IMPLEMENTATION STUDY OF HYBRID CTA ON HUMAN ROBOT INTERACTION

4.1 Motivation of the Study

As an industrial designer working in a company developing electronic systems and equipments for professional users, the author, within multidisciplinary design teams, witnessed the difficulty of designing through system oriented requirements in various design processes. Without user requirements, user needs are attempted to be fulfilled in the design process where the system is already constrained with system oriented requirements. In complex interactive systems, those system oriented requirements are usually gathered directly from the outputs of complex electronics, without intensive concerns about users of the system. As industrial designers usually enter to the system development process at the design phase, it might be too late to modify functional requirements with user-centered concerns. The author investigated user requirements, with the motivation to find an answer to the question “how to determine those in the early phases of the system development?”

Furthermore, she was motivated to study the determination of user requirements early in the development process synchronized with a project continuing in her company. Within the continuing projects in the company, the author selected a Human Robot Interaction project in which she had difficulties in making design decision because of the novel interactions the system required and the high cognitive loads demanded from the users of the system. This HRI project is held for a competition titled Multi Autonomous Ground-robotic International Challenge (MAGIC) 2010. She takes part in the MAGIC 2010 system development process, as an industrial designer, and also as an interaction designer as one of the designers of the Graphical User Interface (GUI). The design team of MAGIC 2010 included twenty people with part-time interdisciplinary contributions. Within this design team, the author's responsibility is mainly on system's conformance with the users.

MAGIC 2010 aims to support innovation in Human Robot Interaction, and challenge the competitors to design a first-of-a-kind robotic system. The main goal of MAGIC 2010 is developing highly autonomous robots. Main challenge in terms of Human Robot Interaction (HRI) in this competition is maintaining situation awareness of the users and supporting their decision making while supervising multiple robots. In the very beginning of the competition period, the author witnesses a significant difficulty in determining user requirements of that first-of-a-kind HRI which would realize the goals of the competition.

Through formative empirical usability evaluation, precious information may be generated from actual users. However, in this case, there were not any available users. In order to gather reliable outcomes through usability evaluation in this specific domain, HRI, the participants should at least be users of any kind of robots. Preferably users in the formative usability study should be SMEs or they should be experienced in similar HRIs. In this case none of these were available. Hence, user requirement determination techniques, without the actual user inputs, are decided to be investigated.

Within the company, HRI Graphical User Interfaces (GUI) has been designed for a while, but up to the competition period, a similar project has not been developed regarding the competition requirements. Even though multi-robot autonomy has been frequently mentioned in the literature (Chadwick, 2006; Chen, Barnes & Qu, 2010; Fujishima, Rankin, Gossage, Chng & New, 2008 etc.) none of them corresponds to the MAGIC 2010 specifications presented in 3.4. Moreover, the design team cannot access to any users experienced in autonomous multi robot interaction or any expert on this specific topic. Even if those are accessed; they would be experts of the previous systems which are argued to be limiting and misleading for the first-of-a-kind system design (Roth et al., 2001).

After scrutinizing the literature on how to determine user requirements of first-of-a-kind systems, the hybrid CTA methodology, recommended for first-of-a-kind systems by Nehme et al. (2006), is selected for the implementation for MAGIC 2010. This implementation aims to exemplify the methodology and observe the level of its success in this specific domain.

Through this implementation, user requirements of MAGIC 2010, specifically the information necessary to be displayed in the HRI in order to build users' situation awareness and aid for their decision making was extracted. Those user requirements are utilized in the design of the HRI Graphical User Interface (GUI).

4.2 Implementation Domain: MAGIC 2010

The Multi-Autonomous Ground-robotic International Challenge (MAGIC) 2010 explains the challenge as follows:

> The challenge is designed to test the ability of the multi-vehicle cooperatives to autonomously and dynamically coordinate, plan and re-plan their task allocation and execution strategies against a changing environment while simultaneously providing a unified situational awareness picture. (International Challenge MAGIC 2010 Down Under, p.5)

In order to succeed in the competition, minimum three robots should be supervised by maximum two operators to "autonomously coordinate their activities to safely, efficiently and effectively explore and map their environment and detect, locate, classify, recognise, track and neutralise a number of static and mobile Objects Of Interest (OOI)" (International Challenge MAGIC 2010 Down Under, p.5).

The team participated to the MAGIC 2010 competition with six robots, shown in Figure 17. Those robots were not within the sights of the two operators who were in Ground Control Station (GCS) during the challenge. Hence, operators were supervising the robots relying on the information gathered from the payloads (cameras and sensors) of the robots and the simulated Unmanned Air Vehicle (UAV) image provided from the competition committee.

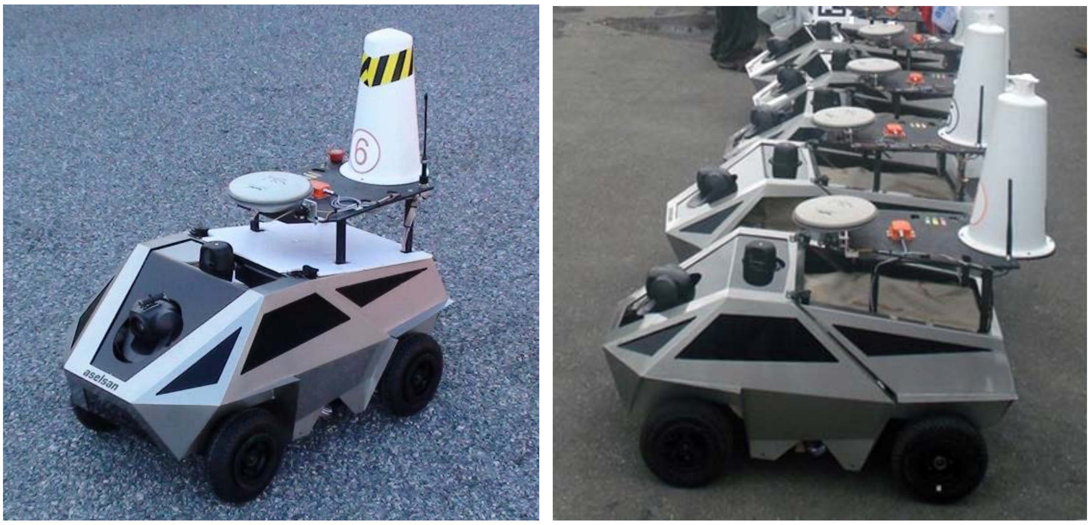


Figure 17 The Robots \ Unmanned Ground Vehicles (UGVs)

Operators were supervising robots through Graphical User Interfaces (GUIs); Figure 18 shows the monitors and controls of the operators.

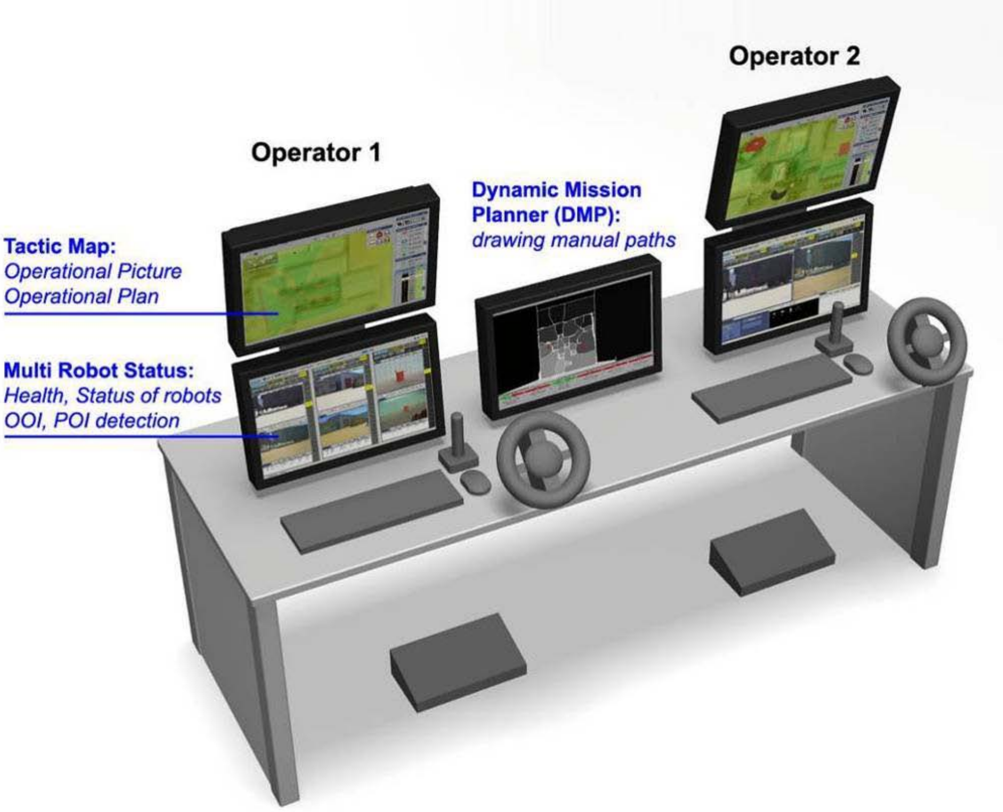


Figure 18 Representative Drawing of the Ground Control Station (GCS) Monitors with their Corresponding Functions

The competition consists of three phases, to be explored within three and a half hours. There are Designated Servicing Zones (DSZS) in each phase and Ground Control Station (GCS) where operators supervise the robots (Figure 19).

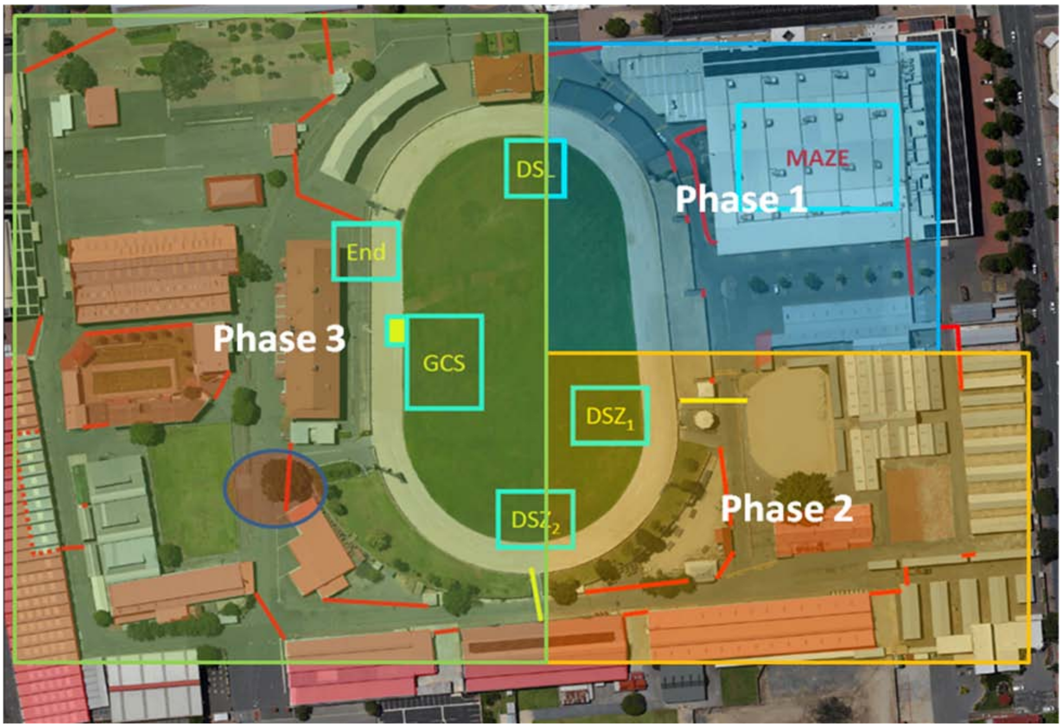


Figure 19 Unmanned Air Vehicle (UAV) Picture of the Competition Area Showing: Phase Areas, Ground Control Station (GCS) and Designated Servicing Zones (DSZS)

The Graphical User Interface (GUI) consists of two displays; one of those is tactic map which is generated over simulated UAV feed. It shows the operational area composition in 3D, which enhances the user's sense of direction. Operational area composition, paths and missions of each robot is provided through layers. Those layers can be hided or shown in order to optimize the map display for varying tasks. The tactic map is shown in Figure 20.

The other display of the GUI is showing the status of the multiple robots through the information coming from their sensors and cameras (Figure 21). In this display, video streams of three robots, the OOIs that are autonomously tracked by the robots and the status information such as communication levels, health and battery are shown.

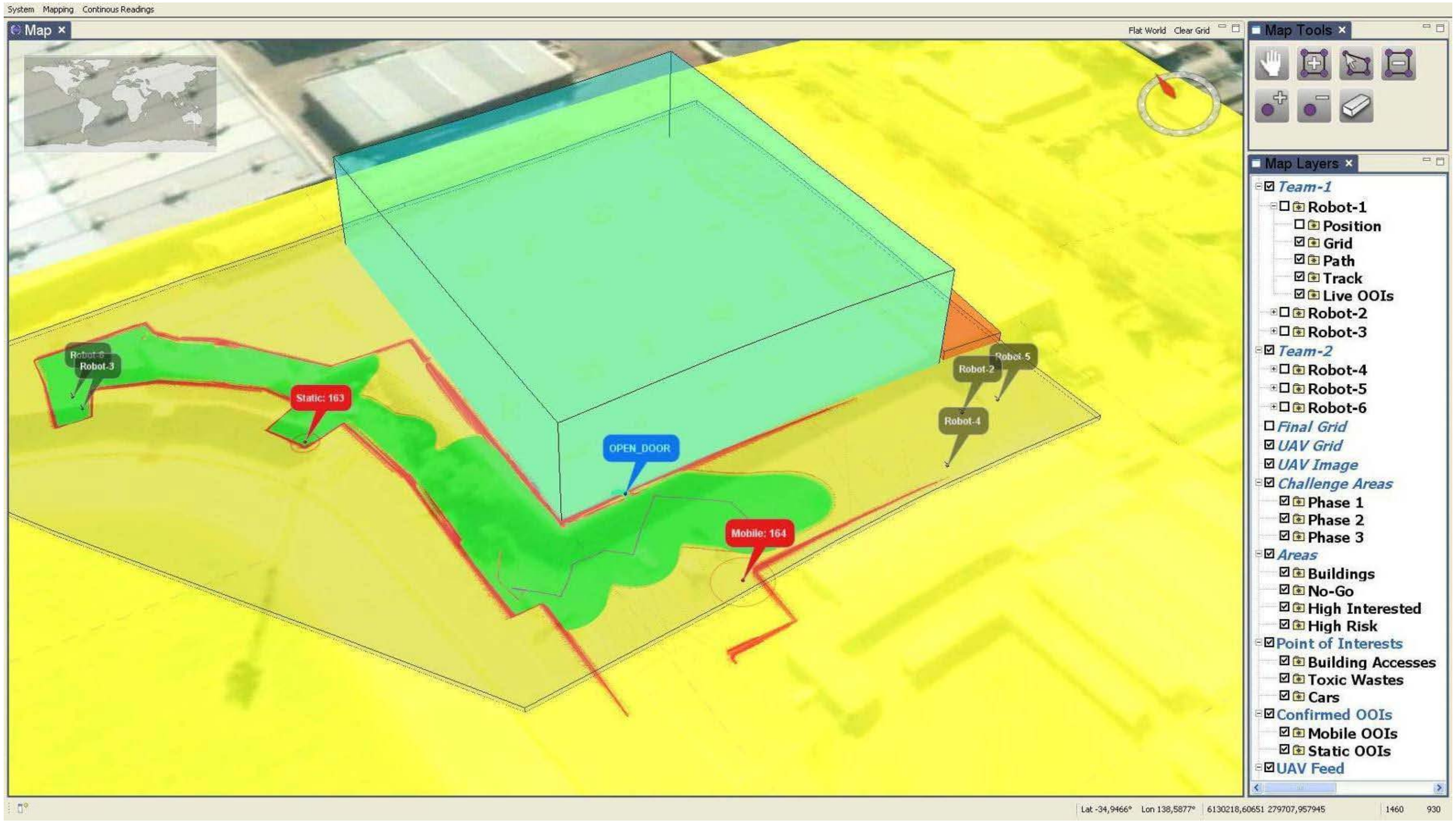
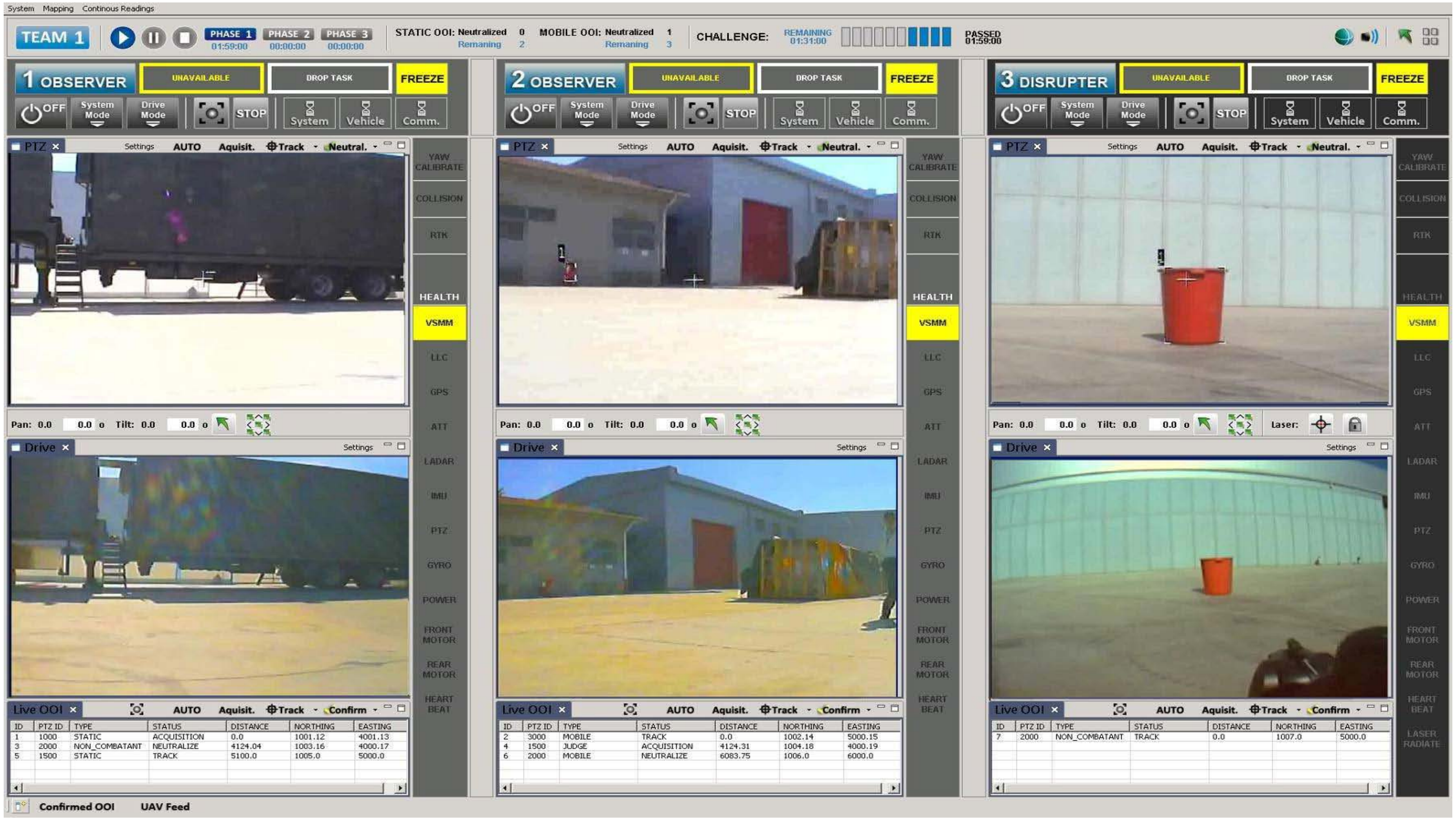


Figure 20 MAGIC 2010 Graphical User Interface (GUI), Tactic Map



ID	PTZ ID	TYPE	STATUS	DISTANCE	NORTHING	EASTING
1	1000	STATIC	ACQUISITION	0.0	1001.12	4001.13
3	2000	NON_COMBATANT	NEUTRALIZE	4124.04	1003.16	4000.17
5	1500	STATIC	TRACK	5100.0	1005.0	5000.0

ID	PTZ ID	TYPE	STATUS	DISTANCE	NORTHING	EASTING
2	3000	MOBILE	TRACK	0.0	1002.14	5000.15
4	1500	JUDGE	ACQUISITION	4124.31	1004.18	4000.19
6	2000	MOBILE	NEUTRALIZE	6083.75	1006.0	6000.0

ID	PTZ ID	TYPE	STATUS	DISTANCE	NORTHING	EASTING
7	2000	NON_COMBATANT	TRACK	0.0	1007.0	5000.0

Figure 21 MAGIC 2010 Graphical User Interface (GUI), Multi Robot Status

The main actions in the operational scenario, the automatically generated information by the robots and the responsibilities of the operators in each action are explained in Figure 22. Within the total competition time, operators have only ten minutes to interrupt the autonomy and supervise robots.

The Unmanned Air Vehicle (UAV) image is processed automatically.

Operator defines the operational area (forbidden zones, high interest zones, building access points and so on)

Operator rearranges the operational area compositions, If there are missing or incorrect information.

Dynamic Mission Planner (DMP) automatically draws the paths of the robots.

Operator redefine the paths of the robots, if these are not appropriate for the mission.

Object of Interests (OOIs) and Point of Interests (POIs) are automatically detected, when these came into the field of views of the robots.

Operator confirm or cancel the detected OOIs/POIs.

Operator classify the detected OOIs/POIs.

Operator confirm or cancel the neutralization processes of the detected OOIs/POIs.

Figure 22 Operational scenario

MAGIC 2010 mainly requires multiple robots to autonomously map an area and detect threats within that area, in a limited time and with limited human interaction. MAGIC 2010 organization committee published a pack of documents explaining the rules and requirements of the competition. Within those documents, beyond other requirements, HRI requirements are also defined. In order to explain what is asked from the competitors, those requirements are categorized into user requirement determination approaches described in the 3.2 Section. HRI requirements defined by MAGIC 2010 are categorized into three groups: performance based, training based and subjective requirements.

1) Performance Based Requirements of MAGIC 2010

As explained in Section 3.2, in order to define performance based requirements tasks, user profiles and performance objectives are critical. Those are gathered from the competition documents in order to build the performance based requirements of MAGIC 2010.

a) **Task:** The main tasks in MAGIC 2010 are: “Accurately and completely explore and map the entire phase area and correctly locate and classify and recognize all simulated threats within 3 and a half hours”. (International Challenge MAGIC 2010 Down Under, p.8). Besides MAGIC 2010 documents describe the tasks and its context in detail which are used as inputs in the implementation.

b) **User profile:** User profile defined in MAGIC 2010 is not clear. Only it is mentioned that the interface should provide “high usability for military operators” (MAGIC 2010 December Information Pack, p.15). However, the experience and education level of the mentioned military operator is not defined which is very critical in order to define requirements. Yet the challenge does not define the operators of the robots during the competition. Only it is said that the maximum number of operators could be two. Hence, those two operators could be selected by the challenging teams, so that they were highly experienced in HRI. Furthermore, they could be trained before the competition.

c) **Performance objectives:** The performance objectives are defined by the MAGIC 2010 in terms of duration limits, which is the limitation of ten minutes of human interaction for the completion of the tasks. However, how that limit is determined is unclear. If it is not a fact observed from a prototype, the achievability cannot be guaranteed.

Consequently the performance based requirements demanded by MAGIC 2010 is as follows:

> **The highly experienced and trained operators** should accurately and completely explore and map the entire phase area and correctly locate and classify and recognize all simulated threats within three and a half hours **with maximum of ten minutes of human interaction.**

2) Training Based Requirements: Training objectives are not specifically defined in MAGIC 2010. However, training is mentioned within the specification of the user profile as “highly experienced and trained operators”.

3) Subjective Requirements (Satisfaction) MAGIC 2010 defines two criteria for the usability of the system as follows:

- “sophistication of the human machine interaction (HMI)
- the completeness of situational awareness (SA) displays“ (MAGIC 2010 December Information Pack, p.15)

In the MAGIC 2010 documents the subjective evaluation of those criteria is explained as follows: “These criteria will be evaluated subjectively by the judges on the basis of the Ground Control Station (GCS) capacity to deliver a streamlined HMI that provides high usability for military operators.” (MAGIC 2010 December Information Pack, p.15). However, how the subjective measurement will be made is not clear. The terms used to describe subjective measures like: “sophistication of the HMI", "completeness of SA displays" and "streamlined HMI" should be further described in order to comprehend the subjective measures of MAGIC 2010.

MAGIC 2010 objectives described above partly shows how final HRIs would be evaluated in the competition. However, it is arguable if those are well defined. Well defined requirements are described as achievable, verifiable, unambiguous, complete, correct, traceable and consistent (Leonard, 1999; IEEE STD 830, 1998; Bahill & Dean, 2009). Even though, described user profile is not complete, HRI performance based objectives set by MAGIC 2010 are measurable. However, subjective measures include ambiguous terms and those are incomplete as the measurement methodology is not clear. Those objectives set by the competition organization describe the challenge and set comparable measures for the evaluations of competitor performances. In order to determine user requirements of the first-of-a-kind system, satisfying those competition objectives, cognitive demands of the users are investigated. In the following section, the methodology followed for the determination of the user requirements of the MAGIC 2010 is explained.

4.3 The Methodology

Within the explained cognitive analysis methodologies (described in Section 3.4), Hybrid CTA (Scott & Cummings, 2006; Nehme et al., 2006) is selected for determining the user requirements of MAGIC 2010. Because, the implementation domains of the Hybrid CTA and MAGIC 2010 have the following commonalities:

- Domain: supervisory control of heterogeneous multiple autonomous robots
- Target user profile: trained professionals
- Level of innovativeness: first-of-a-kind interactive systems, there are no similar systems, no access to experienced users and SMEs

When MAGIC 2010 ended, the technical solutions were published in the proceedings of Land Warfare Conference, which was held in Brisbane in Australia

(Erdener et al., 2010). MAGIC 2010 documents were published on-line and the mentioned article is referenced in Hybrid CTA implementation.

The requirements, gathered from detailed analytical exploration of expected cognitive processes in human mind through Hybrid CTA, are used as inputs in the design of MAGIC 2010 Graphical User Interface (GUI) explained in section 4.2 and Figures 20 and 21. However, because of the limitation in the project schedule, Hybrid CTA is not followed in the requirements determination phase (as explained in Figure 4), but in the design phase. Hence, integrating some of the outcomes to the final design has not been possible.

The steps followed in Hybrid CTA (Nehme et al., 2006) process are shown in Figure 23. Each step is explained in detail in the following section.

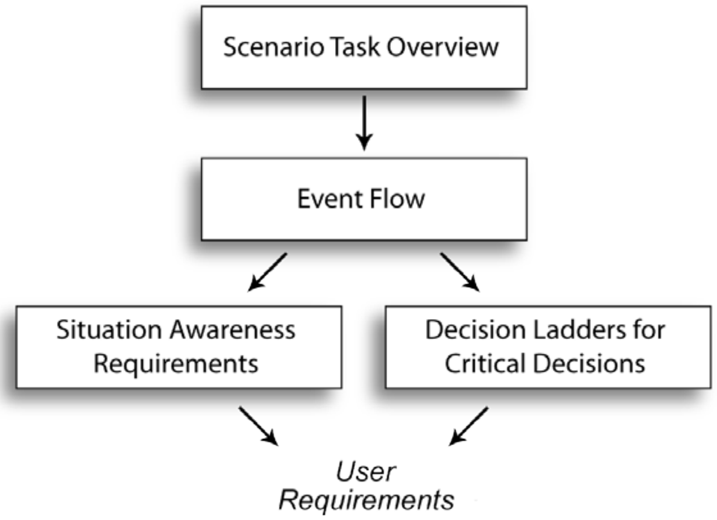


Figure 23 Hybrid CTA Process Adapted from Nehme et al. (2006)

1) Scenario Task Overview

The first step of Hybrid CTA is Scenario Task Overview in which the mission goal is divided into main phases and each phase is divided into sub-goals and explained in detail. MAGIC 2010 documents are the main sources of scenario task overview in this implementation.

The outcome is a table where it is possible to overview the task (Table 2). The information in the table is extracted from the MAGIC documents. There are three main phases: mission planning, mission execution and mission recovery. Each of those phases has two main tasks: generate "operational picture for planning", generate "initial planning for first challenge phase", "explore and map the entire phase area", "locate, classify, recognize and neutralize all OOIs in the phase area", phase completion and servicing of vehicles (International Challenge (MAGIC) 2010 Down Under, 1999, p,16). This information is used for the following study, the event flow diagram, in which those six tasks are further investigated.

2) Event Flow Diagram

Event flow diagram presents the links between tasks, subtasks and events including temporal relations. It is an extended version of "Hierarchical task analysis procedure" (Stanton, 2006). Hierarchical Task Analysis is first specified by Annett and Duncan (1967). In HTA methodology, designer explores the tasks, what the user is expected to do in a hierarchy of goals and when these should be carried out (Annett & Duncan, 1967). The template of the hierarchical task analysis procedure is shown in Figure 24 (Stanton, 2006).

In the event flow diagram: diamonds are decisions, they represent the questions aroused in the users' mind, in the decision making event, and they result in an answer 'Yes' or 'No' which guides to another event. Hexagons are loops; these are repeated without time constraints. Rectangles are processes which would be executed by the user. The events which are highlighted in blue symbols are representing critical decisions which would be extended in decision ladders. Those symbols used in event flow diagrams are given in Figure 25.

For each six goal defined in the scenario task overview, event flows are generated (Figures 26 to 31). Each event in the event flows has an alphanumeric code to be able to follow those all throughout the CTA.

Table 2 Scenario Task Overview

<table>
<tr><td rowspan="2">MISSION PLANNING</td><td>A. GENERATE “OPERATIONAL PICTURE FOR PLANNING”</td><td colspan="2"><i>“Based on information from the UAV feed provided to teams at the pre-brief by facilitators”</i> generate a registered operational picture containing:
• “The location and activity of any potential mobile OOI according to the known basic structure of the challenge area
• Other information provided by facilitators during the pre-briefing session, such as building access points” (International Challenge (MAGIC) 2010 Down Under, 1999, p,16)</td></tr>
<tr><td>B. GENERATE “INITIAL PLANNING FOR FIRST CHALLENGE PHASE”</td><td><i>(Based on the picture generated from the UAV feed)</i> generate mission guidance for the UGV team by autonomous mission planning and task allocation software
The goal is “to explore and map the challenge area to locate, track, recognize, identify and neutralize OOI.”</td><td>Mission guidance can be optimized according to following constraints:
• “the location, orientation and type of terrain
• accessible buildings and OOI present within the environment
• the observed and potential motion of OOI
• the robustness of the proposed solution to OOI and/or environmental uncertainties
• the need to enter buildings
• the individual capabilities of the participating UGVs
• the benefits that derive from the association of UGVs into teams
• communications or sensor scheduling requirements between the UGVs to enable this cooperation
• any “no-go” or “difficult-to-go” zones
• the need to manage power and access to servicing zones
• UGV safety and deconfliction requirements
• the prospect of losing particular classes of UGVs
• the need to continually monitor specific areas or access points for other UGVs to carry out their missions, etc.” (International Challenge (MAGIC) 2010 Down Under, 1999, p,16)</td></tr>
<tr><td rowspan="2">MISSION EXECUTION</td><td>C. “EXPLORE AND MAP THE ENTIRE PHASE AREA”</td><td colspan="2">“Explore their environment, searching for static and mobile OOI inside and outside buildings. As the sensor UGVs progressively explore and map their environment the aerial and ground situational awareness views could be:
• Fused to provide a single, more complete picture.
• Fused and integrated with applications such as geospatial information, track data, imagery and visualization tools to provide enhanced situational awareness to the team leader.” (International Challenge (MAGIC) 2010 Down Under, 1999, p,16)</td></tr>
<tr><td>D. “LOCATE, CLASSIFY, RECOGNIZE AND NEUTRALIZE ALL OOI IN THE PHASE AREA”</td><td colspan="2">“A sensor UGV might autonomously detect a static OOI and coordinate with a disruptor UGV to neutralize it. Based on the simulated UAV feed, another sensor UGV might be cross-cued to approach a potential mobile OOI and, while remaining at a safe distance, discriminate it from a non-combatant. Once this UGV has performed this task, it might then continue to track and possibly pursue the mobile OOI while simultaneously disseminating this information throughout the cooperative in order to task other sensor UGVs to confirm its identity and location for the purposes of neutralization. While either or both of these activities are taking place a mobile OOI or a non-combatant may be detected by a sensor UGV (or the UAV) having emerged from a location previously unobservable by the cooperative’s sensors. The system might then respond by autonomously and dynamically re-tasking all of the UGVs, re-calculating their objectives, re-directing payload activity based on the automatic manipulation and fusion of the data in order to classify the nature of the OOI and its trajectory “ Operator Selecting from a Series of Feasible Options</td></tr>
<tr><td rowspan="2">MISSION RECOVERY</td><td>E. PHASE COMPLETION</td><td colspan="2">“When teams believe they have fully explored and mapped all of the phase area (inside and outside buildings) and detected, recognized, classified and neutralized (as appropriate) all OOI the team leader will notify the judges that the phase is complete.” (International Challenge (MAGIC) 2010 Down Under, 1999, p,17)</td></tr>
<tr><td>F. SERVICING OF VEHICLES</td><td colspan="2">“All UGVs, including the frozen ones, may then be ‘unfrozen’ and maneuvered to the DSL/DSZ for servicing within either the DSL or the newly achieved DSZ. The team leader might also request that organizers collect some of the UGVs that have unexpectedly stopped working so that they may be serviced in the DSZ. Alternatively, teams may immediately task some or all of their UGVs to continue with the next phase without servicing.” (International Challenge (MAGIC) 2010 Down Under, 1999, p,17)</td></tr>
</table>

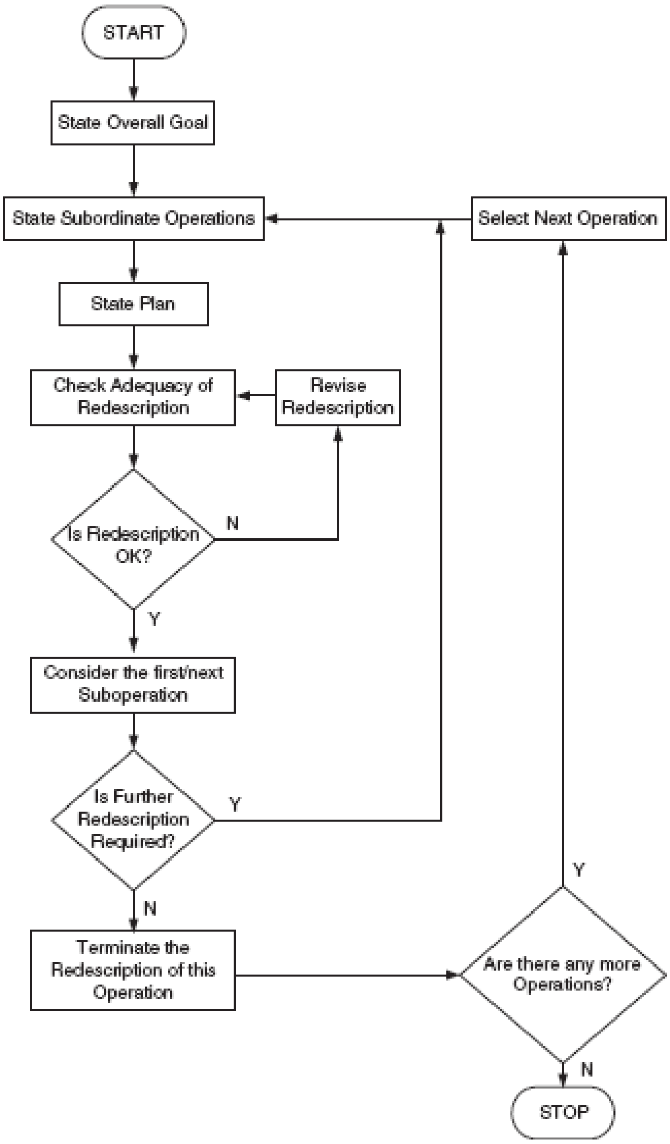


Figure 24 “Hierarchical Task Analysis Procedure” (Stanton, 2006)

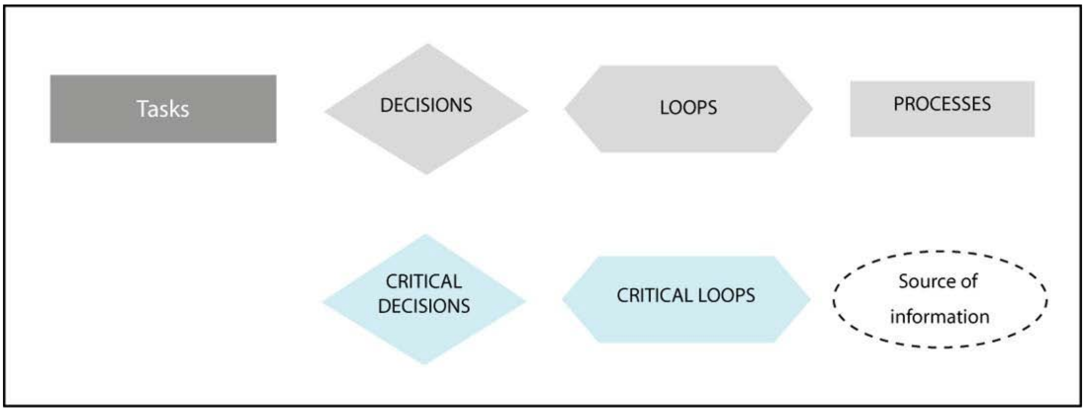


Figure 25 Symbols of Event Flow Diagrams

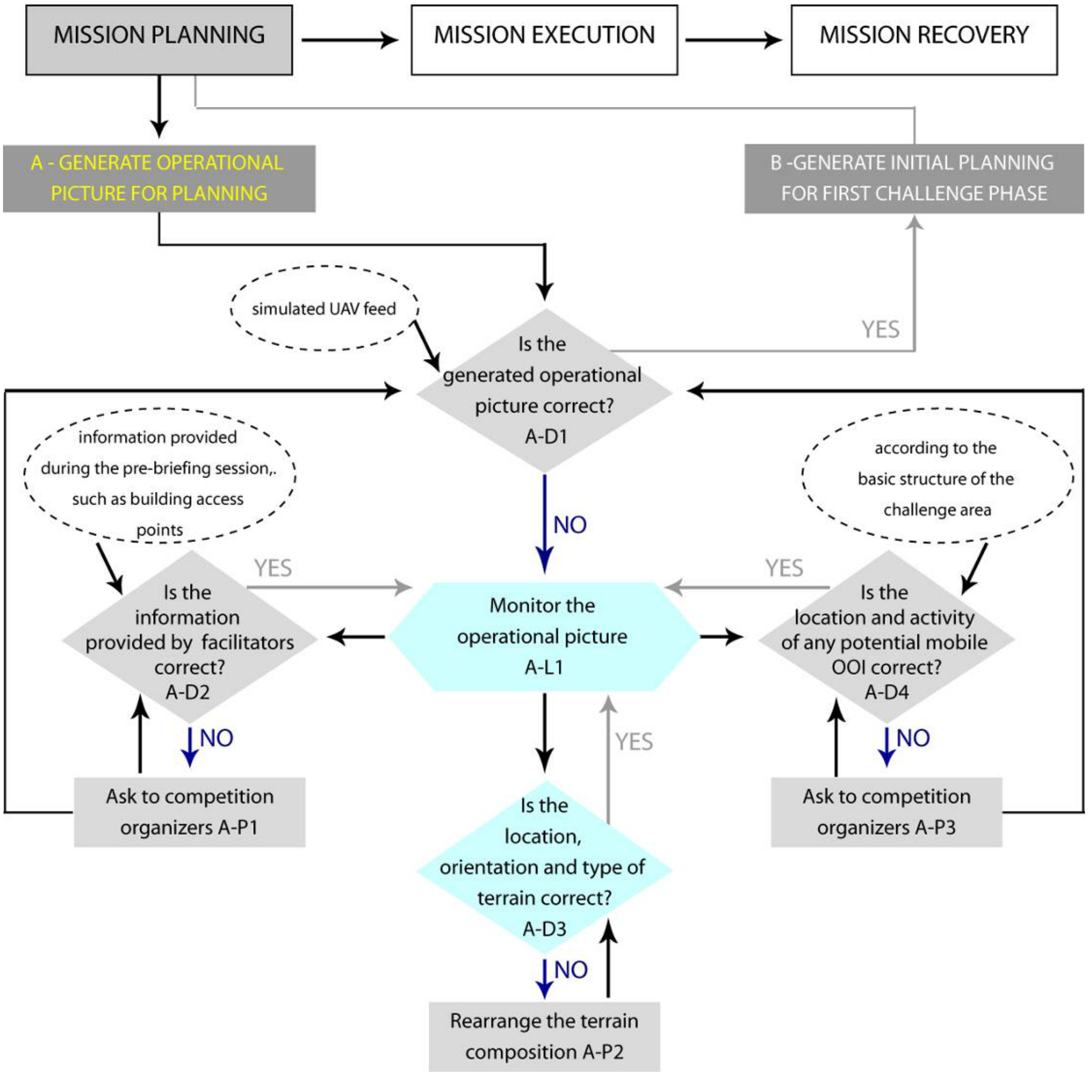


Figure 26 Event Flow for ‘Operational Picture for Planning’

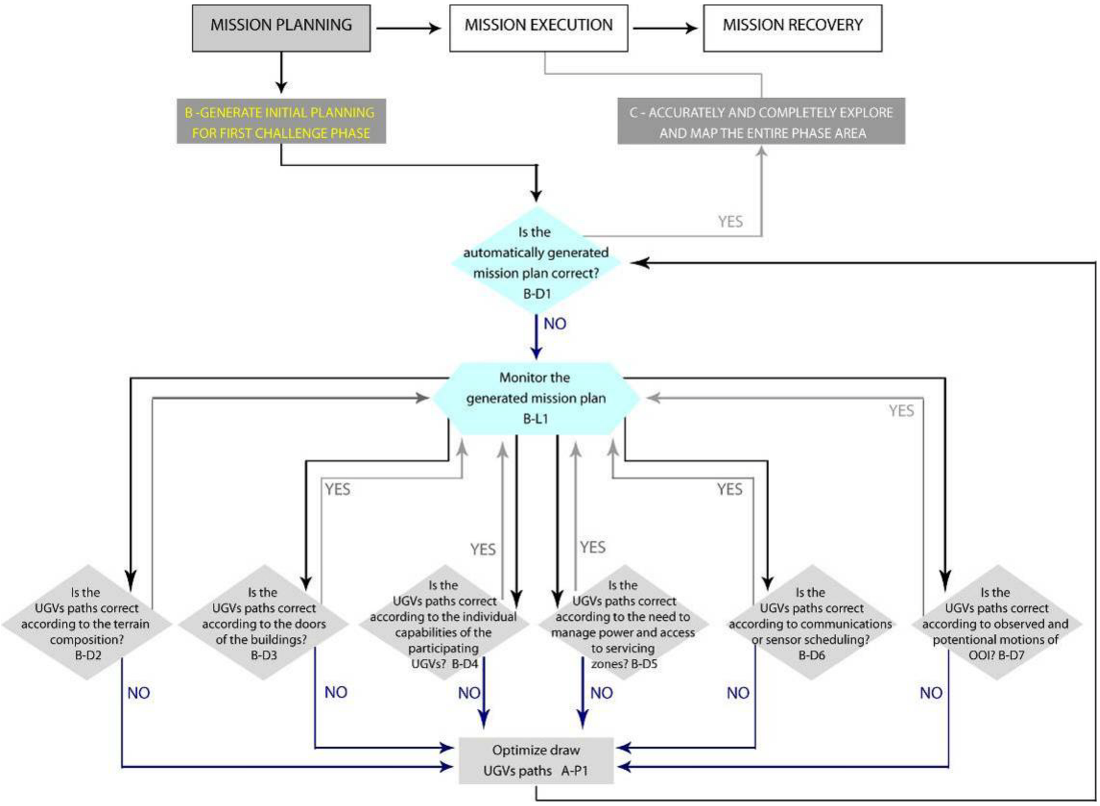


Figure 27 Event Flow for ‘Planning for First Challenge Phase’

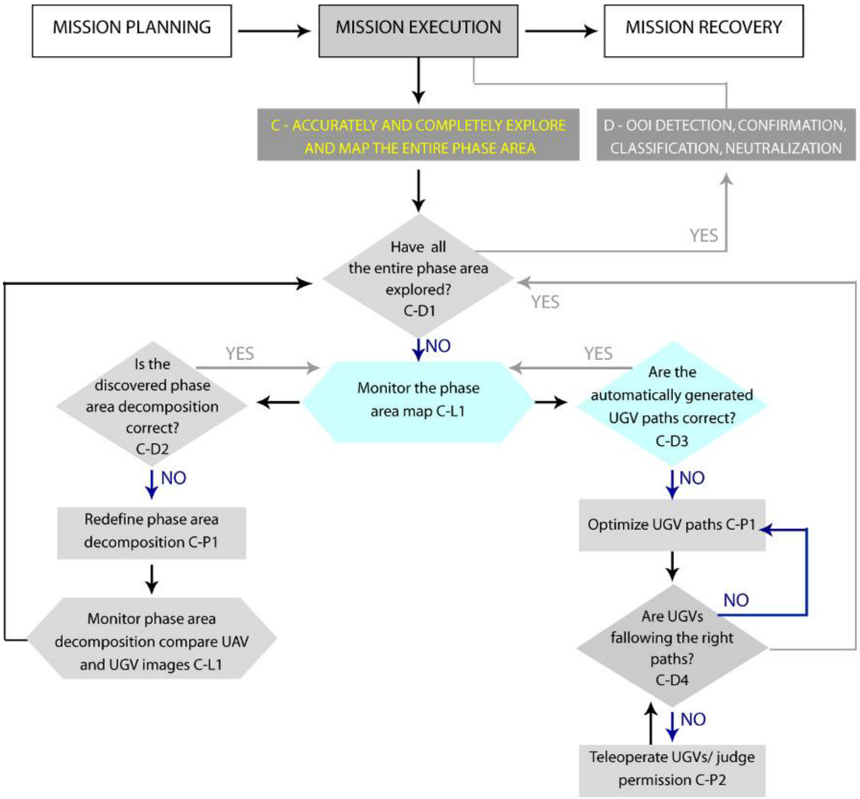


Figure 28 Event Flow for ‘Explore and Map the Entire Phase Area’

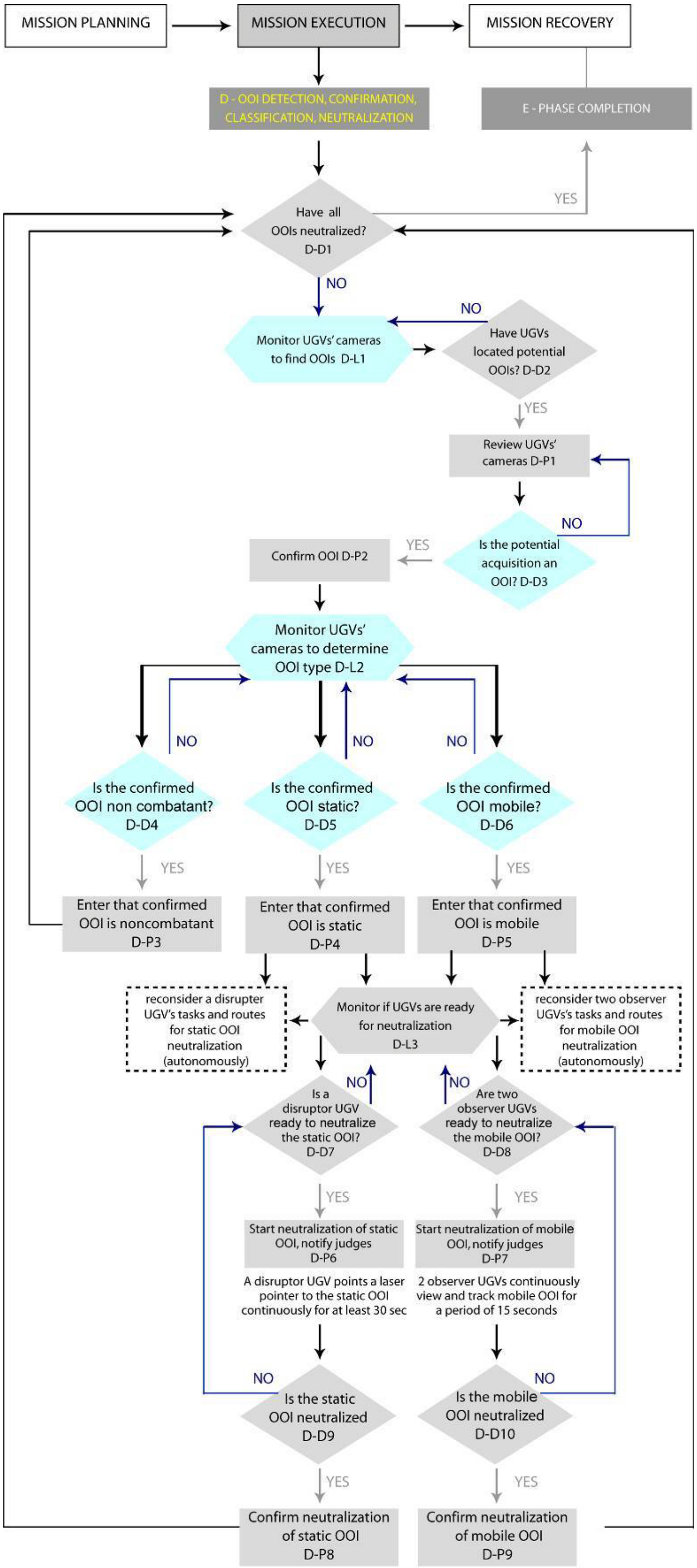


Figure 29 Event Flow for 'Object of Interest (OOI) Detection, Confirmation, Classification, Neutralization'

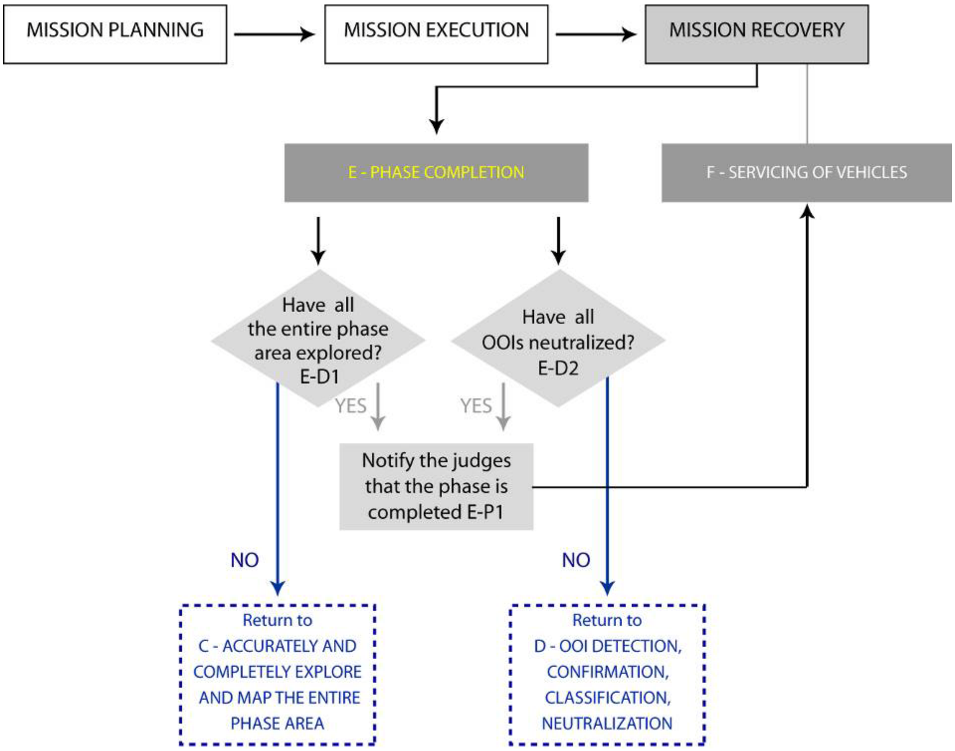


Figure 30 Event Flow for ‘Phase Completion’

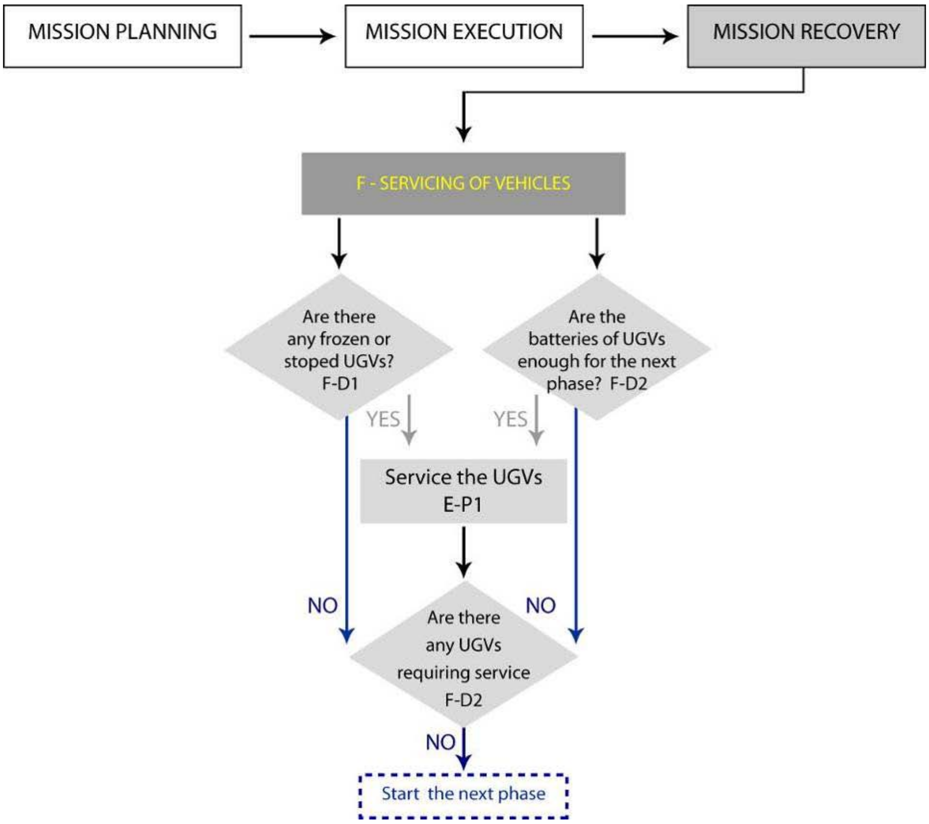


Figure 31 Event Flow for ‘Unmanned Vehicle Servicing’

Event flow diagrams show the relationships between the decisions, loops and processes within time sequences. Those charts set background information for the following techniques: situation awareness requirements and decision ladders, whose outcomes are user requirements. The critical decisions and loops defined in event flows are further investigated through decision ladders.

3) Situation Awareness Requirements:

This step relies on Situation Awareness (SA) theory by Endsley (1988) (SA in HRI is explained in Section 2.5.1). In this step the information that the operators need to perform each goal and make each decision is defined, in terms of the three levels of situation awareness defined by Endsley (1988): perception, comprehension, and projection. The Situation Awareness Requirements is given in Table 3. The phases, goals and sub-goals are consistent with scenario task overview.

There are predetermined three types of displays in the GUI design: tactic map, status monitoring and dynamic mission planner monitor (discussed in Section 4.4). The SA requirements are categorized according to the display in which these are realized into graphical elements. Graphical elements, corresponding to each situation awareness requirement are designed, and those are added to Table 3 in order to show the relationship between the GUI and SA requirements.

The SA requirements highlighted in red are the ones that are not realized in the GUI design, because of the limitations discussed in Section 4.4. Even though, all those SA requirements are not realized in the GUI, this technique enables the designers to comprehend the missing information in the GUI and emphasize user requirements and their role in maintaining SA for further study in the system design. Most of the user requirements which were not actualized in the GUI, are the ones which require extensive modifications in the whole system design.

Table 3 SA Requirements and Corresponding GUI Element

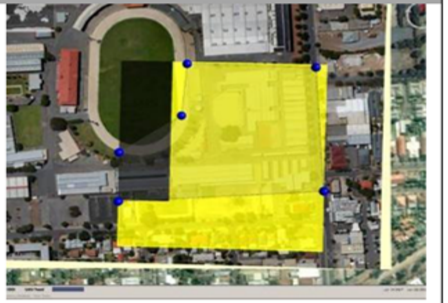
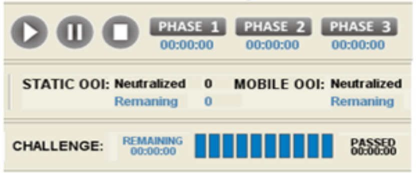
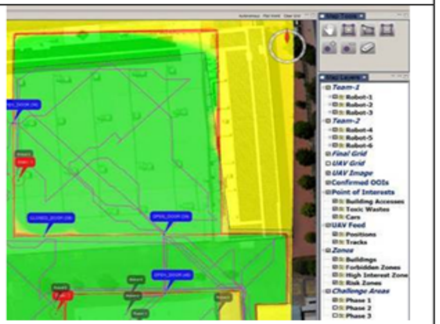
PHASE	GOAL	SUBGOAL	Level 1 (Perception)	Level 2 (Comprehension)	Level 3 (Projection)	Visualization Needs / Graphical Elements
MISSION PLANNING	**GENERATE OPERATIONAL PICTURE FOR PLANNING**	**Monitor competition area map**	Show the information from the UAV (unmanned aerial vehicle) feed provided to teams at the pre-brief by facilitators • The location and activity of any potential OOI *(tactic map)* • Automatically generated competition area decomposition (buildings, roads, obstacles etc.). *(tactic map)* • Other information such as building access points (provided by facilitators during the pre-briefing session). *(tactic map)*	Compare UAV feed picture and automatically generated competition area decomposition (buildings, roads, obstacles etc.). *(tactic map)*	The characteristics of the challenge phase (1,2,3) *(status monitor)*	 *Tactic Map*  *Multi UGV Status Monitor*
		Supervise competition area decomposition	• The location, orientation and type of terrain *(tactic map)* • Accessible buildings and OOI present within the environment *(tactic)* • The observed OOIs and potential motion of OOIs *(tactic map)* • Building access points • "No-go" or "difficult-to-go" zones *(tactic map)*	Show possible Point of Interests (POIs) (building, fence, OOI, tree, etc.) *(tactic map)*		 *Tactic Map*

Table 3 SA Requirements and Corresponding GUI Element (continued)

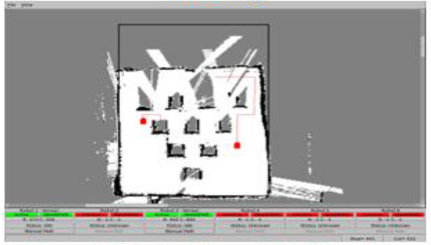
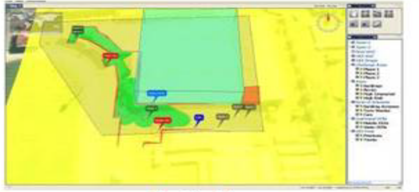
PHASE	GOAL	SUBGOAL	Level 1 (Perception)	Level 2 (Comprehension)	Level 3 (Projection)	Visualization Needs / Graphical Elements
		Monitor initial planning for challenge phase	• Show automatically generated paths of multi UGVs. *(tactic map)* • Show UGV directions *(tactic map)*	Show intersections of generated UGV paths and obstacles *(tactic map)*		 ***Tactic Map***
		Supervise initial planning for challenge phase	• Alternative paths for multi UGVs. *(tactic map)* • The location, orientation and type of terrain. *(tactic map)* • Accessible buildings and OOI present within the environment. *(tactic map)* • The observed and potential motions of OOI. *(tactic map)* • Building access points. *(tactic map)* • Capabilities of the participating UGVs *(status monitor)* • The need to manage power and access to servicing zones *(status monitor)*	The alternative paths of multi UGV in the competition area, regarding roads buildings etc. *(tactic map)*	The estimated **exploration area** when all UGVs fallowed the alternative paths (excluding possible neutralization processes). *(tactic map)* Estimated **time** for all UGVs fallowing the alternative paths (excluding possible neutralization processes). *(status monitor)* The characteristics of the challenge phase (1,2,3) *(status monitor)*	 ***Tactic Map***  ***Dynamic Mission Planer (DMP) Monitor***
MISSION EXECUTION	**ACCURATELY AND COMPLETELY EXPLORE AND MAP THE ENTIRE PHASE AREA**	**Monitor autonomous indoor and outdoor navigation of multi UGV**	• The locations of multi UGVs. *(status monitor)* • The paths of multi UGVs. *(tactic map)* • If each UGV is in indoor or outdoor. *(status monitor)*	• The paths of multi UGV in the competition area, regarding obstacles, roads buildings etc. *(tactic map)* • Show if the UGV paths intersect with obstacles or any restricted area. *(tactic map)*	Alert when the mission plans of UGVs are changed. *(tactic map)* Alert when UGV paths intersect with obstacles or any restricted area. *(tactic map)*	 ***Tactic Map***

Table 3 SA Requirements and Corresponding GUI Element (continued)

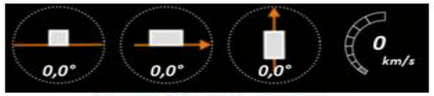
PHASE	GOAL	SUBGOAL	Level 1 (Perception)	Level 2 (Comprehension)	Level 3 (Projection)	Visualization Needs / Graphical Elements
		Supervise multi UGV navigation /trajectory optimization, route- path deconfliction	• Alternative paths for multi UGVs. *(tactic map)* • Adding and deleting way points of the path, drawing UGV path. *DMP Monitor*	The alternative paths of multi UGV in the competition area, regarding roads buildings etc. *(tactic map)*	Show UGV directions, covered path and planned path *(tactic map)*	 ***Dynamic Mission Planer (DMP) Monitor***
		Teleoperate an UGV (only in ambiguous conditions with judge permission)	• The location of UGV in the tactical map. *(tactic map)* • Step by step description of movements of UGV. *(tactic map)* • Teleoperation hardware	Video stream of where UGV is teleoperated, obstacles around. *(tactic map) (status monitor)*		
		Monitor status of multi UGV	• The types of multi UGV observer or disrupter. *(tactic map) (status monitor)* • The mode of multi UGVs (run, freeze, e-stop). *(status monitor)* • The conditions of multi UGV (battery level, velocity, orientation, health etc.). *(status monitor)*	• Velocity comparing with the limits. *(status monitor)* • Battery level, how long it will take to finish. *(status monitor)*		 ***Multi UGV Status Monitor** / Status Bar*  ***Single UGV Status Monitor***
		Monitor competition requirements	• Time *(status monitor)* • Phase level and time • The number of static and mobile object of interests *(status monitor)*	• Time passed and remained. *(status monitor)* • Total operator interaction time left regarding to the 10 min limitation.	• The requirements and characteristics of phase levels (phases: 1,2,3) • The number of static and mobile object of interests remained and neutralised *(status monitor)*	 ***Multi UGV Status Monitor***

Table 3 SA Requirements and Corresponding GUI Element (continued)

PHASE	GOAL	SUBGOAL	Level 1 (Perception)	Level 2 (Comprehension)	Level 3 (Projection)	Visualization Needs / Graphical Elements
	CORRECTLY LOCATE, CLASSIFY, RECOGNIZE AND NEUTRALIZE ALL OOI IN THE PHASE AREA	**Monitor potential OOIs**	• Potential OOIs *(tactic map) (status monitor)* • Which UGV detected which OOI *(tactic map) (status monitor)* • Potential OOI locations *(tactic map)*	Potential OOIs' images *(status monitor)*	Limitations of UGVs' potential OOI detection capabilities. • Communication levels. *(status monitor)* • Mission plan of the UGV *(tactic map)* • Type of the UGV. *(status monitor)*	 *Tactic Map*  *Multi UGV Status Monitor/PTZ camera*  ID | PTZ ID | TYPE | STATUS | DISTANCE | NORTHING | EASTING 1 | 1000 | STATIC | ACQUISITION | 0.0 | 1001.12 | 4001.13 3 | 2000 | NON_COMBATANT | NEUTRALIZE | 4124.04 | 1003.16 | 4000.17 5 | 1500 | STATIC | TRACK | 5100.0 | 1005.0 | 5000.0 *Multi UGV Status Monitor/Live OOI list*
		Confirm potential OOIs	• Confidence levels of potential OOIs • Alert for potential OOI which has higher confidence level then the predefined *(status monitor)*	Potential OOIs' images *(status monitor)*	Alert for UGV which is in acquisition of more OOI with higher confidence levels.	
		Monitor confirmed OOI	• Confirmed OOIs images *(status monitor)* • Confirmed OOIs locations *(tactic map)*			
		Classify confirmed OOI	• Confirmed OOIs *(status monitor)* • Confirmed OOI locations *(tactic map)* • Classifications of classified OOIs *(status monitor)monitor)*	Lethality and activation zones of different types of OOIs *(tactic map)*	• Potential options for OOI classifications. *(status monitor)* • Show if lethality and activation zones of OOIs intersect with UGV paths *(tactic map)*	

Table 3 SA Requirements and Corresponding GUI Element (continued)

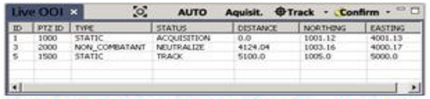
PHASE	GOAL	SUBGOAL	Level 1 (Perception)	Level 2 (Comprehension)	Level 3 (Projection)	Visualization Needs / Graphical Elements
		Start neutralization of classified OOI	• Neutralization status of confirmed OOI *(status monitor)* • Show if disrupter UGV is ready for neutralization. (2 m within activation zone of static OOI) *(tactic map)* • Alert when UGV is ready for neutralization.	Show if team leader has communicated that the neutralization process has started – thus UGVs can enter activation zone of the OOI. *(status monitor)*	• UGVs' current activities and task plans. If they are available for OOI neutralization. *(tactic map)(status monitor)* • Estimated time UGVs would be ready for neutralization.	 ***Tactic Map***
		Monitor the neutralization process	• Show which UGVs' task plan is regenerated for neutralization *(tactic map)(status monitor)* • Show if the disrupter UGV points laser out to static OOI. (Teleoperate laser if not targeted well.)*)(status monitor)*	Show if the disrupter UGV points laser out to static OOI for at least 30 sec. Show if the two observer UGVs' have been tracking the mobile OOI for 15 seconds.	Show regenerated paths of UGVs for neutralization. *(tactic map)*	 ***Multi UGV Status Monitor/PTZ camera/laser***
		Monitor the neutralized OOIs	The locations and numbers of neutralized OOIs *(status monitor)*	Show if detected potential static OOIs are already neutralized *(tactic map)*	How many more OOIs should be neutralized for the completion of competition subgoal. *(status monitor)*	 ID | PTZ ID | TYPE | STATUS | DISTANCE | NORTHING | EASTING 1 | 1000 | STATIC | ACQUISITION | 0.0 | 1001.12 | 4001.13 3 | 2000 | NON_COMBATANT | NEUTRALIZE | 4124.04 | 1003.16 | 4000.17 5 | 1500 | STATIC | TRACK | 5100.0 | 1005.0 | 5000.0 ***Multi UGV Status Monitor/Confirmed OOI list***
MISSION RECOVERY	**PHASE COMPLETION**	**Decide the phase completion**	• Explored areas and unexplored areas within the phase. *(tactic map)* • The number of neutralized static and mobile OOIs. *(status monitor)* • Time spent on phase *(status monitor)*	• Time remained*(status monitor)* • The ratio of explored areas of the phase. • The ratio of neutralized OOIs. *(status monitor)*	• The characteristics of the following phases	 ***Multi UGV Status Monitor***

Table 3 SA Requirements and Corresponding GUI Element (continued)

PHASE	GOAL	SUBGOAL	Level 1 (Perception)	Level 2 (Comprehension)	Level 3 (Projection)	Visualization Needs / Graphical Elements
	SERVICING OF UGVs	**Decide servicing the UGVs**	Health status of UGVs*(status monitor)* Battery levels of UGVs*(status monitor)* Frozen or stopped UGVs *(status monitor) (tactic map)*	Time left to finish the batteries with the average consumptions of the UGVs The meaning of each health item. The reasons for stopping or freezing UGVs	Comparison of time left and battery levels *(status monitor)* The consequences of health statuses. (What happens when VSMM is on alert?)	 ***Multi UGV Status Monitor / Health Bar***  ***Multi UGV Status Monitor / Status Bar***

While user requirements for ‘perception’ level of SA is the first to come in mind ‘comprehension’ and ‘projection’ levels of SA is observed to be having the tendency to be forgotten. Situation awareness requirements are especially helpful to determine all those three levels of user requirements.

4) Decision Ladders for Critical Decisions

Critical decisions distinguished in the event flow diagram are further investigated through decision ladders. As mentioned in Rasmussen and Lind (1982), Rasmussen (1976) analyzes verbal protocols of the users and distinguishes the “states of knowledge” in the users’ decision process and arranges those in a sequence, building the decision ladder model shown in Figure 32.

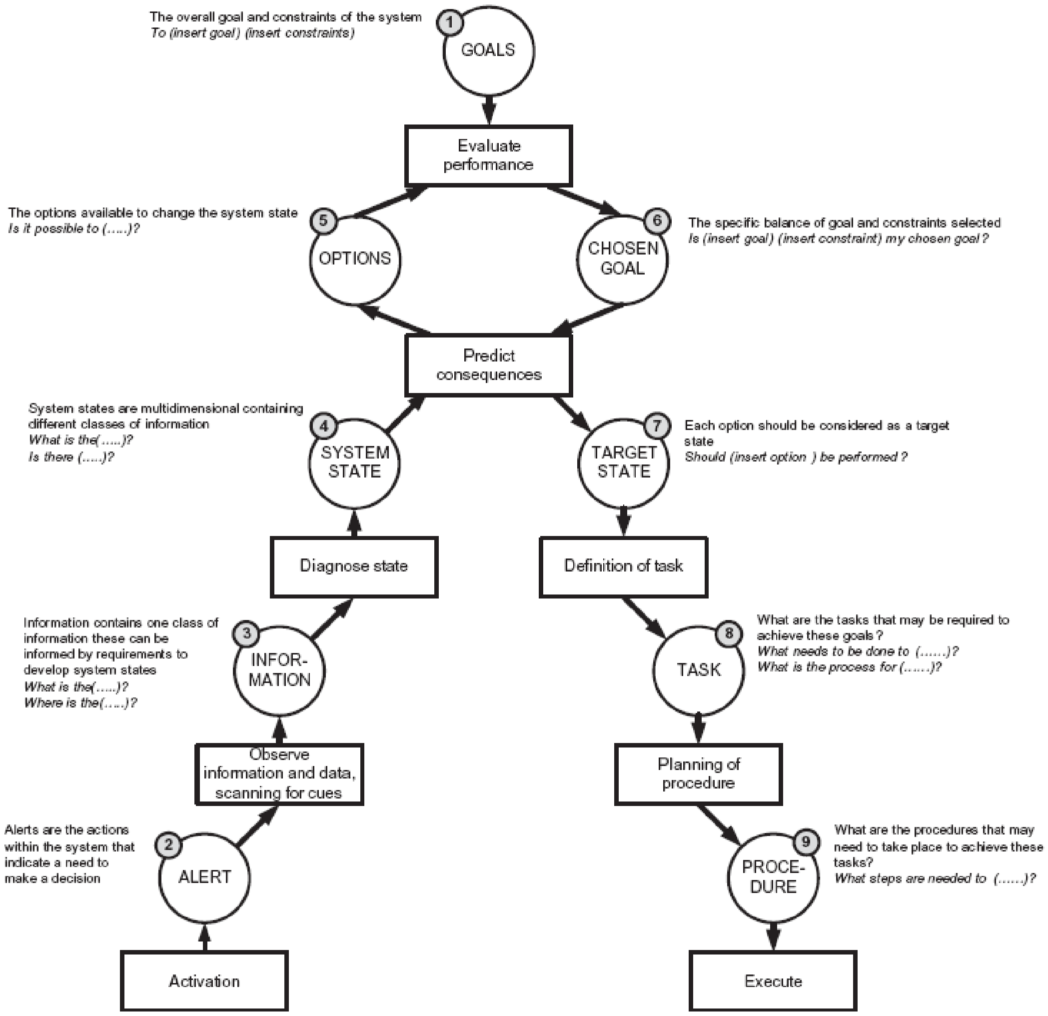


Figure 32 Rasmussen and Lind’s (1982) Model of Decision Ladder Redrawn by Jenkins, Stanton, Salmon, Walker and Rafferty (2010)

Rectangular boxes in the decision ladder represent data processing, while circular ones are the states of knowledge (Figure 32). Besides the goal in the middle, the model is linear in the time, tracing the numbers in Figure 32, starting from the bottom left corner and following a route upwards, and then downwards. Naikar and Pearce (2003) mention that, the left side of the ladder stands for observing the current state while right side represents executing the tasks for accomplishing goals. Even though the ladder is sequential, shortcuts are still expected between the two halves. Two states of knowledge (circular) may be connected without information processing (rectangular) required in between, or an information processing (rectangular) may be connected with a state of knowledge (circular) while bypassing others. Jenkins et al. (2010) state that experienced users usually link the nodes with shortcuts, while novice users follow the sequence. Those shortcuts do not change the results but they shorten the sequences of experienced users.

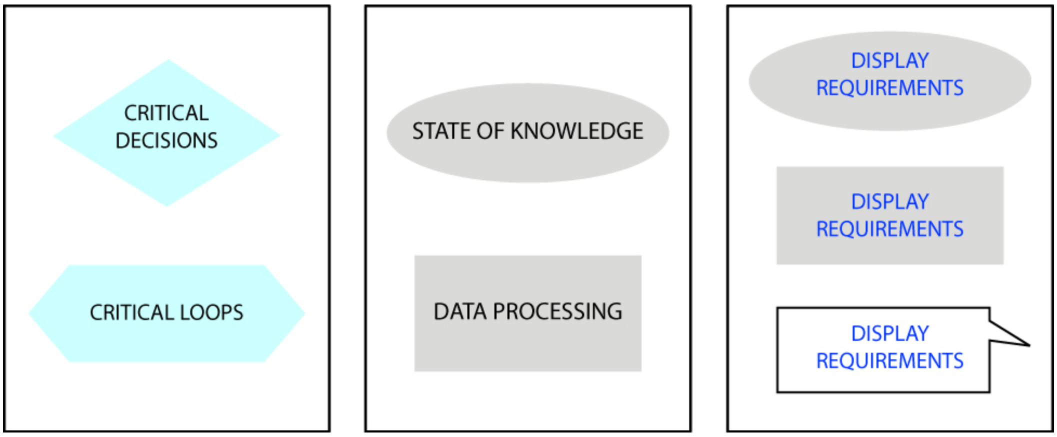


Figure 33 Symbols of Decision Ladders

Decision ladders are built by the author for the critical decisions defined in the event flows (Figures 34 to 38). In the following decision ladders display requirements are highlighted in blue.

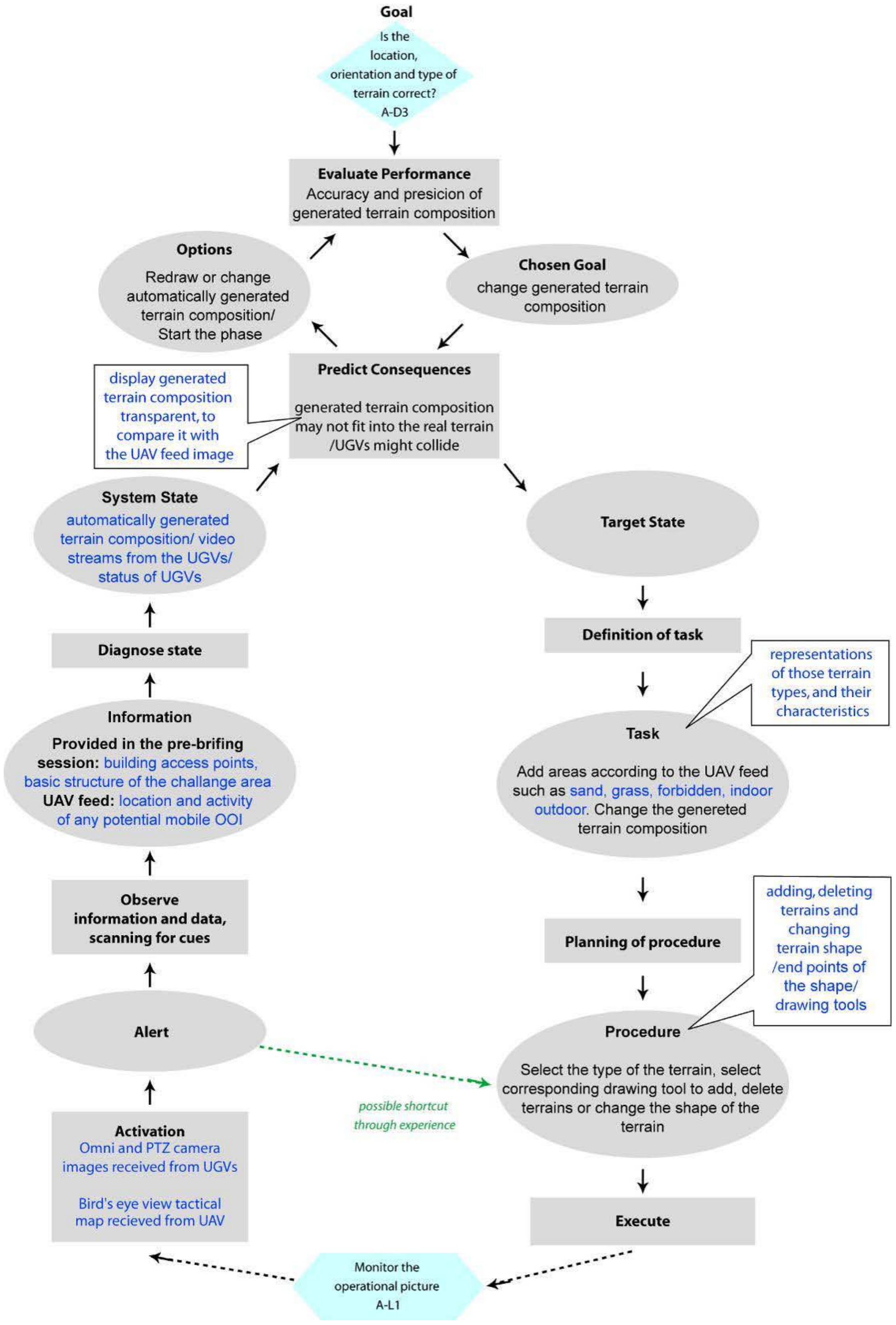


Figure 34 Decision Ladder for ‘Terrain Composition’

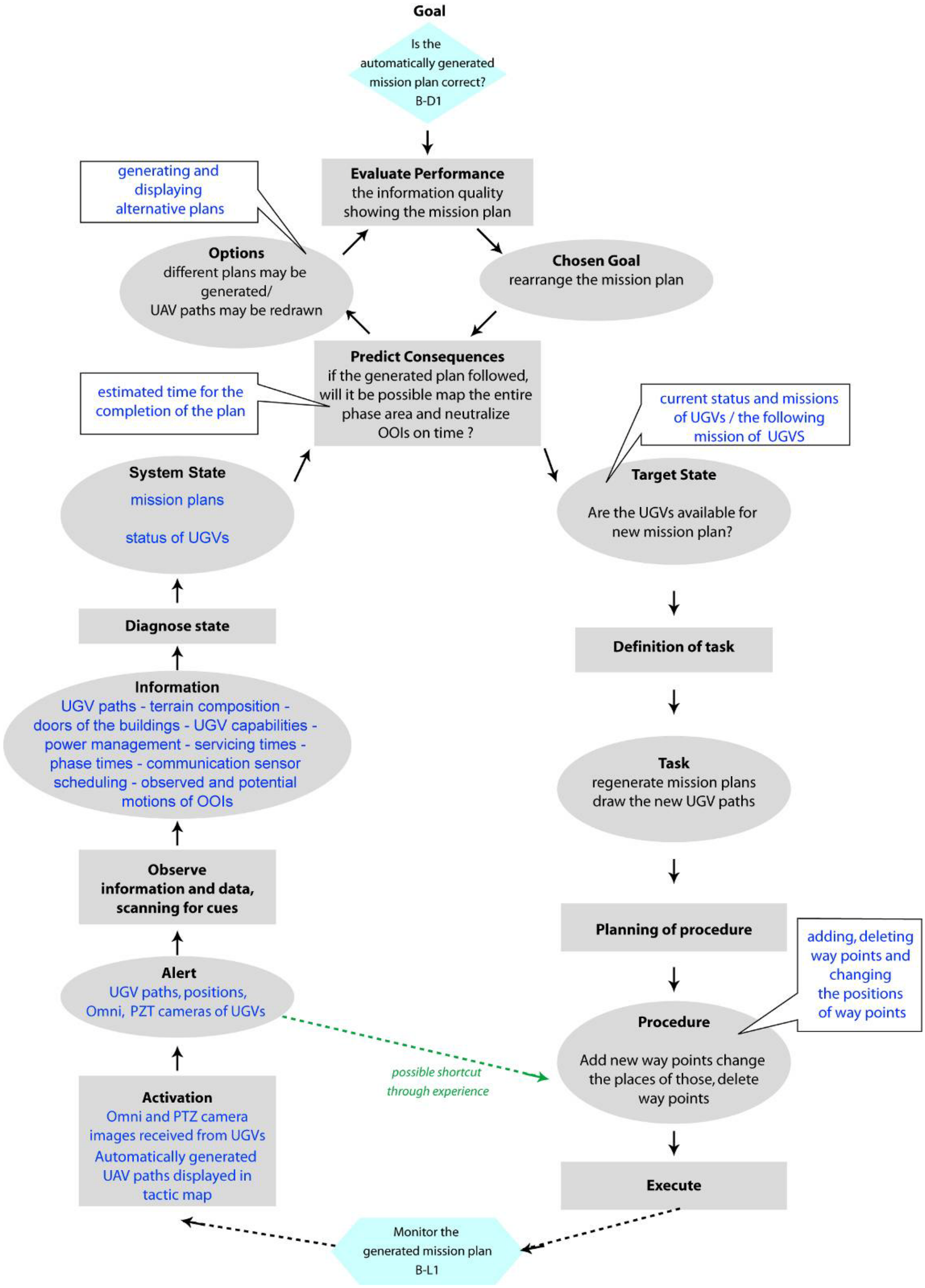


Figure 35 Decision Ladder for ‘Mission Plan’

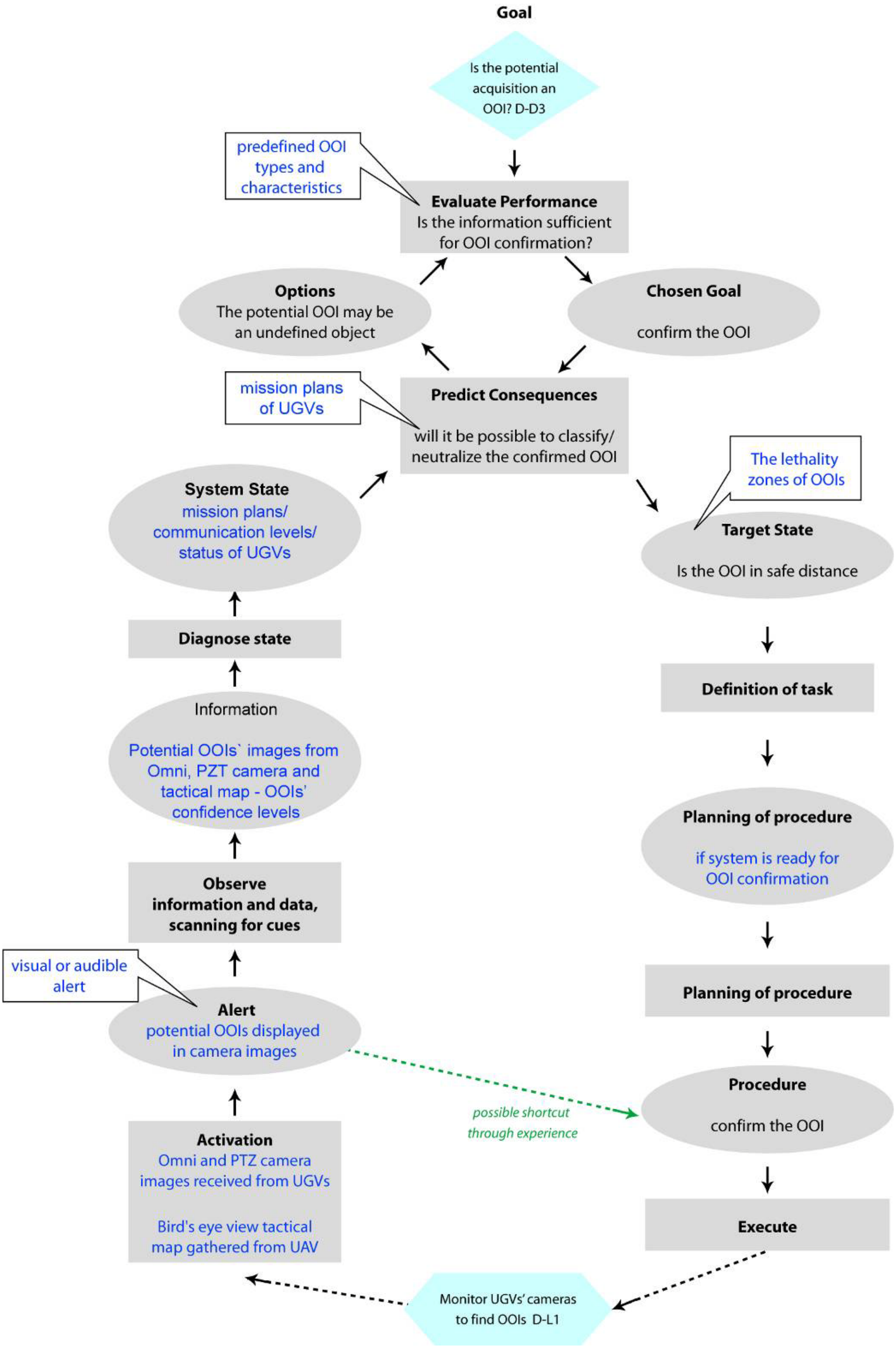


Figure 36 Decision Ladder for ‘OOI (Object of Interest) Detection’

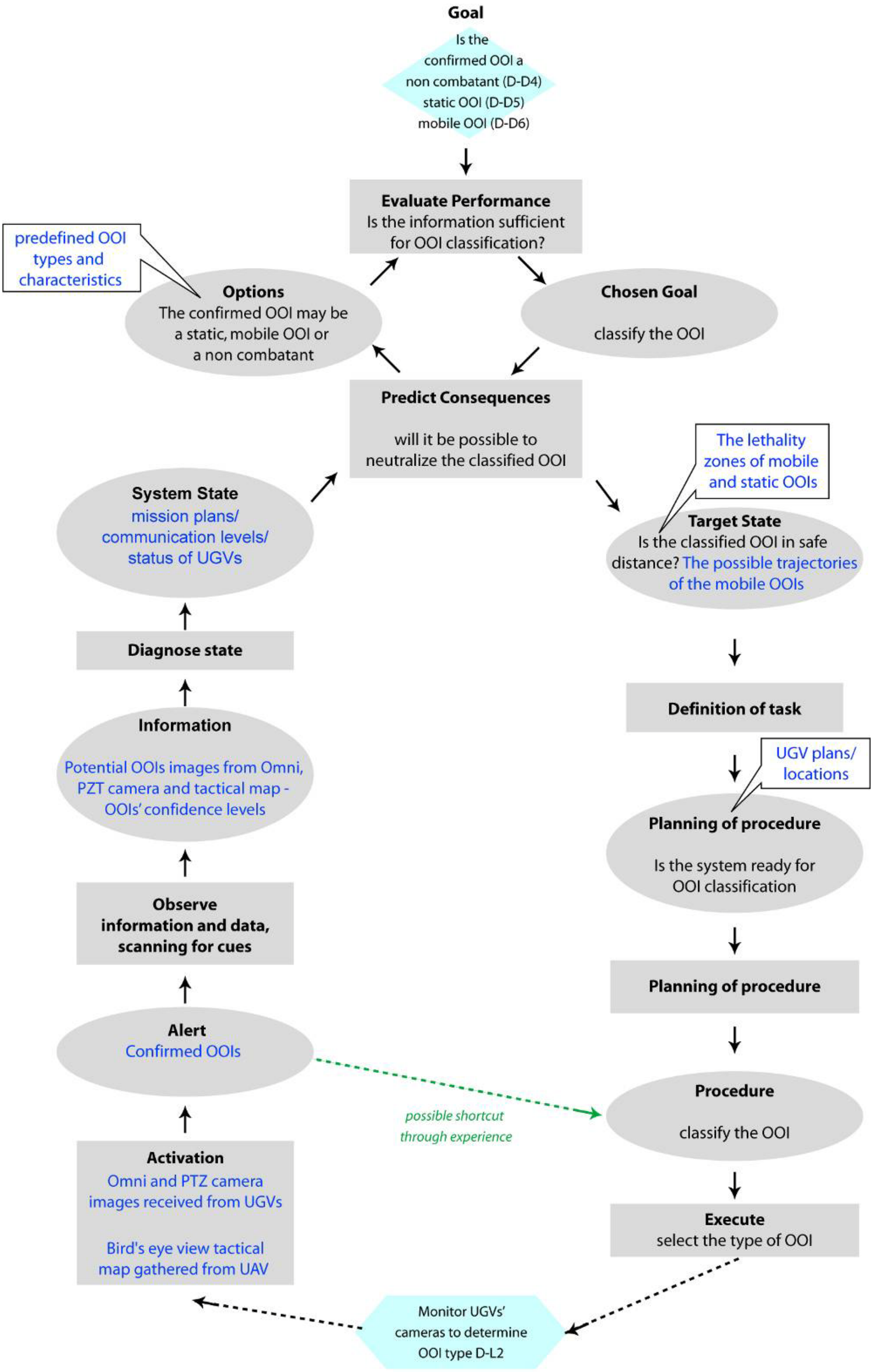


Figure 37 Decision Ladder for 'OOI (Object of Interest) Classification'

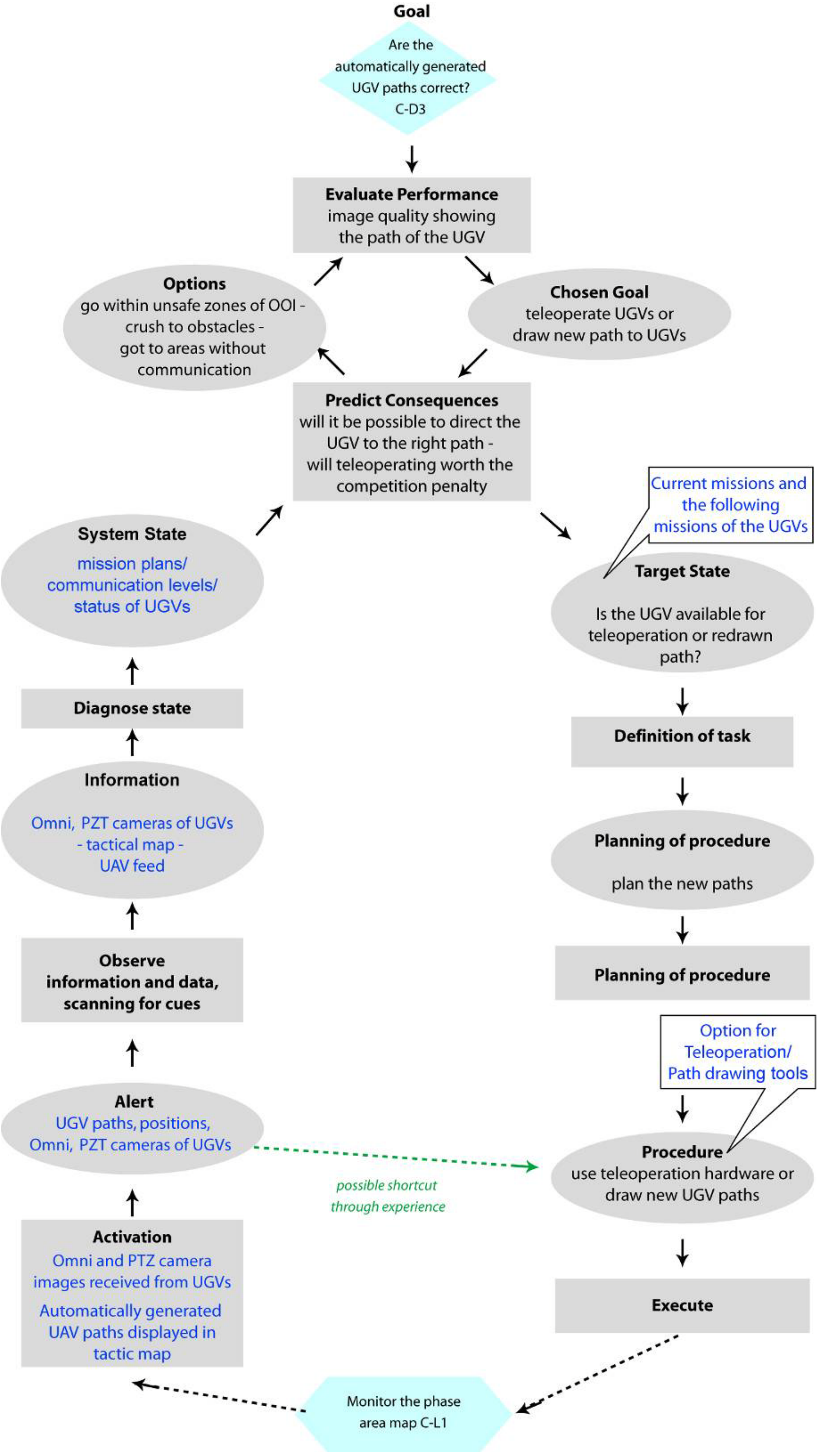
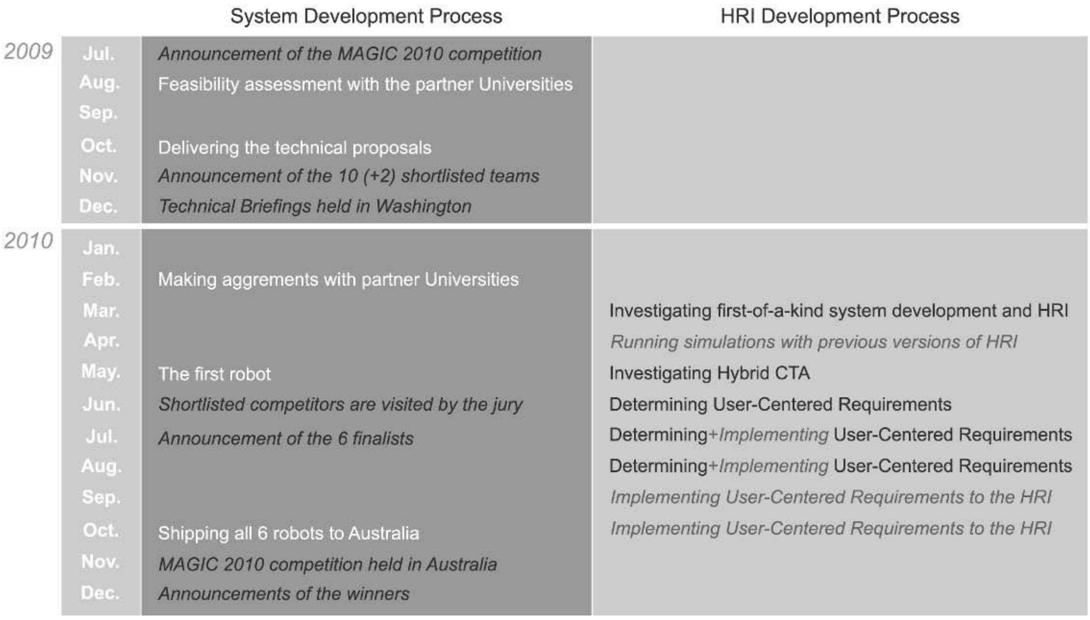


Figure 38 Decision Ladder for ‘UGV (Unmanned Ground Vehicle) paths’

Decision ladder technique is comprehensive in determining user requirements in a structured way, which is argued to be the cognitive process of an operator for decision making. However, the way SA requirements table present user requirements is easier to understand. Hence, the author argues that their combination was useful for determining user requirements of MAGIC 2010. The user requirements gathered from decision ladders are checked with SA requirements and those are also included in the SA requirements in Table 3.

4.4 Limitations of the Implementation

As explained before, the implementation of the Hybrid CTA methodology should be performed before the start of the design process, in the requirements determination phase. However, in the MAGIC 2010, determining user requirements early in the development process has not been possible. Figure 39 shows the timeline of the system development process in MAGIC 2010 with the corresponding HRI development activities.



		System Development Process	HRI Development Process
2009	Jul.	*Announcement of the MAGIC 2010 competition*	
	Aug.	Feasibility assessment with the partner Universities	
	Sep.		
	Oct.	Delivering the technical proposals	
	Nov.	*Announcement of the 10 (+2) shortlisted teams*	
	Dec.	*Technical Briefings held in Washington*	
2010	Jan.		
	Feb.	Making aggrements with partner Universities	
	Mar.		Investigating first-of-a-kind system development and HRI
	Apr.		*Running simulations with previous versions of HRI*
	May.	The first robot	Investigating Hybrid CTA
	Jun.	*Shortlisted competitors are visited by the jury*	Determining User-Centered Requirements
	Jul.	*Announcement of the 6 finalists*	Determining+*Implementing* User-Centered Requirements
	Aug.		Determining+*Implementing* User-Centered Requirements
	Sep.		*Implementing User-Centered Requirements to the HRI*
	Oct.	Shipping all 6 robots to Australia	*Implementing User-Centered Requirements to the HRI*
	Nov.	*MAGIC 2010 competition held in Australia*	
	Dec.	*Announcements of the winners*	

Figure 39 MAGIC 2010 development timeline

Hence, for MAGIC 2010, implementing some of the user requirements has not been possible as those were determined late in the development process. The factors preventing the early implementation of the intended process are as follows:

- **System-Technology Centered Development Approach**

Even though, in this thesis, the importance of determining user requirements before starting the design process is explained, this user-centered approach has not been applied in the company yet. Hence, system-technology centered development process (described in figure 2) is followed also in the development of MAGIC 2010. Therefore, the author working as an industrial designer partake the system development process at the design process, as being responsible for the systems' conformance with the users. However, when the author joined the design process, the system was already constrained with the system oriented requirements. Moreover, while the company leaded the development process of the robots for the MAGIC 2010, the design of some of the system components have been outsourced with partners from varying Universities. Even though, the HRI is developed in-house, some of the outsourced components influenced the HRI. For instance, one of those included functions required to be controlled from the GUI. Integrating this system component to the GUI has not been described within the system requirements. Thus, integrating that system component to the GUI has not been possible within the planned system development resources and schedules. Because of this, one of the user requirements has been verified in the competition with an additional monitor, utilized only for a single function. That additional monitor demanded extra cognitive loads to be monitored and made it difficult to compare the information with the relative ones in the GUI.

- **MAGIC 2010 Schedule**

In MAGIC 2010 the design team had three months for delivering the technical proposal and then an additional six months until the semi final (Figure 39). 'Real' projects funded by stakeholders, especially if those are first-of-a-kind systems, usually take longer for system development than MAGIC 2010. Hence, because of the tight schedules, when the author started to determine user requirements of the HRI through Hybrid CTA, the system was already constrained with system requirements and system design was in progress. Even though, in the beginning of the process, the author aimed to document all the Human Robot Interaction development processes, the tight schedules inhibited the design team to follow a structured development process.

Other limitations of the implementation are as follows:

- **Relying on Observations and Subjective Evaluations**

Some of the discussions in this thesis may rely on the observations of the author, made while conducting the implementation study, and her subjective evaluations about those observations. Therefore, even within the same circumstances and with the same inputs, another researcher may end up with different conclusions.

- **Implementing for a Competition rather than a Project Defined by Stakeholders**

The implementation is carried out for a competition, which includes both limiting and advantageous factors. In the MAGIC 2010, the validation of the system is defined through a specific usage scenario within limited time and limited needs. However, in most of the 'real' projects, the needs defined by the stakeholders in the system specifications are opt to be more inclusive with wider ranges of floating needs, which are not always well defined. It is easier to implement a methodology within the limits of a competition, rather than implement it for 'real' projects funded by stakeholder. However, that may hinder the representativeness of this implementation for projects funded by stakeholders.

- **Limitations of the MAGIC 2010 Regulations**

According to the competition regulations, the two users were monitoring the robots about one meter away from the displays, and have ten minutes in total to go beyond the one meter line and give commands. Even though, this scenario might be developed to limit the time required for intervention and support autonomy, it does not imitate any real world scenario, which limits generalization of the implementation for real world projects.

- **Limitations of Preset System-Technology Centered Requirements**

Before the author started to carry out Hybrid CTA to determine user requirements of the HRI, MAGIC 2010 design team had already determined some of the design requirements. Those system-technology centered requirements are given below.

- **Number and composition of robot teams:** each operator supervises one team composed of two observer robots and one disrupter robot, in total six robots
- **Number and main functions of displays:** each user monitor two displays, one for three robots' status and their video streams, the other for tactic map including area composition generated over the Unmanned Air Vehicle's (UAV) video feed and all six robots' positions with their planned paths (one extra display was included to interrupt autonomy and control robots' paths)

In the competition each user supervised three robots. However, the cognitive loads of the users should have been investigated before deciding on the number of robots each user supervises. Cognitive work analysis methods could have been utilized for determining that the work distribution among users. However, because of schedule limitations those decisions were made without any cognitive analysis and were not examined through user-centered concerns. In the implementation study, Hybrid CTA was conducted taking those as inputs.

- **The Bias of 'Designing for Self'**

The competition regulations specified the maximum number of users as two, but not the characteristics of the actual users who supervise the robots during the competition. Hence, MAGIC 2010 competitors selected those two from their design teams, who are the most experienced in using the GUIs. Within the team, the technical leader of the design team and a software engineer who is one of the engineers of the GUI were selected to supervise the robots during the competition. Hence, the users in the competition were also the designers of the system, which is not the actual case in 'real' projects, funded by a stakeholder. For the designer of the MAGIC 2010, who was also the user of the system, building empathy with the user had been easier. For instance, in the design of the GUI, statements like *"**you are** going to need that information to comprehend the source of the problem in a limited time"* have been pronounced to convince the software engineer in the importance of the user requirements. On the other hand, the designer may have been biased in designing a GUI for himself, an engineer with high experience in computer programming. Similarly, Yanco and Drury (2004) developed HRIs for competitions in which users were also the developers and they mention similar concerns. Thus, they conducted usability testing to evaluate their interface with users who had not worked with robots before. Even though, the MAGIC 2010 defines the user of the system as "highly experienced and trained", that should not imply the training and the experience to be a software engineer. The design team made effort in designing a GUI not requiring excessive training, but its success should be further investigated with empirical evaluations.

In the following section, discussions on the implemented methodology, Hybrid CTA, are delivered.

4.5 Discussions

Nehme et al., (2006) claim that the implemented methodology, hybrid CTA, is beneficial for the following reasons:

1. "enables the analyst to **generate functional and information requirements** from a representative scenario description of a futuristic task domain
2. **compensates for the lack of SMEs** through the decision ladder generation which helps **replicate a potential operator's thought processes**
3. provides the analyst with a **clear mapping of any generated requirements backwards and forwards through each phase,** should any revisions need to be made" (p.5).

These arguments are discussed both from the references in the literature and also the author's self observations while implementing the methodology.

First argument claims that, the methodology generates “functional and information requirements” through “a representative scenario description” (Nehme et al., 2006, p,5). The described step by step analysis of the scenario obviously enables the designer to systematically analyze the functions and information requirements while considering cognitive processes. Thus, when compared with working without any method, the possibility of bypassing some user requirements is decreased by following the Hybrid CTA. However, still the methodology is quite open for the subjective interpretations of the designer. Some individual factors like: the experience level of the designer and his competence in the subject domain are very influential on the success of the implementation of the methodology. In the implementation, difficulties are witnessed in deciding the sequences and cognitive processes of the potential users. In order to cope with these difficulties: the published implementations of the methodology are analyzed (Almirao, da Silva, Scott & Cummings, 2007; Buchin, 2009; Da Silva, Scott & Cummings, 2007; Fisher, 2008; Kilgore, Harper, Nehme & Cummings, 2007; Massie, Nehme & Cummings, 2007; Nehme et al. 2006; Scott & Cumming, 2006; Scott, Wan, Rico, Furusco & Cummings, 2007).

Some of the techniques in Hybrid CTA are performed partly twice in different intervals of the design process. It is witnessed that, some steps are added and some of them are modified while those techniques are carried out for the second time. Hence, it is argued that different event flows, decision ladders and situation awareness requirements could be drawn if those techniques are carried out in another time. The reason for that difference might be the inexperience of the author in those techniques. However, this observation also shows that, different designers may come up with different requirements, even if the same techniques are followed. On the other hand, none of the cognitive analysis techniques can be argued as being totally independent from the analyst’s individual differences and levels of experiences. Still, it may be argued that the four complementary techniques of Hybrid CTA compensate for the inexperience of the author to some extent, which should be investigated further.

Most of the cognitive analysis of first-of-a-kind system requirement determination, the outcomes are not evaluated with actual users (Humphrey & Adams, 2010; Naikar & Pearce, 2003; Nehme et al., 2006). However, Roth et al. (2001) make a series of empirical studies including both objective and subjective measures. They conclude that the design through CTA lead a superior ‘power plant group view display’ which is a first-of-a-kind system. The reliability of the requirements determined through the Hybrid CTA is open for discussion until they are verified by actual users.

Second claim of Nehme et al. (2006) about the benefits of hybrid CTA is that the lack of SMEs are compensated by decision ladders which aid the designer to “**replicate a potential operator’s thought processes**” (p.5). As quoted in Rasmussen and Lind (1982), Rasmussen (1976) analyzes verbal protocols and identifies distinctive statements which he calls “states of knowledge” and draws the decision ladder methodology through rearranging those. Rasmussen and Lind (1982) argue that “these states of knowledge divide the decision process into a sequence of more or less standardized subroutines” (p.7). Hence, the decision ladder is built on the expected sequences of decision making, which is accepted as standard routines. However, Crandall et al. (2006) claim that “skilled IT users are not following steps”, but they are “interpreting the task”, “adopting or rejecting strategies” and “modifying or abandoning standard procedures” (p.164). Obviously, a methodology set on a technique that simulates the standardized routines of the potential users is insufficient in modeling the users’ interpretations, adaptations and rejections.

In decision ladders, experiences of the users are represented with shortcuts through some cognitive processes, so that experienced users end up with decisions and corresponding actions with fewer steps compared with novices. Hence, experienced users’ are claimed to be not requiring some of the display requirements of the bypassed cognitive processing steps. However, which levels are to be bypassed, only relies on the analyst’s prediction. Moreover, the influence of the user’s experience level to his decisions and corresponding actions are not covered in this technique.

Even though, Nehme et al. (2006, p.5) discuss that the Hybrid CTA “compensates for the lack of SMEs”, the author witnesses the difficulty in following the methodology for a system she has never used and that is built for an environment she has never been to. A designer or an analyst cannot simulate or imagine the insights of SMEs without actually working in that environment and comprehend user’s concerns developed for real time critical decisions. Redish (2007) underlines the importance of SMEs in specialized complex systems and explains that, for the designer or analyst “becoming expert in these domains [complex systems] is not a trivial undertaking. This makes it very difficult to apply user-free formative evaluation techniques in which the usability specialist serves as surrogate user.” (p.105). SMEs are not only users who know how to use a specific system, but they are also the experts who are using systems in real time within specific environments and conditions. Consequently, it can be claimed here that through Hybrid CTA, it is not possible to simulate the potential users’ cognitive processes and substitute the qualitative information gathered from SMEs.

The third claim of Nehme et al. (2006) is that the Hybrid CTA methodology enables the designer to map the requirements systematically and see the links between those; so, comprehend the outcomes of the modifications on human cognition. As mentioned, it might be argued whether the methodology represents the thought processes of an actual user or not, but it definitely enables the designer to systematically analyze the tasks and their links. Hybrid CTA not just helps to determine user requirements, but it also reveals the cognitive reasons for these specific requirements. Hence, the consequences of not realizing a requirement are also shown.

The design of the GUI and the details of the competing system are given in Section 4.3 showing the outcomes of the methodology and how the objectives are fulfilled in the HRI. Evaluations and suggestions about the GUI, from the contestants, in other words the users of the system, are included in Appendix A. Those are gathered from the self evaluation reports written by the design team, right after the competition period ended.

Obviously, in order to evaluate the competence of the methodology with the domain, the outcomes should be evaluated with actual users. But still, from both the informal evaluations of the users and the MAGIC 2010 judges who mention that they appreciated the GUI’s capability to maintain situation awareness; it can be claimed that the hybrid CTA served for the betterment of the first-of-a-kind system, compared to traditional design methods, relying only on the intuitions of the designers. However, the level of this betterment, secured by the Hybrid CTA, should be further investigated and compared with the other methodologies.

Even though the Hybrid CTA methodology is argued to be beneficial in a first-of-a-kind system requirement determination process, it may also be utilized in the early phases of various systems in which SMEs cannot be accessed.

Consequently, Hybrid CTA enables designers to comprehend the unexplored user requirements of the first-of-a-kind interactive systems in a highly structured and transparent way, until the development of the first prototypes. User requirements transformed into the first prototypes should be investigated to evaluate the methodology further. Requirement determination is the beginning of the long system development journey in which the foundations are built.

CHAPTER 5

CONCLUSION

Even though the importance of user requirements is widely accepted, those are usually integrated into the design process in the late phases of the system development. Hence, those requirements, which are critical for the systems' conformance with the users, are not always realized in the final design. Within the interactive systems, the focus of this thesis is first-of-a-kind interactive systems which introduce novel experiences to users with or without novel technological advancements. This thesis aims to answer the following question:

> How can user requirements of first-of-a-kind interactive systems be determined?

5.1 Concluding Remarks

The following concluding remarks rely on both the literature survey given in the Second and Third Chapters and the implementation presented and discussed in the Fourth Chapter.

> **User requirements should be determined early in the system development process.**

When user-centered design concerns are assessed as separate variables from the system requirements and integrated to system development processes late, they are usually ignored because of unplanned schedules and resources. In order to design a system that satisfies both the user needs and the system requirements, user requirements are significant. User requirements describe the functions and qualities of a system according to users: their needs, preferences and capabilities. In traditional system development processes, there is a tendency to determine system requirements which do not necessarily include user-centered concerns. Hence, user-centered concerns are usually recognized in the design process or even later in the evaluation phase, when it is too late to modify the design. Even critical user feedbacks are not always realized because of not being investigated in the early phases of the development process. In an organization, the reason for not realizing user requirements is usually because of their high costs in terms of resources and schedules. However, that cost is obviously not the inherent cost of user requirements, but is caused by their late discovery. In the system development process, the costs of modifying requirements increase drastically as the development process proceeds towards the end (Sutcliffe, 2002). In the implementation study explained in Chapter 4, a similar development process is followed because of the mentioned limitations. Because of the late discovery of user requirements, some of user requirements are not realized in the prototype design of the implementation. Thus, these argued disadvantages are also observed in the implementation presented in this thesis.

Design based approaches are appropriate for determining user requirements of first-of-a-kind interactive systems.

Various approaches in determining user requirements such as performance, training, process, outcome, subjective and design are described and discussed in terms of their coherence with first-of-a-kind interactive systems. While requirement determination approaches such as performance, subjective and outcome set objectives for the evaluation, design based requirements describe the contents and elements of the design. Moreover, differentiating from the others, design based requirement determination approaches do not necessarily require specific empirical measures of previous systems, which is not available in first-of-a-kind systems. Hence, design based requirement approaches are argued to be appropriate for first-of-a-kind interactive systems. They include many design decisions such as the information to be displayed or the scopes of the controls, which makes determining the requirements challenging. In the implementation, design based user requirements are determined by a cognitive analysis and utilized in the design of a human robot interaction.

Cognitive analysis techniques, specifically Hybrid CTA, can be utilized to determine user requirements of first-of-a-kind interactive systems.

Within the formative usability techniques, cognitive analysis techniques are frequently mentioned to determine the user's cognitive demands. Especially for complex and dynamic interactive systems, observing the actions of the users may not be enough to determine the user requirements. Cognitive analysis techniques help designers in examining the cognitive processes in the user's mind, which leads them to take actions and make decisions. In most of the cognitive analysis techniques, semi structured interviews with SMEs are conducted in order to gather qualitative data. Design solutions of similar systems and qualitative information gathered from SMEs are important sources of data, especially for complex interactive systems requiring professional training. However, those are not available in first-of-a-kind systems. SMEs of the previous systems have a tendency to rely on their previous experiences, which is argued to be limiting the possibilities of the first-of-a-kind system design (Norman, 2010; Roth et al., 2001). Cognitive analysis techniques that both utilize interviews with SMEs, and the ones that are argued to be compensating the lack of actual users with complementary techniques, are explained in Chapter 3. Among those, the one discussed to be appropriate for the MAGIC 2010 Human Robot Interaction, which is the Hybrid CTA (Nehme et al., 2006) is selected and implemented. The methodology was observed to be useful in order to analyze users' cognitive demands systematically to maintain Situation Awareness (SA), and make decisions in the supervisory control of multiple robots. However, contrary to the arguments, the Hybrid CTA may not be accurately representing the actual user's cognitive processes, in which users are simulated to be following predefined sequences, and factors like the level of experience and the working environment are disregarded. Still, the methodology is beneficial in analyzing cognitive processes and demands of first-of-a-kind systems systematically. Moreover, documenting the requirements with their links, consequences and reasons enables the designer to follow the possible costs of not realizing that requirement.

Until the development of the first prototypes, the methodology helps designers in determining user requirements of the first-of-a-kind interactive systems. However, it is better to underline that, it is only the starting point of the system development process. As the first prototype of the system is built, empirical evaluation of the design might be helpful to further elaborate the benefits of the user design requirements determined through Hybrid CTA.

It is difficult to compensate the lack of Subject Matter Experts (SMEs) by analytical cognitive analysis methodologies.

In the design of complex dynamic interactive systems, which require specialized training and experience from the users, the information presented by the SMEs are indispensible. SMEs are not only users of a specific system; but they are also the ones working in specific environments and making critical decisions in limited time with irreversible consequences. For instance, the user of a team of search/rescue robots in an earthquake or the user monitoring the displays of a power plant may not have a second chance to make the right decision. Hence, simulating or imagining the insights of SMEs, through decomposing tasks and analyzing those analytically, while sitting in a casual office is open for discussions. The same difficulty is observed in the implementation explained in Chapter 4. The cognitive analysis methodology aids the determination of user requirements, but still, it is observed that some of the decisions about the requirements are made relying on the author’s own experiences and perceptions, who neither supervised any robots, nor worked in similar environments before.

Moreover, the analytical methods followed in the Hybrid CTA methodology relies on expected sequences of decision making. However, this approach does not take variables such as experience levels, adaptations, interpretations and rejections of the users into consideration.

It is essential to underline the reason for not consulting SMEs in the implementation (explained in Chapter 4). There are not any SMEs in the implementation domain, which is remote supervision of multiple autonomous robots. There are ongoing research and development projects but none of these are commercialized yet. Hence, it was even not possible to access users who are experienced in working with remotely controlled autonomous robots. The most similar system would be a case in which the duty of exploring an unknown area and classifying specific objects is fulfilled by the human being instead of robot. However, the cognitive demands and working environments of those two are completely different.

Therefore, even though analytical cognitive analysis methodology is discussed as it is not substituting the qualitative data from SMEs; still within the specified limitations, those are argued to be useful to determine user requirements of first-of-a-kind interactive systems.

5.2 Further Research

The implementation study conducted in this thesis is built for a competition which enforces artificial conditions. Those artificial conditions present both advantageous and disadvantageous factors for determining user requirements. Obviously, determining user requirements of a competition brings in different dimensions and constraints when compared with a ‘real’ project funded by stakeholders. Handling those different constraints may create new opportunities for further research.

Furthermore, even though the requirement determination phase is critical to build a solid foundation for the following development phases, it is still only the beginning. While discussing the potential effects of user requirements to the whole system development process, especially the design process and evaluation of the system, the following research questions are raised.

- **The Design Process Supported by User Requirements**

The attempt to determine the user requirements through a formative analytical cognitive analysis was observed to be useful, in order to systematically analyze users’ cognitive demands. Those cognitive demands, which are the sources of the user requirements, are used as inputs for the design of the Graphical User Interface

(GUI) of the Human Robot Interaction (HRI). However, how those requirements are transformed into the design has not been described in this thesis. Following a research through design approach, elaborating the design process in which user requirements are transformed into design concepts would illuminate those requirements' influence to the practice. Different from requirements such as performance, outcome and subjective requirements, which describe the evaluation methodology of the design; design based requirements are argued to be giving clues about how to realize those requirements in the design process. However, further investigation is necessary to answer whether those user requirements aid the designers for concept generation and prototype building, or limit the designers' possible alternative solutions. So, the competency of the user requirements with the design process can be further elaborated.

- **Empirical Evaluation of the Design/Outcomes of User Requirements**

In order to evaluate the outcomes of the user requirements determined by cognitive analysis, an empirical evaluation should be performed investigating the usability of the system. The outcome of the implementation covered in this thesis is the GUI of the HRI. Even though the written evaluations of the first users of the GUI were positive (Appendix A), their evaluations are limited and biased as they were also the designers of the system. In order to evaluate the GUI's SA capabilities and support for decision making, empirical evaluations can be conducted.

Another alternative for further research is on the scope of the cognitive task analysis methodologies.

- **The Comparison of Empirical and Analytical (User-free) Cognitive Analysis Methodologies for the Requirement Determination of First-of-a-Kind Systems**

In this thesis, an analytical cognitive analysis methodology is carried out because of the lack of SMEs in the first-of-a-kind system development. However, there are also studies conducting empirical cognitive analysis methodologies for the first-of-a-kind system development (Humphrey & Adams, 2010; Naikar & Pearce, 2003). The users of the previous versions of these systems are usually selected as participants of qualitative measurements for those studies. On the other hand, it is also argued that those users of the previous systems would reflect the current system, have difficulties in being innovative; and hence, limit the first-of-a-kind system design (Lynn et al., 1996; Maguire & Bevan, 2002; Roth et al., 2001). Moreover, Norman (2010) argues that user-research is not useful for first-of-a-kind system development.

Especially systems for the use of professionals, who require special training and work in specific conditions, the information presented by the SMEs is irreversible, as the designer/analyst cannot easily comprehend that work and its environmental conditions. However, in the specific domain of the implementation, which is remote supervisory control of multiple autonomous robots, besides SMEs, neither users that have worked with robots in previous systems, nor prototype robots were accessible. Still, qualitative research with SMEs, who have been carrying out the proposed duties of robots, may be conducted, even though those might cover totally different working environments and cognitive demands.

Comparison of the empirical cognitive analysis with SMEs of the previous systems and analytical cognitive analysis methodologies, would further elaborate two discussions, if the SMEs of the previous systems limit the first-of-a-kind system design, and if analytical cognitive analysis methodologies are capable of substituting the SMEs.

So this thesis, in the intersection of various areas such as cognitive analysis, human robot interaction, requirement determination and first-of-a-kind system development, might be accepted as it sheds lights on the alternative paths for further research.

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APPENDIX A

EVALUATIONS AND SUGGESTIONS FROM THE USERS IN MAGIC 2010

The corresponding quotations are directly translated from the written evaluations of the MAGIC 2010 users, right after the competition ends.

A.1 Evaluations from the users in MAGIC 2010

- We did not encounter any difficulty in terms of Situation Awareness (SA). Usually we followed what the robots are doing and their situations in a good way.

- Monitoring the cameras and distinguishing OOIs (Object of Interest) and POIs (Point of Interest) have not been difficult. However, we missed the OOI near to the door in the first phase. This occurred because of two reasons: we did not see the video streams because of the communication problems, and the OOI did not completely appear on the video stream as the robots did not go toward that direction.

- It was possible to follow the operational plan and what robots were going to do from the tactic map.

- We only used the Dynamic Mission Planner (DMP) monitor for drawing manual paths.

- The jury liked the property of zooming and turning automatically in our monitors and maps.

A.2 Suggestions from the users in MAGIC 2010

- In competition we observed that, displaying video streams were causing problems because of communication limitations within the competition area. Through improvements on the image processing capabilities of the robots, instead of displaying video streams, we can display snapshot pictures whenever an OOI or POI is automatically detected. So in this way the OOIs and POIs which are not recognized by the operator may also be marked.

- For the mission distribution within the two operators, we may consider assigning one operator for planning, while the others for detecting and classification of OOIs and POIs.

- The planning situations of the robots may be displayed in the tactic map.

- The directions of the cameras and robots may be displayed.

- The color combinations of the tactic may be reconsidered, and the background of the operational area may be transparent in order to make the UAV (Unmanned Air Vehicle) image more visible.