COPPE
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Instituto Alberto Luiz Coimbra de
Pós-Graduação e Pesquisa de Engenharia

COGNITIVE ENGINEERING AND RISK ASSESSMENT IN COMPLEX SYSTEMS: APPLICATIONS IN THE HEALTH CARE DOMAIN

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Tese de Doutorado apresentada ao Programa de Pós-graduação em Engenharia de Produção, COPPE, da Universidade Federal do Rio de Janeiro, como parte dos requisitos necessários à obtenção do título de Doutor em Engenharia de Produção.

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Rio de Janeiro
Abril de 2016

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TESE SUBMETIDA AO CORPO DOCENTE DO INSTITUTO ALBERTO LUIZ COIMBRA DE PÓS-GRADUAÇÃO E PESQUISA DE ENGENHARIA (COPPE) DA UNIVERSIDADE FEDERAL DO RIO DE JANEIRO COMO PARTE DOS REQUISITOS NECESSÁRIOS PARA A OBTENÇÃO DO GRAU DE DOUTOR EM CIÊNCIAS EM ENGENHARIA DE PRODUÇÃO.

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RIO DE JANEIRO, RJ – BRASIL
ABRIL DE 2016

Jatobá, Alessandro

Cognitive Engineering and Risk Assessment in Complex Systems: applications in the health care domain/Alessandro Jatobá. - Rio de Janeiro: UFRJ/COPPE, 2016.

XX, 193 p.: il.; 29,7 cm.

Orientadores: Mario Cesar Rodríguez Vidal
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Tese (doutorado) – UFRJ/ COPPE/ Programa de Engenharia de Produção, 2016.

Referências Bibliográficas: p. 173-193.

1. Ergonomics. 2. Cognition. 3. Health care 4. Risk assessment 5. Fuzzy Logic I. Vidal, Mario Cesar Rodríguez *et al*. II. Universidade Federal do Rio de Janeiro, COPPE, Programa de Engenharia de Produção. III. Título.

Dedicatória

Tudo nessa tese se resume a minha linda, amada mãe, Maria Rita. Por mais piegas que possa parecer, não tenho dúvidas em afirmar que é graças a ela, ao seu sacrifício, que esse trabalho está sendo concluído. Alguns daqueles que leem esse trabalho presenciaram os sacrifícios feitos pela minha mãe para criar a mim e meus irmãos. Não foram poucos, à sua carreira e à sua vida, mas nada era capaz de abalá-la. Mesmo nos momentos mais difíceis, um sorriso, beijos e carinhos eram garantidos, todos os dias.

Certa vez, perguntei à minha mãe, que deixou um emprego promissor para cuidar de mim - sofrendo bastante por isso - se a sua decisão havia sido difícil. Ela me disse, sem vacilar, amável como sempre e com seu conhecido brilho nos olhos: "largar o trabalho para passar os dias na sua companhia foi a decisão mais fácil que eu tomei na minha vida". Como se retribui um amor desse? Anos se passaram e eu ainda não sei.

Foi estranho ler as reações à sua morte. Houve inúmeras demonstrações de saudades de seu bom humor, seu alto astral, de sua bondade, de sua paixão pela vida, pelos filhos e netos. Só Deus sabe como fiquei orgulhoso de ver que ela era querida não só por seus familiares, mas por todos que a conheciam. Me senti muito privilegiado, mais do que nunca. Apesar da dor, naquele dia tive a certeza de que ser filho de Maria Rita era maior honraria que já havia recebido, e que jamais receberia outra igual.

Ainda me lembro de passarmos pela Cidade Universitária e ouvi-la dizer pra mim, ainda criança: "filho, essa é a maior universidade do país. Acho que você vai passar alguns anos incríveis aqui". Como sempre, minha mãe estava certa, e graças a ela passei por grandes universidades, no Brasil e no mundo. Hoje, quase 30 anos depois de ouvir o voto de confiança de minha mãe, ainda estou aqui na UFRJ, vivendo experiências realmente incríveis e tentando deixá-la tão orgulhosa de mim quanto eu sou dela.

Devo tudo à Maria Rita. Escreveria uma infinidade de palavras para ilustrar o que vivemos juntos, do dia nublado do meu nascimento até àquela tarde ensolarada em que ela se foi. Dedicar esse trabalho à sua memória é uma homenagem mais do que justa. Ela merece, não só pelo que fez por mim, mas pela pessoa que foi, por quem se dedicou a ser. Amiga leal, esposa dedicada, mãe e avó amorosa.

Na véspera de seu falecimento, tentei conversar com ela, mas não consegui ser forte o suficiente. Aos prantos, tudo que consegui dizer foi que a amava. Ela, já bastante enfraquecida, com sua doce voz sumindo, me disse baixinho: “Eu também te amo. E não chora assim que tudo vai ficar bem, você vai ver”. E foi isso. Essa foi minha última conversa com minha heroína. Como disse anteriormente, nada era capaz de abalar Maria Rita, e não importa o quão difícil a situação estivesse, um carinho era sempre garantido.

Por favor, uma salva de palmas para Maria Rita! Obrigado por tudo, mãe.

Agradecimentos

Primeiro, ao meu país, o Brasil. Obrigado por ter me concedido o privilégio de estudar, mesmo tendo que lidar com a miséria de mais de 50 milhões de pessoas. Tenho certeza de que chegará o dia em que estudar não será mais um privilégio, mas efetivamente um direito de todos.

À Maria Rita, minha mãe, a quem dedico esta tese. Por ter tomado a difícil decisão de me deixar nascer. Por ter deixado eu me agarrar em sua perna. Pelo colo, pelos lenços em seu cabelo, pelas noites em claro. Pelas velas acessas para meu anjo da guarda. Por me ensinar – com muita insistência, reconheço - que é possível amar incondicionalmente. Enfim, por isso e todo o resto.

Ao meu pai Aramis. Que apesar das nossas diferenças, não deixou de pavimentar o caminho para que eu alcançasse meus objetivos. Carrego sua influência e colhi muitos benefícios disso. Fique em paz, pois de minha parte, tudo está resolvido. Onde estiver, espero que esteja orgulhoso.

A minha linda família. De tudo que fiz na minha vida, minha família é aquilo que fiz de certo. Me faltam palavras para expressar meu enorme, incondicional amor por minha esposa e meus filhos. Tomo emprestado, então, frases de outros:

Valentina, minha princesa, minha chefe, “algum dia você correrá tanto, e para tão longe que sentirá seu coração pegar fogo”.

Felipe, meu salvador, meu melhor amigo, “não sou particularmente orgulhoso de muitas coisas na minha vida, mas sou muito orgulhoso de ser o pai do meu filho”.

Patricia, amor da minha vida, “se eu vivesse para sempre e todos os meus sonhos se tornassem realidade, minhas memórias de amor ainda seriam de você”.

Aos meus grandes amigos Mario Vidal e Paulo Victor de Carvalho. Por, em troca da constante aporrinhação que lhes causei, terem me dado uma carreira. Nunca serei capaz

de retribuir-lhes. Não é fácil encontrar professores que inspiram. Eu tive muita sorte, pois achei dois! Muito, muito obrigado, de coração.

A minha querida amiga canadense Catherine Burns, por, como Mario e Paulo Victor, ter tido uma enorme paciência comigo, além de ter me recebido em seu laboratório com a máxima boa vontade e disposição. Também nunca vou ter como retribuir essa oportunidade, que mudou minha vida e carreira para sempre.

Ao amigo e mentor Amauri Cunha, pela orientação formal no mestrado e, informal, no doutorado. Não estaria concluindo esse trabalho sem o seu apoio.

Ao meu grande amigo Hugo, camarada tanto na hora de pesquisar em campo, escrever e publicar, quanto na hora do chopp após as aulas.

A minha amiga, heroína da Ergonomia, Angela Poletto, por ter sido a “banca virtual” (junto com o Hugo) nos inúmeros e intermináveis ensaios para a defesa.

Aos meus colegas do Grupo de Ergonomia e Novas Tecnologias (GENTE)/UFRJ Rodrigo, Jorge, Júlio Bispo, Caíque, Luiz Ricardo, Claudio Grecco, Renato Bonfatti, Fabrício, Suenia e Perboni.

Aos meus amigos do Advanced Interface Design Lab/University of Waterloo, Yeti, Leila, Plinio, Justin, Liz, Dev, Danniel, Murat, Anson, VK, Melissa, entre outros que passaram por aquele maravilhoso lugar durante o período em que estive lá, e assim, inevitavelmente, participaram dessa realização.

A Isabella Koster, Emilia Correia e Gisele O’Dwier, além de todos os corajosos profissionais de saúde da família que contribuíram com extrema disposição para a realização dos meus estudos.

Ao Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), especialmente ao Programa Ciência sem Fronteiras, por ter tornado possível a realização do doutorado-sanduíche na Universidade de Waterloo, no Canadá.

“Para cada tarefa, há a ferramenta
certa. A única ferramenta certa para
qualquer tarefa é o cérebro. ”

Meu pai, Aramis Jatobá

Resumo da Tese apresentada à COPPE/UFRJ como parte dos requisitos necessários para a obtenção do grau de Doutor em Ciências (D.Sc.)

ENGENHARIA COGNITIVA E CLASSIFICAÇÃO DE RISCO EM SISTEMAS COMPLEXOS: APLICAÇÕES NO DOMÍNIO DA SAÚDE

Alessandro Jatobá

Abril / 2016

Orientadores: Mario Cesar Rodríguez Vidal

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Programa: Engenharia de Produção

Nesta tese é explorado o tema do projeto de sistemas complexos, aplicado no campo da atenção básica em saúde, mais precisamente na avaliação do risco dos pacientes, com implicações na triagem para o atendimento. Como ponto específico foi abordada a tomada de decisão na priorização e triagem de pacientes, no sentido da elaboração de meios informatizados que permitam uma classificação de risco mais confiável, precisa, adequada, como contrapartida de eficiência e tornando o trabalho na saúde primária mais confortável para os trabalhadores, como contrapartida de bem-estar.

O conteúdo empírico foi elaborado a partir de etnografia em unidades de atenção básica que possuem a Estratégia Saúde da família, em esforço de pesquisa que soma aproximadamente 300 horas de trabalho. Este esforço ensejou a produção de cinco artigos científicos, todos publicados ou em processo de revisão por periódicos internacionais.

Tais resultados ressaltam os efeitos do contexto sobre a tomada de decisão na triagem de pacientes. Por este viés foi possível evidenciar como a engenharia cognitiva ajuda a incorporar esses aspectos na concepção de ferramentas de suporte e, consequentemente, no aprimoramento do processo de trabalho.

Abstract of Thesis presented to COPPE/UFRJ as a partial fulfillment of the requirements for the degree of Doctor of Science (D.Sc.)

COGNITIVE ENGINEERING AND RISK ASSESSMENT IN COMPLEX SYSTEMS: APPLICATIONS IN THE HEALTH CARE DOMAIN

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April / 2016

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In this thesis, we explore the theme of complex systems design, employed in primary health care, specifically in patient risk assessment, with implications for triage and assistance. As a specific topic, we approached decision-making aspects on patient prioritization and triage, in order to enable the conception of information technology to support more reliable, precise, and adequate risk assessment, increasing efficiency and making work in primary health care more comfortable for workers.

Empirical data was collected through ethnographical studies in primary health care facilities that perform the Brazilian Family Healthcare Strategy. The research effort comprises approximately 300 hours of work. Such effort enabled the writing of five scientific papers, all of them published or under review by international journals.

The results emphasize the effects of context over decision-making in patient triage. This approach pointed out how cognitive engineering may help incorporate such aspects in the design of support tools and, consequently, improve work processes.

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FHS – Family Healthcare Strategy

CWA – Cognitive Work Analysis

EWA – Ergonomic Work Analysis

CTA – Cognitive Task Analysis

HCD – Human-centered Design

UCD – User-centered Design

EID – Ecological Interface Design

DMI - Direct Manipulation Interfaces

PNAB – Política Nacional de Atenção Básica (Brazilian Primary Healthcare National Policy)

CD – Contextual Design

SUS – Sistema Único de Saúde (Brazilian Healthcare System)

PHF – Primary Healthcare Facility

EHF (ou HFE) – Ergonomics and Human Factors

1 Introduction

The simpler way to imagine how organizations work is by examples like airports, power plants, gas stations, etc. Therefore, when one wants to transform organizations, the regular thing to do is to split those systems in subsystems in order to understand them by the study of their parts, which seems not just logical, but easier.

Although this approach has worked well for traditional systems, not all system design problems can be addressed through decomposition, as it may result in the loss of important information about interactions among the components of the system. Moreover, in complex systems like health care no one has the authority or resources to design the system completely, thus, these kinds of systems usually have these design limitations (ROUSE, 2000; HOLLNAGEL e WOODS, 2005).

Furthermore, the outcomes of a complex system are more than the sum of the resulting parts of an eventual decomposition. The behaviour of a complex system emerges from the interaction among the agents, and it’s often non-linear and unpredictable over time. Thus, as the elements and their behaviour are changeable, the relationships among them are also non-linear and sensitive to small changes.

Humans in complex systems respond to their environment by using internal rules. These rules are expressed as instincts, constructs, and mental models. For example, health care professionals explore the patient's complaints, opinions about what harms them, concerns, and expectations (PLSEK e GREENHALGH, 2001). In addition, in health care systems, a large number of workers – or kinds of players like providers, patients, and other stakeholders – do not focus only in providing adequate assistance to people, but also in their own personal interests.

Moreover, there are conflicting interests among stakeholders and workers, and there are different definitions of quality. Therefore, even assuming that all agents are well intentioned, the levels of health care assistance provided are never as good as they might be, since the outcomes might be compromised and the costs of delivering these outcomes might be higher than they should (ROUSE, 2008).

If and when possible, complex systems should be designed, rather than emerge. However, the only way to understand how a complex system works is to observe it in order to collect data about its behaviour, e.g. how the system tackles unexpected events. However, unexpected events do not occur very often, thus, they are difficult to observe, although they modify significantly the behaviour of the system.

Designing products and services is not a big problem for most mature companies. However, in health care systems it’s impossible to control the preferences, current or past health conditions, or background of people seeking assistance. Moreover, as complex systems self-organize, no one can impose an organizational design (ROUSE, 2008). Thus, one cannot assume that agents will be able to manage the complexity of the system, and, therefore, the design should be focused on managing such complexity by providing ways of monitoring and influencing system performance.

Design should begin with the recognition that the health care work situation includes all stakeholders, whether they are patients, workers, or government agencies. This overall understanding of the system should be obtained with focus on increasing complexity in ways it can be managed.

In order to cope with the reality of complexity in health care systems, we present in this thesis the contributions of the ergonomics and human factors discipline – through a cognitive engineering approach – to the design of support devices, tools and processes. We focus our study in the patient triage process, as we consider this process an essential element of care, once it is the first contact of patients with the system.

In the next subsections of this introduction chapter we explain the research problem and questions addressed by this thesis. The enunciation of the research problem describes the directions of the thesis and provides an insight of its conceptual significance. Following, we present the motivation, exploring in higher level of detail the relevance of the research problem for the Brazilian health care system. The research settings section, where we give an overview of the Brazilian health care system and general overview of the family healthcare strategy, complements the explanations of the relevance. We describe the structure of the thesis in the subsection 1.5.

1.1 Research Problem, Significance, and Objective

Understanding human work in complex systems is not a trivial job. Observing and describing the interplay between extremely dependent components is mandatory in the analysis of the behavior of the system, although these aspects are very hard to observe. Events and relationships have to be understood within context, and control and adaptability must be present in the description of the system (HOLLNAGEL e WOODS, 2005).

This thesis is situated in the health care domain, to be more specific, in patient triage in the Brazilian Family Healthcare Strategy (FHS), the major strategy for primary health care in Brazil (MINISTÉRIO DA SAÚDE, 2006). In primary health care, assistance occurs in the edge of the system, i.e. relations of trust between patients and health care workers are essential aspects of care. Enabling this scenario involve diverse interfaces like administration of health care organizations, work processes, and relationships between agents of the system, where critical issues like promotion of health and prevention of diseases emerge (SCHREIBER, PEDUZZI, *et al.*, 1999).

Thus, in order to cope with the scenario of increasing complexity in health care, and the resulting difficulties for the design of support devices, the improvement of work situations, and mitigation of harmful situations for health care workers, the research problem addressed by this thesis is structured as follows

- Research topic: in this thesis we study the decision-making in the prioritization and triage of patients in primary health care;
- Major research question: we address this topic in order to understand how to design suitable support tools, devices, and processes that enable more reliable and precise patient triage, prioritization, and risk assessment, reducing workload, and making work in primary health care more comfortable for workers;
- Significance: This work is relevant to the extent that will help its readers in understanding how ergonomics and human factors improve the design of

technologies that increase human performance and reduce errors and problems in patient triage in primary health care.

Specific features in complex systems makes them difficult to be supported by technology, since design for such work environments demands techniques capable or tackling variability, uncertainty, emergence, and the dependence among systems' components and variables.

Thus, this thesis has the objective of describing promising contributions from cognitive engineering to the design for complex sociotechnical systems, applied in the health care domain. We believe that the ergonomics and human factors discipline plays an important role as a provider of methods, concepts, and techniques to describe work in complex environments, and, thus, enabling the design and implementation of more suitable support devices.

1.2 Research (Sub) Questions

As we can see in section 1.1, our research problem comprises the following research question, which we call our **major research question**:

> How can one design suitable support tools, devices, and processes that enable more reliable and precise patient triage, prioritization, and risk assessment, reducing workload, and making work in primary health care more comfortable for workers?

In order to show how existing methodologies can address our research problem, our major research question has been split into three questions – or sub questions, as we can see below:

- How can one improve work situations and design support devices in order to improve the risk assessment process in primary health care?
- How can one enhance requirements specifications for complex systems in order to enable the design of more adherent, robust, and resilient computer support?

- How can health care workers’ practices, protocols, mental models, and decision making be embedded into an inference machine capable of providing a decision support tool in order to improve work situations in patient risk assessment in primary health care?

Initially, we address the problem of finding ways to build consistent real work descriptions of the patient triage processes in the primary health care domain, in order to foster the design of improved work situations and support devices. By Addressing the second research question, we believe that software engineering can take advantage of human factors and ergonomics, which fits between human sciences and technology design and brings techniques to improve the understanding of how people work, enabling the design of better technology

The third research question is addressed in order to find out ways of building decision support tools that improve the patient triage process in ways that health care workers are able to get access to reliable indications of patients’ conditions. By addressing this question we are able to understand the benefits and limitations of technological tools in supporting decision-making in patient triage in primary health care.

In the results chapter (chapter 5) we present four subsections, addressing each research (sub) question. Each section corresponds to a scientific paper. It’s important to highlight that two papers were written to address the third research question; hence the results chapter incorporates four scientific papers.

1.3 Motivation

The Brazilian health care system - SUS, acronym in Portuguese for *Unified Healthcare System* – is one of the largest and broader health care systems in the world. It has been created to reach all kinds of health care assistance – from outpatient to emergency care, as well as vaccination. It is comprehensive and universal to the entire Brazilian population.

As such aspects have been stated in the Brazilian constitution, one can imagine how hard it is to ensure health care coverage to the entire population of Brazil, a huge country with approximate 8,000.000 km² of area – much of it covered by rain forest - and more than

200 million people – almost 50 million in extremely poor conditions. Thus, it is right to say that the SUS does not cover the entire population with acceptable levels of care, therefore, failing constitutional precepts.

Difficulties faced by local assistance programs that implement the strategies established by the SUS, occur in all levels, e.g. difficulties in taking health care to inhospitable areas in the Amazon forest, difficulties to gather reliable data to support decision-making, and difficulties in using such data to provide good medical assistance to people in clinics, hospitals, and other kinds of health care facilities.

Moreover, as any sociotechnical systems, the health care field is also under the pressure of the modern world, especially the technological ones (KOSTER, 2008). Thus, many attempts to use technological support in health care work environments have happened and continue to happen, transforming work situations, with repercussion in how health care services are delivered to the society.

Transforming work situations in healthcare is especially difficult because work in health care relies on the competencies of experts, and those experts demand autonomy in the performance of their tasks. Therefore, personal preferences, moral values, individual decisions inevitably affect how activities are performed (DUSSAULT, 1992).

Furthermore, primary health care in Brazil has become the most relevant source for health care assistance. Professionals interviewed during the elaboration of this thesis have confirmed that the FHS is the care strategy that people prefer, although there is still some cultural aspects that hamper the proper functioning of the strategy, e.g. people still don’t understand perfectly the distinction between primary and emergency care. Anyway, as more people will demand this kind of assistance, tensions on the system tend to rise, and health care worker will need better support mechanisms to cope with this situation.

Thus, the motivation of this thesis lies in our belief that, as health care is a highly complex sociotechnical systems, the design of better support technology and processes will be useful for workers in these environments. We have chosen the patient triage process due to its importance for patient reception and for the proper functioning of primary care, as bad patient triage overloads the system, increases the waste of resources, and results in risk for patients and workers.

We believe that the ergonomics and human factors discipline can be helpful in the design of tools, devices, and processes more adequate to work situations in patient triage, therefore workers will be able to assess patients conditions more comfortably, with less errors, and, therefore, provide better care to people.

1.4 Research Settings

Established in the Brazilian Constitution, the access to health care services in Brazil must be comprehensive and universal, enabling promotion, protection, and recovering, with priority given to prevention, but with no loss to assistance services. Thus, regarding priority to preventive actions, the Brazilian health care framework introduces the Family Healthcare Strategy (FHS) as its major strategy for primary healthcare.

FHS is a shift on the primary health care assistance model, introducing actions for health promotion and disease prevention through the definition of territorial range and the creation of assistance clinics called primary health care facilities, or PHFs (MINISTÉRIO DA SAÚDE, 2006). Moreover, a family health care team comprises:

- One physician;
- One nurse;
- Two orderlies;
- One dentist;
- One dentistry assistant;
- Six to 12 community health care agents.

In order to make the range of services broader, and improve the coordination of the many actions necessary to a comprehensive level of assistance, the primary health care facilities must be integrated to the rest of the assistance network, especially when patients need more complex kinds of assistance and treatment.

The coordination of such actions demands technologies for clinical management, communication procedures and devices, and integration of services to ensure the continuity of patient assistance (ESCOREL, GIOVANELLA , *et al.*, 2007). The relation between patients and healthcare services, the health-disease process, must not be led by only one professional category. It is usual, if not mandatory, that patients relate to various kinds of professionals during their life.

Regarding work processes, a healthcare system is as complex as industrial systems, although initially we could think of it as a completely distinct system. Just like any other area, work in health care systems suffers impacts and pressures (especially technological ones) imposed by the modern world context.

While providing healthcare assistance to patients, professional skills are a determinant factor for success. In this case we claim that health care systems – publically or privately held – are extremely dependent of skills and specialties that their professionals possess, many of them obtained through academic education – and, in consequence, of the protocols that each profession has developed.

Furthermore, in primary health care, actions and activities occur "upon the edge of the healthcare system" and involve many interfaces between planning and management of the system and its work processes, arising essential issues about assistance, such as promotion of health and prevention of disease (SCHREIBER, PEDUZZI, *et al.*, 1999) s.

This means that the user of the system – the patient – is directly involved, like "clients", not only demanding services, but helping to develop new services and/or customizing them on demand. In primary health care the patient interferes directly in the way workers develop.

1.5 Structure of the Thesis

This thesis contains seven chapters. Following this introduction chapter, we present the conceptual framework, where we describe the essential disciplines that provided the major concepts incorporated in this work.

Thus, we describe in chapter two the essentials of complex sociotechnical systems, starting from Bertalanffy's general systems theory (BERTALANFFY, 1975), and then describing specific theories that address complexity. Following we present concepts related to cognitive engineering inside the ergonomics and human factors discipline. Finally, we describe an essential component of this thesis: the concepts of triage, prioritization and risk assessment. Such concepts are presented both in general ways, and specific for the health care domain.

In chapter three we present the methodologies summary. Since this thesis starts with four research questions, it resulted in four scientific papers – each one addressing a research question, and one extra paper to address the third research question. Thus, in the chapter three we describe the methodological approach used to address each research question – and, consequently, each scientific paper and chapter.

The first approach presented in chapter three refers to Ergonomic Work Analysis (EWA). Following, we present Vicente's Cognitive Work Analysis (CWA) framework (VICENTE, 1999) and its foundations. Finally, we describe concepts of the Fuzzy Sets Theory and fuzzy logic.

Chapter four is dedicated to a literature review, conducted in order to collect scientific evidence on related work, i.e. studies that also explore the design for patient triage and risk assessment in the health domain through ergonomics and human factors. This literature review followed a systematic method, and resulted in a scientific paper as well. We present the results of the literature review classified in four types of outcomes for selected studies, as follows:

- Design of risk assessment decision support for health care: papers fit this class when the outcomes propose the implementation of new tools to support decision making in health care risk assessment work situations;
- Design frameworks, processes, and methods for risk assessment in health care: this class relates to publications which outcomes present frameworks or processes applied to the design of risk assessment work situations in health care environments;
- Recommendation or implementation of improvements in risk assessment work situations in health care: This class of outcomes is met by articles

suggesting transformations in the work place, environment, or equipment, or processes in risk assessment work situations in health care;

- Analysis of the impacts of new technologies or processes to risk assessment in health care: this class is met by articles that present studies about the implications of transformations made by new devices and/or processes for risk assessment in health care environments.

Chapter five presents the results, i.e., the papers produced in order to address the research questions stated in this thesis. Although we present three research questions, one extra paper was written to address the third research question. This extra paper appears in the chapter 5.4.

Therefore, the correlation between chapters and research question is structured as follows:

- Chapter 5.1: How can one improve work situations and design support devices in order to improve the risk assessment process in primary health care?
- Chapter 5.2: How can one enhance requirements specifications for complex systems in order to enable the design of more adherent, robust, and resilient computer support?
- Chapters 5.3 and 5.4: How can health care workers' practices, protocols, mental models, and decision making be embedded into an inference machine capable of providing a decision support tool in order to improve work situations in patient risk assessment in primary health care?

All papers have been either published or submitted and full citation for each paper is presented in the corresponding chapter's foreword.

We remember that the literature review chapter also resulted in on scientific article. Thus, we present a summary of all papers produced for this thesis, and status on the date of completion of this thesis in the Table 1-1.

Table 1-1: Summary of scientific articles produced for this thesis

Title of Article	Status	Date of submission/acceptance/publishing
Designing for Risk Assessment in Primary Health Care: a literature review	Accepted by "JMIR Human Factors" journal. Minor reviews underway while this thesis is completed	Accepted in January, 2016
Designing for Patient Risk Assessment in Primary Health Care: a case study for ergonomic work analysis	Published in "Cognition, Technology, and Work" journal	Published in January, 2016
Contributions from Cognitive Engineering to Requirements Specifications for Complex Sociotechnical Systems: a case study in the context of health care	Published in the "Human Factors and Ergonomics in HealthCare" Proceedings	Published in August, 2015
Supporting Decision Making in Patient Risk Assessment Using a Hierarchical Fuzzy Model	Under review by "IIE Transactions on Occupational Ergonomic and Human Factors" journal	Submitted in February 2016
A Fuzzy AHP Approach for Risk Assessment on Family Health Care	Published in "Advances in Human Aspects of Healthcare"	Published in August, 2014

2 Conceptual Framework

In this chapter we present an overview of the disciplines that were incorporated as the conceptual framework of this thesis. Such disciplines provide concepts and theories that guided the development of this work.

We begin with an explanation on complex sociotechnical systems, presenting foundations and related concepts; then, we present an overview of cognitive ergonomics, also with foundations and related concepts, especially cognitive systems engineering, is in the basis of this thesis. Finally, we describe the concepts that help in situating this thesis, as the concepts we have incorporated are applied in patient triage, prioritization and risk assessment.

2.1 Complex Sociotechnical Systems

The General Systems Theory (BERTALANFFY, 1975) studies the abstract organization of phenomena, regardless their form and configuration. It investigates all the principles of complex entities, and models that can be used for their description. Moreover, every system is sociotechnical, since they always comprise people and their devices, although it is necessary to distinguish between systems where the technology has the central role, and systems in which people are responsible for determining what is done and how work occurs (HOLLNAGEL e WOODS, 2005).

According to Bertalanffy, a system is an organized entity consisting of a set of elements and interactions. Bertalanffy also states that there are models, principles and laws that can be applied to systems in general, regardless of their type, nature of the elements that compose them, or their relations.

Thus, according to the general systems theory, systems organize in two categories:

- Open Systems: self-regulatory systems that perform permanent interactions with the environment, generating positive and negative feedbacks. Their self-regulatory mechanisms make them keep their internal organization, thus evolving in an increasingly complex way;

- Closed systems: systems that work isolated from their environment, in increasing entropy, i.e., those systems which elements lack of interaction and synergy, generating disorder.

Regulatory actions occur in order to make the system operational at a given time interval. Therefore, even with the intrinsic or extrinsic interference of external or internal agents the system is able to keep its purposes (VIDAL and CARVALHO, 2008).

Thus, the self-regulation of systems is a spiral process in which a portion of the system outputs is fed back, serving as input for the same system. While the positive self-regulation increases fluctuations in system operation promoting changes that affect its stability, negative self-regulation outweigh the variations observed in order to stabilize the operation of the system.

Furthermore, no work activity occurs solely. Activities take place in sociotechnical system through the interactions between people, the technology, and the organization. Therefore, the operation of systems depends essentially on their socio-technical features. Thus, systems are, most of all, characterized by their purpose, structure, or function. Purpose is defined by the organization of systems' components in order to achieve a goal, forming an organized structure by linking functions.

Regardless of whether the application is autonomous, a technological system is always embedded in a sociotechnical context. Every system has been designed, constructed, and used by people. Every system produces something with an intended use, therefore with an intended user (HOLLNAGEL e WOODS, 2005). This is what makes it possible for a system to be represented and supported by a device, a machine or a set of rules.

Figure 2-1 presents the layers of a complex sociotechnical system, showing that, in order to achieve the desired level of performance, not only the capabilities and limitations of the individual must be understood, but also the interactions with the technical system must considered. Moreover, social-organizational factors also play a crucial role in system performance (VICENTE, 1999).

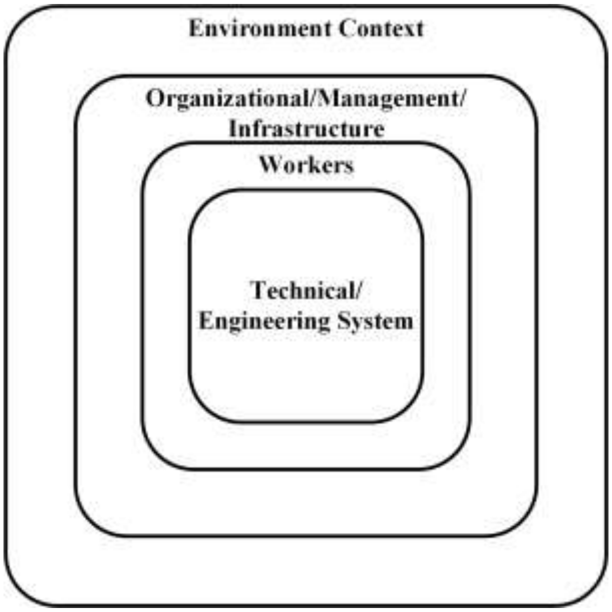

Figure 2-1: Layers of a complex sociotechnical system (adapted from Moray and Huey (1988))

To what concerns complexity, every system tackles big or small levels of complexity, depending on the conditions to which the system in exposed. However, as higher the complexity the more difficult it is to represent its essential parameters without losing its functional properties. Thereby, four properties are described for complex sociotechnical systems as follows:

- **Non-determinism**: it is impossible to anticipate the behavior of systems precisely, even when their features are fully known;
- **Limited functional decomposability:** it is difficult, if not impossible, to study the system properties for its decomposition in stable parts;
- **Distributed nature of information and representation:** some functions of complex systems cannot be positioned. The information is located in different places and usually in possession of different agents. A system is distributed when its resources are physically or virtually spread out across multiple locations. This distribution can be made by redundancy, contingency, or as a result of work organization;
- **Emergence and self-organisation:** when situations are unpredictable, new information arises also unpredictably. In order to flow information, agents reorganize the system's structure, usually changing its cooperation

> mechanisms. The transmission of information between agents depends on environmental factors and on the cognition of each individual agent. On the other hand, emergence does not occur due to incomplete information about the system components, but due to the non-linear and distributed aspect of interactions. Moreover, if a system is able to reorganize itself, its functions have a greater response time, and thus it cannot be described as functionally stable

The essential properties listed above make it possible to identify relevant issues concerning the functioning of sociotechnical systems. Also, the identification of distributed nature of systems shows how their capacity to cope with unpredictability is related to control of locally situated information.

The possibilities of unexpected events, as well as the difficulties in describing their operation, are associated to variability and workers' improvisations, performed in order to fulfill specification gaps and accomplishing expected results. Moreover, if it is hard to specify the system, it is obviously harder to design support devices for it.

Therefore, complexity increases the possibility of emergence of new types of failures in systems, as it allows for more process variation, which can be combined in unexpected ways. Critical systems, like the ones that comprise risks to the physical integrity of its members – like health care systems – demand support devices designed taking into account relevant elements of how work takes place.

2.2 Cognitive Ergonomics

Ergonomics is the study of the interactions of people with technology, the organization, and the environment, aiming for interventions for improvements in comfort, well-being, and the effectiveness of human activities (ASSOCIAÇÃO BRASILEIRA DE ERGONOMIA, 2004). This definition complements Wisner's (1987), which states: "Ergonomics is the scientific knowledge related to man, and necessary for the design of tools, machines, and devices that can be used with maximum comfort, safety and efficiency."

Thus, the objects of ergonomics are work situations - the interrelations between the elements of activity - in order to improve the conditions in which workers carry out their activities, by adapting them to the psychophysiological characteristics of operators, in order to provide maximum comfort, safety and performance.

Work conditions might include aspects related to loading, transportation, and unloading of materials, furniture, equipment, as well as environmental conditions of the job, including the organization of work and cognitive load of workers. The psychophysiological characteristics relate to all knowledge concerning the functioning of the human being, including the usage human beings make of their abilities, through anthropological, psychological, and physiological point of view (MINISTÉRIO DO TRABALHO E EMPREGO, 2004).

Activity, i.e. the set of articulated actions performed by workers, is carried out through artefacts such as devices and instruments. Signs like procedures, practices, and methods are defined by regulations, rules, or practices (VIDAL e CARVALHO, 2008).

Actually, ergonomics emerged to deal with physical problems of workers, as the search for better settings for systems in order to make human usage comfortable, which means that equipment, tools, environments, and tasks should be chosen or designed to be compatible with human abilities and limitations. However, there is a straight relation between physical and cognitive workload. Physical overload can generate mental distress, as well as psychological suffering can lead to harmful situations in a physical level, as cognition interferes in the way workers perform their tasks.

Thus, to cope with cognitive issues in human work, cognitive ergonomics is the aspect of ergonomics that focuses on the fit between workers’ skills and limitations to machines, tasks, and the environment, but also takes into account the use of mental abilities people use in order to reason and make decisions at work. Therefore, cognitive ergonomics focuses on workers’ mental models and their elements. In addition, in order to include essential aspects of work in the analysis – like the context in which it takes place - it takes more than describing activities, but describing the cognition of workers.

In order to the analyze the activity from a cognitive point of view, it is necessary to take into account the level of demands placed on the task under the actual conditions in which it is performed, as well as its respective mental and physical events needed in order to accomplish the task's requirements. Measures of workload in these cases are called **mental workload**. Making workload suitable to human capabilities refers to eliminating the occurrence of overloads, which could lead to fatigue, but also eliminating underload, which could generate monotony.

Furthermore, a possible method for evaluating the suitability of working conditions to psychophysiological characteristics of workers is the Ergonomic Work Analysis (EWA) approach, which addresses the working conditions set out in the Brazilian regulatory standards 17 (NR-17) (MINISTÉRIO DO TRABALHO E EMPREGO, 2004).

We must also highlight the Cognitive Tasks Analysis (CTA) framework as a set of methods that can be used to describe knowledge and reasoning. The CTA approach focuses on workers' awareness, cognitive skills, and strategies during task performance. The analysis comprises the description of how workers respond to complex situations, as well as purposes, goals, and motivations of cognitive work (CRANDALL, KLEIN e HOFFMAN, 2006).

The purpose of CTA is to capture way the mind works – the cognition – in order to understand how people perform their tasks, or how workers see the way their work occurs. In complex systems, it is not enough to observe people's actions and behaviour. It is necessary to find out what they were thinking while performing their tasks. Furthermore, figuring out how context variables affect work performance is an informative task, since all workers are always influenced by the configuration at the time when activities are performed.

Thus, two aspects must be taken into consideration in improving work situations: how to make people work easily; and how to make people work safely. Making work easier relates to design support mechanisms, or create ways in which workers understand work better. Making work safer relates to prevent failures, incorrect task performance, or providing mechanisms for fast error detection (HOLLNAGEL e WOODS, 2005).

2.3 Triage, Prioritization, and Risk Assessment

Prioritization is the natural path to cope with limited resources and emergent necessities. Defining priorities has always been a human issue, as it is not always possible to provide everything to everyone. Therefore, if one must consider the differences within the society, their needs and demands, the prioritizations is not the major concern itself, but how prioritization is performed. Furthermore, there is an additional concept related to prioritization – the rationing of resources (RYYNÄNEN, MYLLYKANGAS, *et al.*, 1999)

It is the need for rationing limited resources that results in the limits, criteria, and parameters for prioritizing what is going to be provided, and whom the resources will be offered to. Such decisions usually involve moral values of the society, as well as political, economic, and legal aspects (FORTES, 2008).

In the health care domain, rationing is not a new concept. Rationing is inevitable in any area, especially in developing countries, that experience population growth, aging, recession, and other issues that put pressure on the allocation of available resources. Rationing health services comprises policies to restrict care.

When the demands for medical care exceed the capability of providing it, care is rationed. Moreover, as resources are always limited, the sickest patient is assisted first – and this demands patients to be **triaged** (REPINE, LISAGOR e COHEN, 2005). On the other hand, prioritization is performed by the definition of hierarchies to organize alternatives of care within the limits of the health care system.

Triage (from the French "*trier*", i.e. choose among many), was initially used as a military term, in order to designate the prioritization of wounded soldiers in the battle field, determining which soldier would have access to the medical resources, in which order, and to which extent (SWAN e SWAN, 1996). It has also been used in to describe the sorting of agricultural products (WINSLOW, 1982).

"Triage," "rationing," and "allocation" are terms intrinsically related when used to refer to the distribution of medical resources. However, there are clear differences among them. The broadest of tem – allocation - does not necessarily imply that the resources are scarce. Rationing refers to resource distribution but implies that the available resources are not sufficient to satisfy all needs or wants.

Triage is the narrowest in scope, the term that makes the connection between all three terms. Though it may be used in an extended sense to refer to any decision about allocation of resources, its use implies some level of scarcity (since no triage is necessary if the available resources are enough to everyone in need), the assessment of patients' conditions by a health care worker, and the use of a system, plan, or method for triage (ISERSON e MOSKOP, 2007).

Moreover, triage must not be understood simply as a process of sorting and ordering the patients according to severity, as this does not consider the numerous factors influencing the allocation of care once patients are categorized. The most important issue in patient triage is the judgement of how to proceed with the treatment of the patients after they have been prioritized, in order to ensure the higher benefit can be obtained with the use of limited personnel and material resources (REPINE, LISAGOR e COHEN, 2005).

According to the Manchester Triage Group, triage is a clinical process that involves risk management to provide patient flow when clinical need exceeds capacity, enabling the diagnosis, disposal, or clinical priority (MANCHESTER TRIAGE GROUP, 2005). This rations patient treatment efficiently when there's no possibility of treating all patients at the same time.

In the health care domain, triage and risk assessment is the process of quantifying the probability of a harmful effect to individuals or populations from certain human activities or situations (SZABO e LOCCISANO). The triage of patients is based on the assessment of their risk of presenting diseases, either to themselves or to others, e.g. their vulnerability, suffering, current diseases and conditions.

The word "risk" is used in many different senses, colloquially or technically. Dictionaries usually relate risk with some sort of hazardous situations, e.g. “the probability or possibility of harm or hazard”. While the relation between risk and hazard is acceptable, risk is generally understood to have two components: frequency, i.e. the measure of how likely it is that an event occurs; and severity, i.e. the effects of eventual occurrence.

Furthermore, the terms “hazard” and “harm” have an intrinsic relationship, as hazard represents a circumstance capable of causing harm.

Insurance brokers use the work “risk” in a probabilistic perspective, in order to describe the possibility of occurrence of an undesired event with the insured’s property, leading to a claim, which occurrence is described by the amounts of money to be paid by the company at each claim using random variables (GRANDELL, 1991). This approach relates to the statistical perspective of risk described by Wald (1950), which defines risk as the sum of expected cost of experimentation and expected losses that occur due to wrong decisions.

Thus, risk is a broader concept that can generally connote the assessment of consequence or exposure loss in some extent, although not restricted to likelihood of an adverse event, but a combination of probability, frequency, and severity of occurrence of a hazardous situation.

Moreover, there is the relation between risk and uncertainty, e.g. situations becomes risky due to actions that might lead to many different, mutually exclusive outcomes with known probability of occurrence. However, when probabilities of occurrence are unknown, the situation involves uncertainty (KNIGHT, 1921; BORCH, 1967). This concept occupies a central position in theories of decision under risk and uncertainty (TVERSKY e KAHNEMAN, 1974; KAHNEMAN e TVERSKY, 1979).

The definition of risk stated in the ISO 31000:2009 standards also relates risk and uncertainty, as it is described as the effects of uncertainty on organizations’ objectives, since organizations of all types and sizes face internal and external factors and influences that make it uncertain whether and when they will achieve their goals (INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, 2009).

According to the authors of the ISO 31000:2009 standards, effects are deviations from the normal conditions. Thus, risk is expressed in terms of a combination of the consequences of potential events and their respective likelihood of occurrence. In this case, uncertainty is the state of deficiency of knowledge about an event, its consequence, or likelihood.

Moreover, risk management strives to enable risk-informed decision-making and investment planning throughout an engineering system's life cycle (GARVEY, 2009), as different work systems based on different technologies and activities pose quite different hazards and different modes of safety control.

Risk management traditional approaches are usually based on two presuppositions: that risk is acceptable only if it is outweighed by greater benefits; and that there has to be a continuous striving to reduce the level of risk to a point where it is held to be tolerable or socially acceptable (HOOD e JONES, 1996).

Engineering risk management aims at continuous identification, management, and resolution of risks in order to enable the design of a system to be accomplished within cost, delivered on time, and according to user needs. Among the goals of risk management under an engineering perspective, we highlight (GARVEY, 2009):

- Early and Continuous Risk Identification An engineering risk management program fosters the early and continuous identification of risks so options can be considered and actions implemented before risks seriously threaten a system's outcome objectives.
- Risk-Based Program Management: Engineering risk management enables risk-informed decision-making and course-of-action planning throughout a program's development life cycle and particularly when options, alternatives, or opportunities need to be evaluated.
- Estimating and Justifying Risk Reserve Funds: An engineering risk management program enables identified risk events to be mapped into a project's work breakdown structure. From this, the cost of their ripple effects can be estimated. Thus, an analytical justification can be established between a project's risk events and the amount of risk reserve (or contingency) funds that may be needed.
- Resource Allocation: The analyses produced from an engineering risk management program will identify where management should consider allocating limited (or competing) resources to the most critical risks on an engineering system project.

- Situational Awareness and Risk Trends: Engineering risk management can be designed to provide management with situational awareness in terms of a project's risk status. This includes tracking the effectiveness of courses-of-action and trends in the rate that risks are closed with those newly identified and those that remain unresolved.

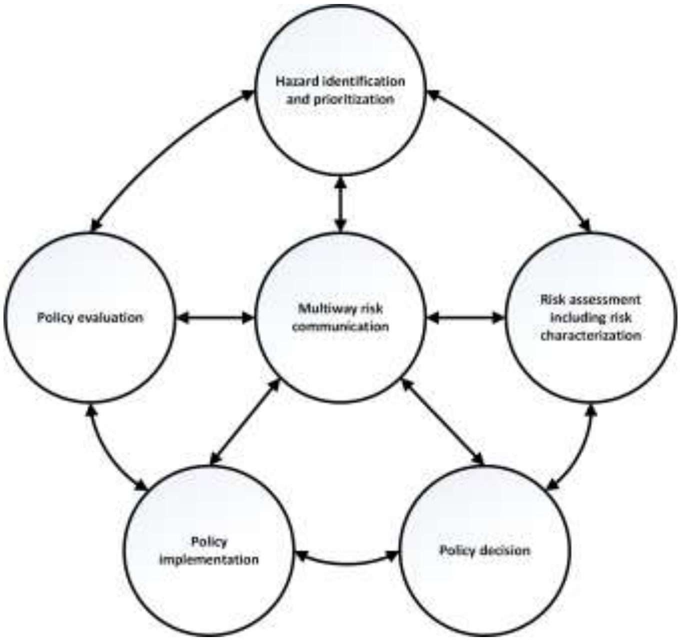

Figure 2-2: The risk management cycle according to Hood & Jones (1996)

Hood & Jones (1996) present a risk management cycle based on six processes. Based on communication, it starts with the identification of hazards and their prioritization, followed by risk assessment. According to the cycle proposed by Hood & Jones, the decision and implementation of risk mitigation actions, as well as evaluation of results are performed according to organizational policies like regulations and norms.

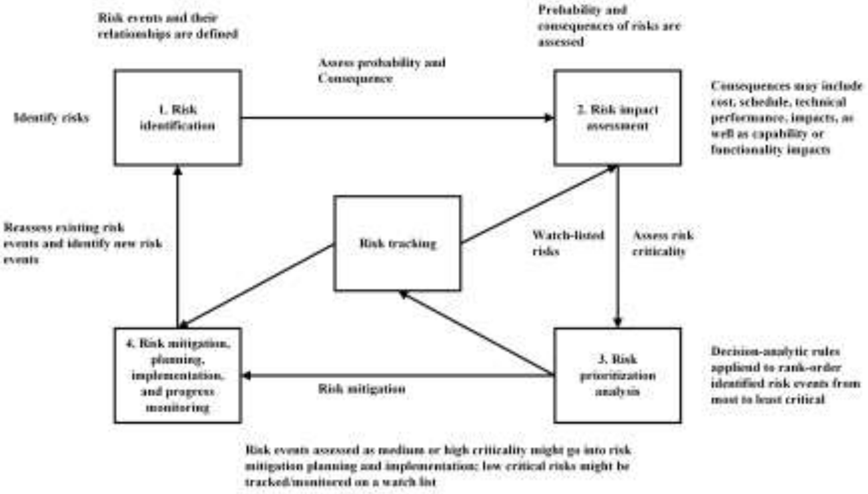

Figure 2-3: The risk management cycle according to Garvey (2009)

Similarly, Garvey (2009) proposes a five-phased risk management cycle that begins with the tracking of risk. It also includes identification, assessment, and prioritization, as well as mitigation actions. According to Garvey, between identification and mitigation the risks might need to be reassessed in order to redefine their events and relationships. Moreover, risks are prioritized from the most critical to the least critical, as the assessment of risks is based on their consequences and probability.

In order to make decisions and perform actions, people instinctively weigh the options and variables, based on information about the activity. Therefore, risk management requires some quantification. However, even though the analytical methods of calculating risk are usually simple, in many cases, psychologists or sociologists get more precise measurement of risk perception than scientists in their calculations, as people's perception of risks involve multiple imprecise aspects.

Thus, the concept of risk assessment comprises the determination of quantitative or qualitative value of risk related to a concrete situation and a recognized hazard. It consists of objective evaluation of risk in which assumptions and uncertainties are clearly considered and presented. Quantitative risk assessment requires calculations of the magnitude of the potential loss, and the probability of occurrence. Many fields like nuclear, aerospace, oil, rail, military, and health care have a long history of dealing with risk assessment, although methods may differ between industries (LIBRARY OF CONGRESS, 1983).

From a scientific perspective, the risk of a specific event is equal to its frequency or probability of occurrence multiplied by the event's severity or consequence. However, experience, intuition, and judgment are factors that affect the perception of risk. Moreover, Risk perception disregard any type of structure, affected by many aspects such as age, gender, vocation, culture, etc. (JONES, 2012).

Thus, the challenge for risk assessment is to establish techniques for measurement of risk taking into account different people, with different values, opinions, backgrounds, and experience, without influencing their views.

The Manchester Triage Group (2005) proposes a methodological approach for patient triage, in order to promote the shift from an intuitive to a reproducible and auditable way of performing prioritization. It aims at establishing consensus amongst senior emergency physicians and emergency nurses about triage standards, set under five headings, as follows:

- Development of common definitions;
- Development of a robust triage methodology;
- Development of a training package;
- Development of an audit guide for triage.

The methodology proposed by the Manchester Triage Group is used to select patients with the highest priority first, enabling the health care worker to rapidly assign a clinical priority to each patient. It should work without making any assumptions about diagnosis, although the authors recognises that emergency departments are to a large extent driven by the patients presenting signs and symptoms (MANCHESTER TRIAGE GROUP, 2005).

The process of triage using the methodology proposed by the Manchester Triage Group is quite simple. Health care workers assign patients to a triage category and then managed in order of priority and time of attendance, according to the parameters as we see in Table 2-1. Each of the triage categories has a number, a colour and a name, as well as an ideal maximum time to access treatment.

Table 2-1: Categories in the Manchester Triage Protocol

Number	Name	Colour	Max time (minutes)
1	Immediate	Red	0
2	Very urgent	Orange	10
3	Urgent	Yellow	60
4	Standard	Green	120
5	Non-urgent	Blue	240

Triage methods can provide health care workers with the diagnosis, with the disposal, or with a clinical priority. The Manchester Triage Scale gives health care practitioners the means to allocate clinical priority, as of three aspects:

- The aim of the triage encounter in an Emergency Department is to aid both clinical management of the individual patient and departmental management; this is best achieved by accurate allocation of a clinical priority.
- The length of the triage encounter is such that any attempts to accurately diagnose a patient are doomed to fail.
- Diagnosis is not accurately linked to clinical priority, the latter reflects a number of aspects of the particular patient's presentation as well as the diagnosis; for example, patients with a final diagnosis of ankle sprain may present with severe, moderate or no pain, and their clinical priority must reflect this.

It is easy to become confused between the clinical priority and the clinical management of a patient. The former requires that enough information is gathered to enable the patient to be placed into one of the five defined categories as discussed above; the latter may well require a much deeper understanding of the patient's needs, and may be affected by a large number of extraneous factors such as time of day, the organization of the staff, or the number of beds available.

Furthermore the availability of services for particular patients will fundamentally affect individual patient flow. Separately staffed "streams" of care for particular patient groups will run at different rates. This does not affect underlying clinical priority, which affects the order of care within, rather than between streams in such a system.

3 Methodologies Summary

This chapter presents the summary of the methodologies used to address the research questions presented in this thesis. Since we describe three research questions, three methodologies have been approached.

3.1 Ergonomic Work Analysis

According to Sanchez & Levine (2001), there are two primary kinds of work analysis: descriptions of people performing their work: and descriptions of work itself. Most analysis methods provide means of collection data on workers' tools, machines, and support devices. Deeper analysis include contextual factors of people's work such as features of the job, environmental hazards, social organization of activities, standards, errors, procedures, as well as customer requirements. This is useful in documenting and supporting decisions based on performance, and training.

According to Guerin et al. (2001) ergonomics exists to transform work situations. Such transformations will foster the conception of new work situations that do not present harms to workers. Therefore, workers will be able to explore their competencies individually and collectively, helping their employers in accomplishing the companies' objectives.

Wisner (1987; 1995), proposes an approach for work analysis through ergonomic actions - ergonomic work analysis (EWA) – that aims at solving problems related to unsuitability between work and human features. Most of problems of this kind come from production systems inadequately designed, adaptation or conception of production systems taking into account only financial or technical aspects, disregarding human functioning and variability.

Thus, in order to transform the work situation and reduce harmful conditions, the analysis must consider distinctions between work as it was intended to be performed (task, or prescribed work) and work as it is actually performed by workers (activity, or actual work) (RICART, VIDAL e BONFATTI, 2012; WISNER, 1995; OMBREDANE e FAVERGE, 1955). The prescribed work consists in a set of mandatory acts engaged in order to achieve the goals of the task (normative thinking). Differences between results of the prescribed and normative work shows opportunities for the design of improved work situations.

Moreover, the purpose of ergonomic action is to enable workers’ everyday activities to take place favorably in their own context. Therefore, ergonomic action is based on observations in actual work settings in order to lead to modifications in the context (WISNER, 1995). Collecting data by observation in real workplaces enables the inclusion of many individual and social aspects in the analysis, such as conflicts, misunderstandings, and negotiation processes. However, this way of gathering empirical data does not exclude the possibility of interaction between the observer and workers, resulting in new specific and situated questions about procedures, automation systems design, workplace layout, safety, etc. (ENGESTRÖM, 1999; CARVALHO, 2006).

By focusing in the essential role of the signal rather than on workers’ motions on machines, ergonomic work analysis becomes opposites to the work analysis based on the study of time and motion (OMBREDANE e FAVERGE, 1955; WISNER, 1995). Thus, cognitive aspects of in work performance becomes an essential aspect of observation of worker behavior through ergonomic work analysis, as distinctions between observed behavior and the way in which the operator represents his activities are an important element of the analysis, and such phenomena are hardly captured in interviews.

The core of ergonomic work analysis is activity analysis, which aims at discovering causes of disturbances and changing critical situations. In order to obtain objective data, the ergonomist must study the behavior of the operator and select not only motor aspects, but also the information gathering and communication behavior.

Thus, one could use a conversational approach (VIDAL e BONFATTI, 2003) within ethnographic observation when interviewing methods cannot capture aspects of complexity. In this context variability in work situations appears as the main observable aspect in which resides the most important element for understanding how people work.

Although they share the same principles, there are many approaches to ergonomic work analysis. Wisner considers the work of Ombredane & Faverge (1955) the start of ergonomic work analysis as an approach focused on *in situ* observations to cope with the variability in work situations. Thus, Wisner (1994) proposes a methodological framework that works as the basis for ergonomic work analisys, organized in five basic steps as follows.

1. Framing: should provide the basis for the environmental and activity analysis, based on the way workers express their needs for transformation of work situations. The essential action performed by the ergonomist in this phase is listening to workers opinions and, complaints.
2. Analysis of the environment: This is the first observational phase, in which we highlight the general aspects of the organization, such as financial, technical, organizational and social. This phase is useful to define the limits of ergonomic action and establish the work situations that should be focused
3. Activity analysis: This is the core of the analysis, carried out among workers in the established work situations. Observations in this phase will enable the description of how work is actually performed and provide elements for the transformation of work situations
4. Recommendations: This phase aims at the elaboration of a project resulting of planning interventions of ergonomists to transform work situations.
5. Validation: Consists in the negotiation between ergonomists and workers in order to indicate how the intervention will happen. The involved parts – ergonomists, workers, employers – read the intervention project and define the actions needed for its execution.

This five-phased approach works as basics to many frameworks for work analysis centered on observation, as the work presented by Vidal (2002). We use this approach to answer one of the research questions of this thesis in chapter 5.1.

3.2 Cognitive Work Analysis

Professors Erik Hollnagel and David Woods (HOLLNAGEL e WOODS, 2005) start their book "Joint Cognitive Systems: foundations of cognitive systems engineering" by listing what they call "driving forces" – forces that originated the need for an approach to systems engineering based on cognitive aspects of work. These forces, according to Hollnagel and Woods are:

- The growing complexity of socio-technical systems: due to the constant growth of computerisation or applied information technology, computers have become the dominating medium for work, communication, and interaction, transforming work performance and creating new fields of activity;
- Problems and failures created by clumsy use of the emerging technologies: rapid changes in work performance worsened the conditions for practitioners who already had insufficient time to adjust to the existing imposed complexity. The major consequence of this scenario is a succession of real world failures of complex systems that made human factors, human actions, and, in particular, human error, more noticeable;
- Limitations of linear models and information processing paradigm: engineering and computer science communities subtly adopted the notion that humans are information-processing systems, fragmenting the view of human-machine interaction.

Still according to Hollnagel and Woods, one must distinguish technological system from organizations. In technological systems, technology plays a central role in determining what happens; while in organizations humans play the central role in determining what happens. Thus, Hollnagel and Woods propose an approach to cognitive systems engineering that considers organizations as artefacts of a social nature made for a specific purpose.

Hoffman and Woods (HOFFMAN e WOODS, 2000) introduce the concept of “complex cognitive systems”, i.e. work environments in which the knowledge and reasoning of individuals play an important role, but so do the cognition and reasoning of larger groups of people, including teams and even entire organizations. In addition, these complex cognitive systems often involve people interacting with computers and interacting with each other via computers in intricate networks of humans and technology. If one wants to support - or improve – the complex work performed in these systems observing their actions is not enough. One must understand what they are thinking while performing their activities.

Professors Beth Crandall, Gary Klein, and Robert Hoffman propose a set of methods for studying thinking and reasoning in the performance of work in complex systems. Their cognitive task analysis approach provides procedures for understanding work in complex work settings. Their approach supports the systematic identification of key cognitive issues in people’s work, useful in the development of tools and technologies, as well as work processes (CRANDALL, KLEIN e HOFFMAN, 2006).

Crandall, Klein, & Hoffman’s approach is based on three primary aspects: knowledge elicitation, data analysis, and knowledge representation. Knowledge elicitation comprises a set of methods used to obtain information about what people know and how they know it; data analysis consists in structuring data, identifying findings, and discovering meaning; knowledge representation includes tasks of displaying data, presenting findings, and communicating meaning and discoveries.

Earlier, Rasmussen also stated that every system, regardless how automated it is, rely on human intervention in some level (RASMUSSEN, 1979). Even though they do not depend of human interaction while in normal functioning, their existence depends on extensive support by a human staff to maintain the necessary conditions for satisfactory operation, especially if their operation involves high possibility of unforeseen conditions.

Rasmussen suggests that in highly automated sociotechnical systems, as humans supposed to act goal-oriented, technology experts tend to model human activity with focus on the discrepancy between what is intended and what is actually achieved. However, human activity in a familiar environment will not be goal-oriented, but oriented towards the goal and controlled by rules previously proven successful. In unfamiliar situations, behaviour may be goal-oriented in the sense workers make different attempts to reach the goal and, then, select a successful sequence.

Thus, Rasmussen proposes a set of categories of models of human activity to stratify the span between the physical reality and human purposes, i.e., the reason for the physical systems in which people work. The author defines the following structure for models of human activity:

- Models of physical form: represent the spatial distribution of matter in the environment, like a portrait of the physical landscape. It is objective, i.e., independent of the intentions of the modeller, although is it dependent upon the intended use of the environment;
- Models of physical function: represent the physical structure of the system and its functional properties, e.g. technical components, and their properties. Physical objects are limited by boundaries that can be rearranged according the level of aggregation or decomposition into objects;
- Models of functional structure: the main element of these models is a set of relations among variables across boundaries of physical parts, or "functions". Such functions represent standardized, generic elements of system purposes;
- Models of abstract function: represent the overall function of a system in a generalized causal network, moving in abstraction level independently of the local physical or functional properties;
- Models of functional purpose: represent the observable constraints within the relationship among the variables of the system. These models describe the properties of a system in terms of relations between variables or states and events in the environment.

The taxonomy of models of human activity proposed by Rasmussen appears in Vicente's (1999) work as a framework for work analysis called Cognitive Work Analysis (CTA). Vicente proposes an integrated framework based on behavior-shaping constraints of the work environment and contains models of the work domain, control tasks, strategies, social-organizational factors, and worker competencies. According to Vicente, the constraints of the work environment are limits between the possibilities for behaviour of workers.

The CWA approach is ecological, i.e. it is centered on the analysis of the constraints that the environment imposes on action. Thus, it gives designers the possibility of developing interfaces compatible with such environment constraints. The objective of CWA is to ensure that workers will acquire mental model of the environment that represents, as accurately as possible, the actual behaviour of the context in which workers are involved.

The CWA framework comprises five phases as follows:

- Work Domain Analysis: the purpose of this phase is to identify a set of constraints on the actions of workers and provide a description of the domain in which work is performed. The abstraction hierarchy (RASMUSSEN, 1979) is the main modeling tool for this phase (see Figure 3-1).
- Control Task Analysis: the objective of this phase is to identify the requirements associated with recurring classes of situations, and the constraints on work performance, no matter who performs the activities or how they are carried out. We use the decision ladder (RASMUSSEN, 1979) as the tool for writing control task models.
- Strategies Analysis: this phase aims at understanding the different ways of accomplishing the activities identified in a control task analysis. Therefore, its models must describe **how** work is done rather then **what** is done. Information flow maps (RASMUSSEN, 1979; RASMUSSEN, 1980) is the modeling tool suggested by Vicente in order to perform this.
- Social Organization and Cooperation Analysis: this phase addresses how work requirements are distributed among human workers and automation, and how such actors communicate and cooperate. Modeling tools used in the previous phases are revisited in the social organization and cooperation analysis in order to represent how the social and technical factors in a sociotechnical system can enhance the performance of the system.
- Worker Competencies Analysis: the fifth and final phase of CWA focuses on the identification of the competencies that workers in the analyzed domain must have. This is performed by letting requirements of the application domain determine what kinds of competencies workers need, in

order to accomplish their goals. The modeling tool used to conduct worker competencies analysis is the skills, rules, and knowledge taxonomy (RASMUSSEN, 1983).

Figure 3-1 shows the elements of an abstraction hierarchy model. The structure of the abstraction hierarchy represents means-end relationship between the elements of its five levels, which increases the understanding of the system. By moving up the hierarchy, we focus on the purposes; by moving down the hierarchy, we focus on how those purposes can be carried out. Higher levels are less detailed than lower levels. Shifting from a low to a higher level of abstraction can make complex domains look simpler.

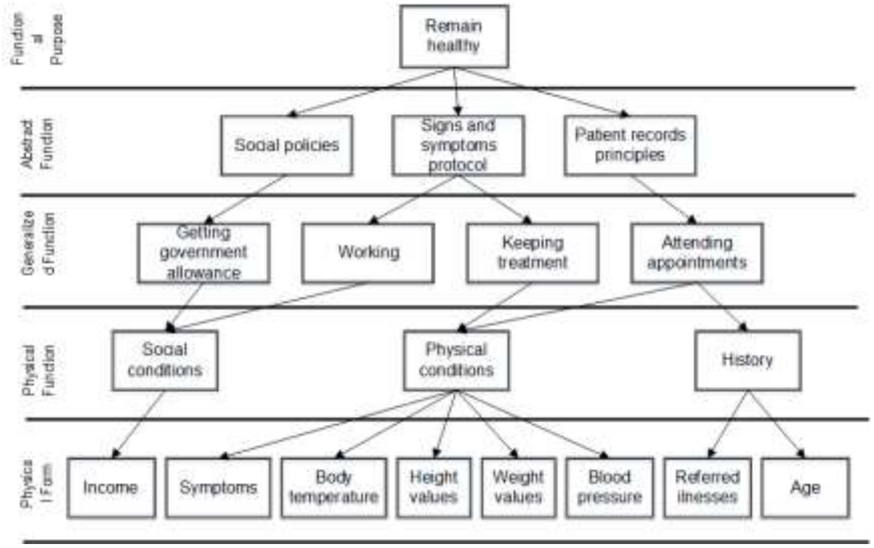

Figure 3-1: An example of abstraction hierarchy

Figure 3-2 presents the decision ladder as proposed by Rasmussen (1979). Used as the main modeling tool in control task analysis, the decision ladder represents the relationships between information-processing activities and states of knowledge. Information-processing activities are the expert routines in which actors need to engage to accomplish task goals. Furthermore, states of knowledge are the results of information-processing activities, e.g. the products of information-processing activities.

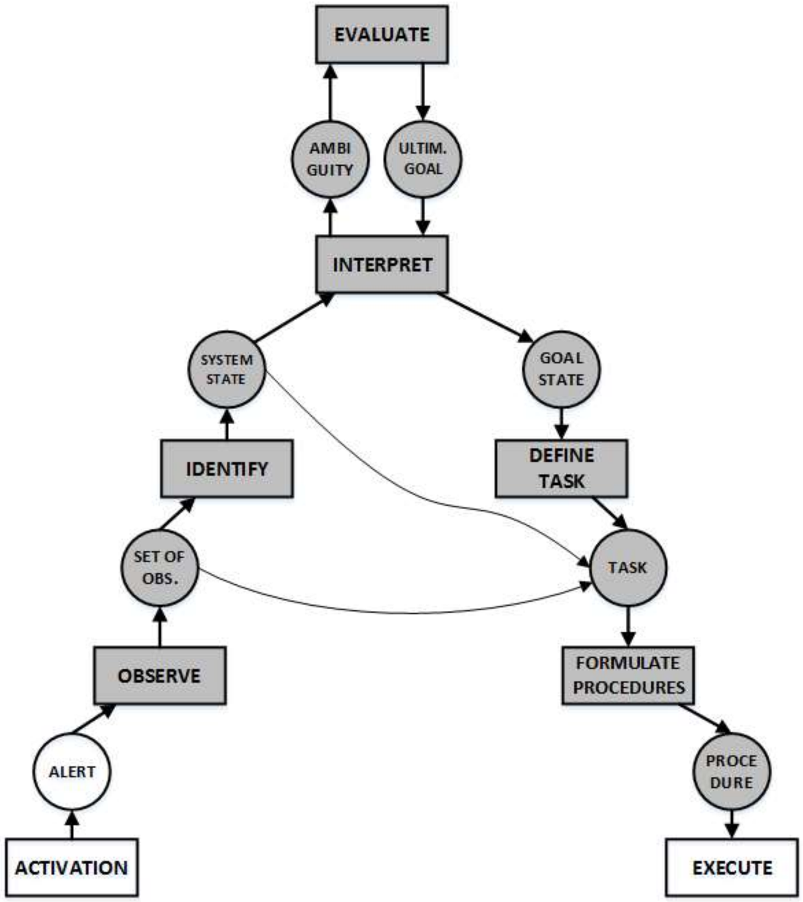

Figure 3-2: An example of Rasmussen's decision ladder

Relationships between information-processing activities and states of knowledge can be of two kinds: shunts or leaps. Shunts are the followed by experts, therefore connect an information-processing activity to a state of knowledge. Leaps connect two states of knowledge directly, without any information-processing activity in between them.

Vicente uses information flow maps (see) to describe the categories of cognitive task procedures that constitute workers' strategies. Information flow maps illustrate the sequence followed by a particular worker during a specific troubleshooting episode. According to Vicente, action sequence instances are variable, but treating strategies are idealized categories that can be instantiated during particular situations, providing ways of coping with complexity

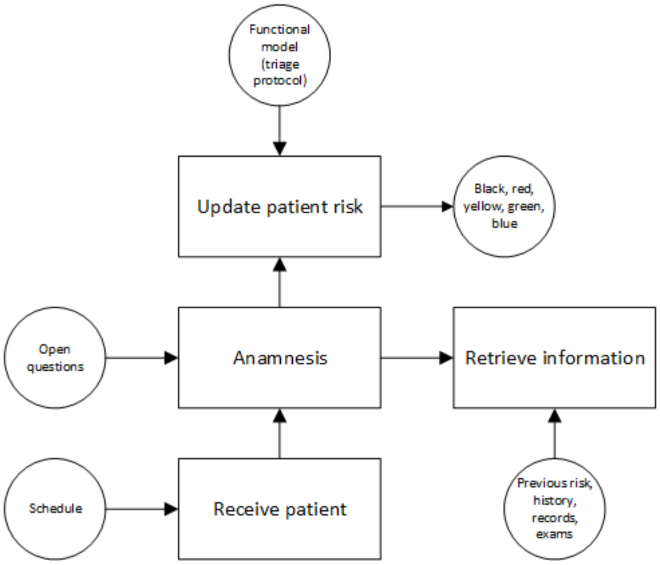

Figure 3-3: An example of information flow map

Vicente recommends the use of the skills, rules, knowledge (SRK) taxonomy (RASMUSSEN, 1983) in the final phase of CWA to organize knowledge into a form that is more useful for systems design. Its structure is a three-level taxonomy, since each level of cognitive control is based on a different type of human performance.

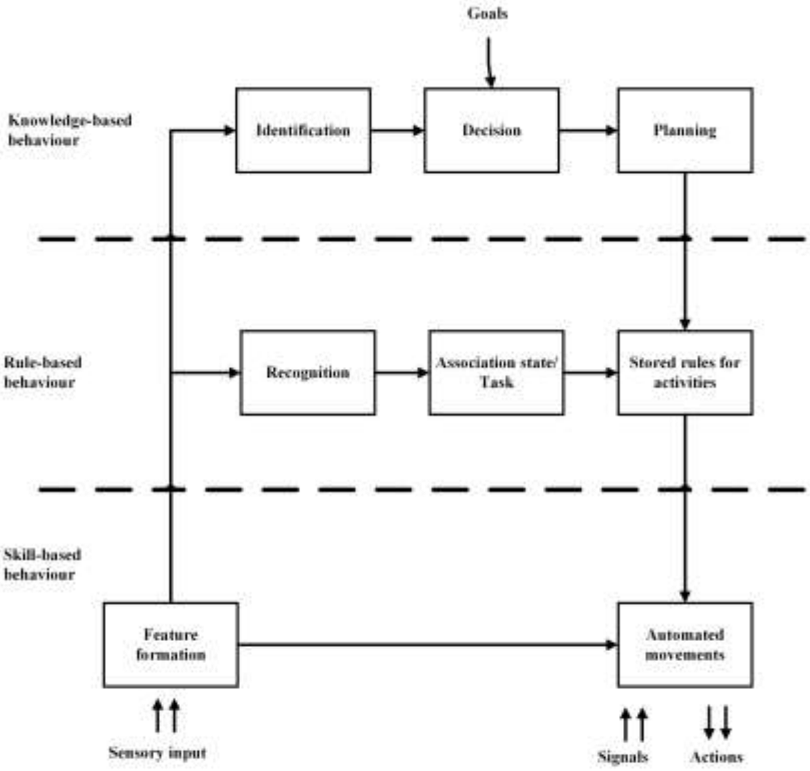

Figure 3-4: Rasmussen's (1983) SRK taxonomy

Figure 3-4 shows the structure of an SRK taxonomy. It comprises three kinds of behavior of workers: knowledge-based behavior, i.e. analytical reasoning based on a symbolic representation of environment constraints; skill-based behavior, i.e. automated and highly integrated actions performed by workers without conscious attention; and rule-based behavior, i.e. previously stablished rules and procedures, experience, instruction, or problem-solving activities.

These models, used along the phases of CWA, should provide designers better insight about workers cognition while performing activities. Due to the ecological orientation, CWA focuses on both the environment and human cognition. Thus, by describing the related constraints it enables the design of more suitable support technology for workers on complex sociotechnical systems.

3.3 Fuzzy Sets Theory and Fuzzy Logic

Traditionally, decision-making is the interface between the evaluation of the situation and the choice among alternatives of action, or the combination of both aspects (HOLLNAGEL, 2007). However, most decisions routinely made are dynamics, and dynamic tasks vary in terms of complexity, e.g. presents a number of decisions rather than a single decision, decisions are interdependent, and the environment in which the decision is set changes (EDWARDS, 1962).

As complexity stems from the number of variables in the task system and their interrelations (DÖRNER, 1996; JOSLYN e ROCHA, 2000), in dynamic tasks, the decision-maker and the task system are entwined in feedback loops whereby decisions change the environment, giving rise to new information and leading to the next decisions (QUDRAT-ULLAH, 2015).

Moreover, human reasoning occurs in imprecise, approximate ways rather binary and linearly like the binary computer logic. Therefore, in order to express the human inference mechanisms, one must use methods capable of embedding uncertain, vague values, as well as subjective evaluations, mostly expressed in natural language. The fuzzy logic (ZADEH, 1965; ZADEH, 1975) provides ways to deal with the approximate reasoning, inherent to the mentioned situations.

In sociotechnical systems, as complexity increases, human capacity of making precise and relevant assertions decreases to the level when precision and relevance become mutually exclusive. Thus, fuzzy logic provides concepts to approximate models from reality of decision-making in complex environments (ZADEH, 1973; CHAMOVITZ e COSENZA, 2010).

The fuzzy logic embeds the concepts of the fuzzy sets theory (ZADEH, 1965), which aims at providing a natural way to tackle human problems, in which imprecision comes out due to the absence of well-defined membership criteria for the elements of a set. This conceptual structure is similar to the traditional sets theory, but can be applied in a broader range of situations.

Thus, the fuzzy logic describes an imprecise logical system in which the truth-values are subsets of the unit interval, and are represented by linguistic values (ZADEH, 1975) based on natural language. Through this concept, semantic rules provide means of computing the meaning of each linguistic value with number between 0 and 1. Consequently, the rules of inference in fuzzy logic are inexact and dependent on the meaning associated with the primary truth-value (ZADEH, 1975).

There are two kinds of fuzzy numbers: triangular and trapezoidal. In a conceptual universe, fuzzy subsets are defined by their membership functions – which uses values between 0 and 1 to map the level of membership of an element in the set, when compared to other elements. Thus, the value of the membership function describes “how much” an element “belongs” to the set. Figure 3-5 shows the graphical representation of a trapezoidal fuzzy number.

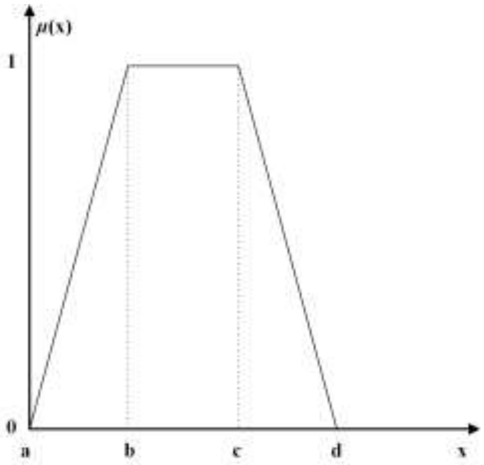

Figure 3-5: Trapezoidal fuzzy number

In some cases where b is equal to c, we have a triangular fuzzy number, represented as Figure 3-6 shows.

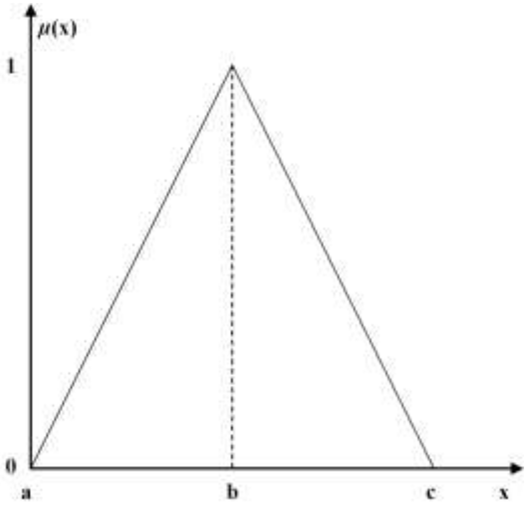

Figure 3-6: Triangular fuzzy number

Fuzzy numbers are used to represent linguistic variables, i.e. variables that store values in words or sentences expressed in natural language. The purpose of a linguistic variable is to enable the approximate characterization of complex, poorly defined phenomena. Thus, using linguistic rather than quantified definitions, complex systems can be analyzed by conventional mathematical terms (GRECCO, 2012).

Figure 3-7 shows how fuzzy triangular numbers represent the linguistic variables “very good” (VG) and “very bad”(VB), as used in chapter 5.3.

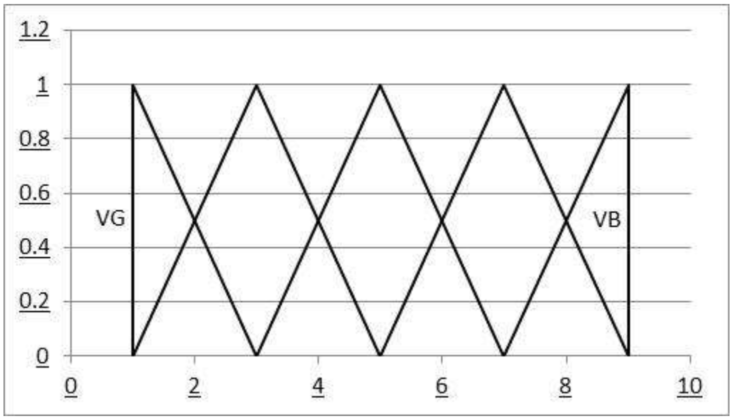

Figure 3-7: Fuzzy representation of linguistic variables

When linguistic values inserted in the fuzzy inference machine, they are turned into fuzzy sets in a process called *fuzzyfication*. During *fuzzyfication*, the input values are evaluated and calculated according to fuzzy rules inherent to the fuzzy model that has been used. Each fuzzy function of the model produces output values between 0 and 1, representing the membership level of the output value in comparison to the fuzzy rule. Then, the fuzzy inference machine aggregates the suitable output options. Finally, the resulting value – still in linguistic terms – must be turned back to discrete values in a process called *defuzzyfication*.

The fuzzy sets theory and fuzzy logic has been used extensively in decision-support mechanisms, mostly as a method to help works to find out the best option among alternatives in a decision problem, combining defined criteria with the opinion of experts in order to accomplish an objective. Results of the use fuzzy models show promising, especially in prioritization problems (COSENZA, 1981; LIANG e WANG, 1991; HSU e CHEN, 1996), which justifies the use of fuzzy logic as a methodological approach suitable with the research problem presented in this thesis.

4 Literature Review

In this chapter we present a systematic literature review, conducted in order to identify, analyse and interpret scientific evidence related to the contributions of human factors and ergonomics to the design of tools, devices and work processes to support risk assessment in the context of health care. This literature review has the following highlights:

- It is a review of the current status of research on design for patient triage;
- 1,845 papers have been initially retrieved, with 16 selected for data extraction;
- Selected papers were stratified according to four classes of outcomes;
- We describe and evaluate the extent to which published studies explore the research topic of this thesis.

The literature review incorporated by this chapter resulted in one scientific article, and citation information for it is described below.

Jatoba, A., Burns, C., Vidal, M., & Carvalho, P. (2015). Designing for Risk Assessment in Primary Health Care: a literature review . *JMIR Human Factors (accepted)* .

4.1 Introduction

In the health care domain, patient triage and risk assessment has always been a major concern (MANCHESTER TRIAGE GROUP, 2005; SAVASSI, CARVALHO, *et al.*, 2012; LOWE, BINDMAN, *et al.*, 1994; BEVERIDGE, DUCHARME, *et al.*, 1999). Keeping patients safe and ensuring that they receive the right treatment has been subject of different research areas like psychology (CIOFFI, 1998; MCCANN, CLARK, *et al.*, 2007), software engineering (MURDOCH, BARNES, *et al.*, 2015; GOLDENBERG, EILOT, *et al.*, 2012), ergonomics (NEMETH, WEARS, *et al.*, 2008; CARAYON, WETTERNECK, *et al.*, 2014; CARAYON, 2012), and others. These studies of how health care workers make decisions in such complex systems has given some insights of how to design for patient safety.

Furthermore, in order to improve patient triage, system designers must understand functional work requirements and constraints in the beginning of the design process, defining the optimal workload. Otherwise, it becomes difficult to incorporate human factors after the design is completed (OTTINO, 2004). While interacting with a complex physical environment, only a few elements of a problem can be within the span of human consciousness simultaneously (RASMUSSEN, 1979).

Thus, the objective of this paper is presenting a systematic literature review that aims at identifying, analysing and interpreting available scientific evidence related to the contributions of the cognitive engineering (HOLLNAGEL e WOODS, 2005; RASMUSSEN, PEJTERSEN e GOODSTEIN, 1994) to the design of tools, devices and work processes to support patient triage and risk assessment. This paper reviews the state-of-art research in this topic, identifying gaps in order to suggest further investigation. We explore the topic of decision-making in patient triage, examining the extent to which empirical evidence supports or contradicts the theoretical hypothesis of the importance of actual work descriptions in the design for the health care domain.

The conceptual significance of this paper resides on providing the means to help researchers understand how the ergonomics and human factors discipline contributes to the improvement of work situations in the health care domain, enhancing the design of devices and work processes to support the course of action (THEUREAU, 2003) in the patient triage and risk assessment process.

4.2 Materials and Methods

We performed electronic search on seven bibliographic databases as follows:

- Science Direct;
- PubMed;
- Springer Link;
- ACM Digital Library;
- Wiley Online Library;

- Scopus;
- IEEE Xplore.

We consider those databases appropriate due to the amount of indexed journals and coverage of relevant disciplines like health sciences, engineering, and computer sciences. The flexibility of the search engines (for combining search terms) and the ability of exporting results to formats accepted by reference managing software have also been considered in the selection of academic databases.

4.2.1 Research Questions

Below, we describe the major research question that guides our study:

- How to design suitable support tools, devices, and processes that enable more reliable and precise patient triage, prioritization, and risk assessment, reducing workload, and making work in primary health care more comfortable for workers;

In order to address this major research question we formulated two sub-questions, which this literature review investigates, as follows:

- Should we expect more effective patient triage and risk assessment when applying human factors and ergonomics in the design of support tools and processes?
- What evidence is there that applying human factors tools and technics brings more significant results for understanding real work in patient triage and risk assessment?

Thus, in this paper we collect, classify, and analyse recent work related to this research topic in order to assess the contributions, advantages and disadvantages of employing human factors and ergonomics in the design for risk assessment in the health care domain.

4.2.2 Selection Criteria

This literature review includes original journal papers published in English between 2011 and 2015, including the ones available online in 2015, in order to concentrate on more recent contributions to our research questions and represent more accurately the current status of research related to our topic. Conference papers, books, chapters, and reports have not been included in this literature review.

Table 4-1 shows a summary of the search terms and respective variations derived from the research questions. We have used free search terms with no controlled descriptors in order to have a broader search.

Table 4-1: Search terms and variations

Term	Variations
Cognitive engineering	Cognitive ergonomics; Cognitive systems engineering; Cognitive work analysis; Cognitive task analysis; Human factors; Ergonomics
Risk assessment	Triage; Patient triage; Risk management
Health care	N/A

We use variations of search terms to match eventual synonyms, abbreviations, alternative spellings, and related topics. We performed trial searches using various combinations of search terms in order to check lists of already known primary studies, using the following search query:

- (“Human factors” OR “Ergonomics” OR “Cognitive ergonomics” OR “Cognitive engineering” OR “Cognitive systems engineering” OR “Cognitive work analysis” OR “Cognitive task analysis”) AND (“Risk assessment” OR “Triage" OR "Patient triage” OR “Risk management”) AND (“Health care”)

We describe inclusion and exclusion criteria in Table 4-2:

Table 4-2: Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
• Studies that assess difficulties, critical factors, challenges, or problems in applying human factors and ergonomics in the design of risk assessment support tools or processes in healthcare; • Studies that present good practices, lessons learned, and success factors in applying human factors and ergonomics concepts in the design for patient triage and risk assessment;	• Studies that do not address any of the research questions; • Literature reviews

- Studies presenting models, processes, techniques, or tools to enable the improvement of patient triage and risk assessment in health care.	

In addition to general inclusion exclusion criteria, the quality of primary studies have been evaluated, as well as their suitability to the presented research questions, in order to investigate whether quality differences provide useful explanations, guide the interpretation of findings, and determine the strength of inferences, as well as how they meet the research questions. The quality of a scientific study relates to the extent to which it minimizes bias and maximizes internal and external validity (HIGGINS e GREEN, 2011). The following aspects have been evaluated in the articles:

- Objective, research questions, and methods well defined
- The contributions are well described
- The kind of scientific study is clearly stated
- Source population is identified
- The interventions or strategies are sufficiently described to allow reasonable replication
- Outcome is defined and measurable
- Objectives are accomplished and research questions are clearly answered
- The study meets the major research question
- The study meets the first sub-question
- The study meets the second sub-question

Selected publications have been given scores from 1 to 5 to each aspect, as 1 corresponds to “strongly disagree” and 5 “strongly agree”. The sum of the scores determined their methodological quality and suitability to research questions as follows:

- Very high—100% of the methodological quality aspects met,
- High—75–99% met,
- Medium—50–74% met,
- Low—0–49% met.

A committee of four researchers applied the inclusion and exclusion criteria and performed the assessment of methodological quality of the selected papers. Committee members are doctorate students in systems design engineering and have the same level of expertise in ergonomics and human factors. A tenure professor, head of the ergonomics and human factors lab, supervised the committee during the process. After reading the papers, the committee met in order to present their evaluation. The final score for each criterion for methodological quality represents the consensus of committee members. A study proceeded to data extraction when it met at least 50% of the methodological quality.

4.2.3 Definition of Outcomes

We stratified the selected papers according to four classes of outcomes as follows:

A. Design of risk assessment decision support for health care: papers fit this class when the outcomes propose the implementation of new tools to support decision making in health care risk assessment work situations;
B. Design frameworks, processes, and methods for risk assessment in health care: this class relates to publications which outcomes present frameworks or processes applied to the design of risk assessment work situations in health care environments;
C. Recommendation or implementation of improvements in risk assessment work situations in health care: This class of outcomes is met by articles suggesting transformations in the work place, environment, or equipment, or processes in risk assessment work situations in health care;
D. Analysis of the impacts of new technologies or processes to risk assessment in health care: this class is met by articles that present studies about the implications of transformations made by new devices and/or processes for risk assessment in health care environments

4.3 Results

Among the seven databases searched, five of them had results exported to a library in the reference management software Zotero. Results of two of them (IEEE Xplore and Springer Link) could not be exported to Zotero due to limitations of the search engine, but could be exported to the CSV format and organized in Microsoft Excel spreadsheets. Steps for paper selection included title reading, abstract reading, and full reading. Table 4-3 shows the results of paper selection steps.

Table 4-3: Summary of search results

Database	**Selected papers**				
	Search results	**Selected after title reading**	**Selected after abstract reading**	**Selected after full reading**	**Percentage of selected papers**
Science Direct	403	55	8	4	0.99%
PubMed	249	19	6	5	2.01%
Springer Link	149	27	3	2	1.34%
ACM Digital Library	159	18	3	2	1.26%
Wiley Online Library	238	22	5	1	0.42%
Scopus	33	10	5	1	3.03%
IEEE Xplore	614	31	6	1	0.16%
TOTAL	1845	182	36	16	0.87%

We retrieved an amount of 1,845 in the initial search. After abstract reading, 36 papers have been selected for full reading. Among these, 16 papers met the inclusion/exclusion criteria and were submitted to quality and suitability evaluation, as well as data extraction. Table 4-4 summarizes the key elements of the selected articles.

Table 4-4: Summary of selected papers

Author(s)	**Summary**	**Type of study**	**Outcome**
McClean et al., 2011	McClean et al. propose the use of a framework for modeling the care process in hospitals in order to improve the assessment of patients' clinical status and define the length of their stay at the hospital. The paper presents a case study based on data extracted from patients of a hospital in Belfast and demonstrates results of patient survival rates when using their length of stay and destination as outcomes.	Case study	B
Alemdar, Tunca and Ersoy, 2015	The authors adopt techniques for human behavior analysis from a medical perspective through the analysis of daily activities in terms of timing, duration and frequency and propose an evaluation method applicable to real-world applications that require human behavior understanding through an experimental study.	Experimental study	A
Hundt et al., 2013	According to Hundt et al. most vulnerability in the design of computerized tools to support physician order entry occur by not considering the work system in which the technology is implemented, therefore, the authors state that the human factors engineering discipline offers a range of approaches for anticipating vulnerabilities, enabling designers to address them before technology implementation.	Case study	A
Card et al, 2012	Card et al. present a case study that shows the rationale for taking a proactive approach to improving healthcare organizations' emergency operations. It demonstrates how the Prospective Hazard Analysis (PHA) Toolkit can drive organizational learning and improve work situations.	Case study	B
Pennathur et al., 2014	Through a study conducted in hospitals, Pennathur et al. propose an information trail model for capturing fundamental characteristics of information that workers on emergency	Exploratory study	B

	departments create and use for patient care. The model proposed by Pennathur et al. meets our research sub-questions by presenting a method for tackling complexity and prevent failures by increasing understanding of the information flow in the process of assessing patient conditions, based on the idea that people in a complex cognitive work system organize information by their own.		
Aringhieri, Carello, and Morale, 2013	In their paper, Aringhieri, Carello, and Morale present an exploratory study on the ambulance location and management in the Milano area, in which they evaluate the current emergency system performance. According to the authors, despite the availability of technological support, in Italy, the use of resources in emergency departments is based on operators' experience.	Exploratory study	C
Iakovidis and Papageorgiou, 2011	Iakovidis and Papageorgiou propose a model and evaluates its effectiveness in two scenarios for pneumonia risk assessment. His results indicate that the major contribution of the proposed model is that it incorporates additional information regarding the hesitancy of the experts in the definition of the cause–effect relations between the concepts involved in the health care domain. Iakovidis and Papageorgiou state that the proposed approach is capable of modeling real-world medical decision-making tasks closer to the way humans perceive them.	Exploratory study	A
Kong et al., 2012	Kong et al. propose the employment of a belief rule-base inference methodology using the evidential reasoning approach in order to support modeling and reasoning with clinical domain knowledge. According to Kong et al. the approach they propose helps reducing uncertainties in clinical signs, clinical symptoms and clinical domain knowledge, which are critical factors in medical decision-making.	Exploratory study	A
Cagliano, Grimaldi and Rafele, 2011	Cagliano, Grimaldi and Rafele propose a framework that operationalizes the Reason's theory of failures (REASON, 2001) by developing a methodology for investigating health care processes and related risks on patients based on expert knowledge. They apply their approach to the pharmacy department of a large hospital.	Exploratory study	B
Park, Lee and Chen, 2012	Park, Lee and Chen studied how the design of electronic medical records (EMR) systems affects medical work practices. They analyzed consequences of EMR on clinical work practices and related design issues, such as usability or functionalities of EMR systems, in order to associate the work practices changes led by the EMR system with the actual design of the system.	Case study	D
Hepgul et al., 2012	Hepgul et al. present an examination of the role of clinical expertise and multidisciplinary teams in identifying patients at risk of developing depression, and in monitoring those receiving treatment for the occurrence of depression.	Case study	C
Glascow et al., 2014	Glascow et al. propose a comparison between risk estimates from statistical models previously developed and evaluated, and risk estimates from the patients' surgeons. Through this comparison, they are able to evaluate the predictive validity of the decision support model for safer surgery in predicting risk for specific complications. Moreover, they enable the assessment of the validity of this model by correlating its predictions to the ones made by experienced surgeons.	Exploratory study	D
Johnston et al., 2014	Johnston et al describe the importance of overcoming hierarchical barriers between junior and senior surgeons as crucial success factor for prioritization of health care.	Case study	C
Ferguson and Starmer, 2013	Ferguson and Starmer highlight the role of expertise in risk assessment in health care facilities and evaluate the impacts of framing risks in the improvement of interpretation in such environments.	Experimental study	C
Norris et al., 2014	In their paper, Norris et al. describe a project that takes a systems approach to identify risks, engage health care staff and patients facilitate ideas, and develop new designs for the bed-space in order to demonstrate the application of human factors to a complete design cycle.	Case study	C
Hastings et al., 2014	Hastings et al. propose a method to classify older adults in the emergency department according to healthcare use, by examining associations between group membership and future hospital admissions.	Case study	C

Most studies are case studies (8 papers), followed by exploratory studies (6 papers). Finally, two out of the 16 selected papers are experimental studies. After the assessment of methodological quality and suitability of the selected articles, we proceeded with the data extraction and the stratification of papers according to the four classes of outcomes described in section 4.2.3, as we show in Table 4-5.

Table 4-5: Publications classified according to outcomes

Database	**Outcomes**			
	(A) **Design of Risk Assessment Decision Support for Health Care**	**(B)** **Design Frameworks, Processes, and Methods for Risk Assessment in Health care**	**(C)** **Recommendation or Implementation of Improvements in Risk Assessment Work Situations in Health care**	**(D)** **Analysis of the Impacts of New Technologies or Processes to Risk Assessment in health Care**
Science Direct	1	1	1	1
PubMed	-	-	4	1
Springer Link	-	1	1	-
ACM Digital Library	1	1	-	-
Wiley Online Library	-	1	-	-
Scopus	1	-	-	-
IEEE Xplore	1	-	-	-
TOTAL	4	4	6	2
%	**25.00%**	**25.00%**	**37.50%**	**12.50%**

In the next subsections, we present an overview of the selected publications, describing how they address our research questions.

4.3.1 Design of risk assessment decision support for health care

Regarding our research questions, Iakovidis and Papageorgiou (2011) propose the use of fuzzy cognitive mapping, which includes concepts that can be causally interrelated and represent uncertain and imprecise knowledge through fuzzy logic. These concepts encompass tools for modeling and simulation of dynamic systems, based on domain-specific knowledge and experience.

According to Iakovidis and Papageorgiou by using fuzzy cognitive maps in intuitionistic systems like health care, a factor of hesitancy is introduced in the definition of the cause–effect relations among the system, providing an additional cue regarding the experts' knowledge and way of thinking, which increases understanding of real work and improves decision-making.

Related to our major research questions Kong et al. (2012) suggest that the complexity of inference mechanisms and difficulties in representing domain knowledge hamper the design of clinical decision support systems like the ones used in patient risk assessment. Therefore, representation of human reasoning and uncertain medical knowledge are critical areas that require refined methodologies and techniques.

Regarding our sub-questions Kong et al. conclude that the approach they propose provides reliable and more informative diagnosis recommendations than manual diagnosis using traditional rules when there are clinical uncertainties, which brings significant improvements to the system diagnostic. After evaluating a prototype built using their approach, they also state that the clinical risk stratification provided the triage of patients to appropriate levels of care, tackling uncertainties in incomplete patient data, improving decision-making.

The paper of Alemdar, Tunca, and Ersoy (2015) also addresses the challenges in understanding human behavior from a well-being assessment perspective in order to enable the construction of a health conditions assessment device based on models of machine learning. The approach proposed by Alemdar, Tunca, and Ersoy is not specific for health care risk assessment applications, but uses data from studies of human behavior for health assessment perspective in their experiments.

Hundt et al's work (HUNDT, ADAMS, *et al.*, 2013) relates to our major research question as it describes the implications of poor understanding of how work is performed in technology design, and its impact on workflows and processes. Regarding our second research questions, according to Hundt et al. the use of proactive risk assessment can help designers identify potential problems that, if disregarded, commonly result in poor health IT implementation.

Regarding our second sub-question, Hundt et al. highlight that proactive risk assessment methods demand high commitment by team members, and their effectiveness for health IT implementations has not yet been examined. Although the physician order entry is not a risk assessment process *per se*, managing patients involves the evaluation of their health conditions and the prioritization of treatment, which is similar to the patient triage process.

4.3.2 Design frameworks, processes, and methods for risk assessment in health care

The framework McClean et al. (2011) propose aims at identifying better pathways to patients based on their characteristics like age, gender, and diagnosis. Therefore, the framework enables the assessment of patients' risks and helps determine the pathway of the patient. McClean et al. present a case study to show the application of the approach they propose, which meets our first sub-question.

According to Card et al. (2012) risk management in health care is largely concerned with routine risks that stem from everyday service provision, which makes it possible for health care organizations to learn from experience and make risk management more effective. However, regarding emergency operations, workers do not often use previous experience to improve risk management processes.

Thus, Card et al. used the PHA Toolkit to examine and increase comprehension of the system in order to reduce the risk associated with the hospital's emergency operations, thus addressing our major research question. By drawing organizational learning from the PHA, the authors suggest that the probability of loss of organizational changes - made by other techniques like exercises and drills - has decreased.

Although it doesn't address directly our sub-questions, Card et al. recognize that domain comprehension is a major concern in the design of support devices, and state that the use of the PHA Toolkit helps designers to better understand the domain and work processes for risk management in health care environments – and this relates to our major research question in some extent.

According to Pennathur et al. (2014) diagnosing patient conditions from their major complaints and lab tests results, as well as predicting patients' progress over the course of their stay (which relates to patient triage and risk assessment), demand situation awareness and real-time decision making under high stress for health care workers. Even for routine care, workers have to interpret quantitative and qualitative information from patient history, physical conditions, and many other aspects in order to generate diagnosis and treatment plans.

To which concerns our research questions, Pennathur et al. state that work in health care emergency involves significant information-based cognitive activities, however, it’s mostly supported by exogenously designed information systems, which are produced with gaps of information about the domain and insufficient input from end users on their needs and practices. This fact imposes limitations to the effectiveness of such support tools.

According to what Pennathur et al. present in their paper, the presence or absence of information determines how and why people in a work system create endogenous artefacts, work practices and strategies. Moreover, the study of information provides an understanding of how information technologies to support complex cognitive work can be designed better.

According to Cagliano, Grimaldi and Rafele (2011) the clinical risk is determined by many factors relating to the system, the environment, and the interplay of individuals operating in the processes connected to the delivery of care, which increases the possibility of medical errors during therapy prescription, preparation, distribution, and administration. Thus, there is strong need for understanding the triggering events of medical errors as well as their correlations, in order to decrease the probability of occurrence.

To which concerns our research sub-questions, according to Cagliano, Grimaldi and Rafele the mapping of the discrepancies in the system barriers (failure modes and kinds of waste), they were able to make operators aware of both risks and waste existing in a health care process, supporting decision makers in setting priorities for intervention.

4.3.3 Recommendation or implementation of improvements in risk assessment work situations in health care

According to Aringhieri, Carello, and Morale (2013) huge amounts of data about health care workers activities are never used for improving the system performance and the prioritization of resources. Thus, in their paper these authors explore the question if such data could be used to foster the design of decision support tools.

Regarding our research questions, Aringhieri, Carello, and Morale suggest that modelling, simulation and mathematical programming can be successfully applied to an emergency service, in order to evaluate its current performance and to provide suggestions to improve the way resources are prioritized. The prioritization of resources in health care services relates to the triage of patients that shout receive priority assistance, therefore the study of Aringhieri, Carello, and Morale – which explores the allocation of resources such as ambulances according to people's needs – is suitable to our research questions, although not a perfect fit.

The work of Hepgul et al. (2012) meets our major research question, since it aims at showing the implications of understanding of staff experience in the decision-making process in clinical services like patient triage or treatment for the risk of depression in patients with hepatitis C.

According to Hepgul et al. the contact between patients and professionals is the major process of gathering information about patient conditions. Therefore, the relationship between patient and health care professionals must be understood in order to improve the diagnosis process or implement decision support devices.

According to Johnston et al. (2014), the recognition of patient deterioration and subsequent communication to a senior colleague is typically performed by a junior doctor, who is most of the times the first point of contact for nursing staff when a postoperative patient becomes unstable. This relatively inexperienced doctor must make a rapid assessment of the patient conditions in order to decide whether to ask a senior colleague for assistance.

Deficiencies in this process may occur due to lack of experience, but also due to unavailability of information about patient conditions, poor risk assessment guidelines, communication failures, and lack of consideration to the human, technical, and patient factors involved in this critical process. All these aspects refer to our major research question.

Regarding our sub-questions, Johnston et al's study uses the Healthcare Failure Mode and Effects Analysis (HFMEA) (STALHANDSKE, DEROSIER e WILSON, 2009) in order to assess and analyze risks in the escalation of care process, enabling the identification of failure, and avoid patient harm, making possible to describe recommendations to improve patient safety on surgery departments. According to Johnston et al. human factors and technological failure were identified as the major causes of communication failures between workers.

Ferguson and Starmer (2013) address our research questions by examining the effectiveness of framing as a tool for improving understanding about health risks. According to Ferguson and Starmer, although risk information can be framed in a number of ways, they focused on frequency-based representations exploring, in particular, the natural frequency effect (NF), which results in improved problem solving compared to logically equivalent information presented as conditional probabilities.

According to Ferguson and Starmer, there is evidence that framing lead to more accurate calculations of patient risk, although it is unclear whether they also improve diagnostic understanding, as the link between calculating and understanding has not been examined before. This statement relates to our second sub-question, although Ferguson and Starmer state that incentives improved work performance and interpretation of patient conditions, regardless of framing.

Norris et al. (2014) cite examples to illustrate the value of human factors in design of solutions for the health care domain. According to Norris et al. it is necessary to understand the health care processes in question, through observations carried out jointly by the research teams, in order to ensure multi-disciplinary perspectives and enable the improvement of work situations and the design of effective support devices.

Although the work of Norris et al. was restricted to a part of the total care pathway of an elective surgery patient (it excluded diagnosis, surgery, discharge and recovery within the community), they state that it gives an idea of the size and complexity of entire health care systems, including the evaluation of patient conditions.

Although they do not address directly our major research question Hastings et al. (2014) highlight the importance of studying patterns in service as a source of information about the domain, in order to provide accurate prioritization for older adults in emergency departments – which addresses our first research sub-question.

Hastings et al. do not suggest specific human factors concepts. However, the authors highlight aspects of complexity in health care services, especially how variability hampers the identification of patterns; and suggest ways of improving health assistance. Moreover, Hastings et al. recommend the use of Latent Class Analysis (P.F. e HENRY, 1968) (J.K. e MAGIDSON, 2002) to identify groups of individuals in the emergency department with unique patterns of health service use.

According to Hastings et al. the group membership was predictive of the future unscheduled health care use, providing an example of how available data from electronic health records can be combined into meaningful clusters, improving quality and cost of care provided to seniors.

4.3.4 Analysis of the impacts of new technologies or processes to risk assessment in health care

The objective of Park, Lee and Chen's study (PARK, LEE e CHEN, 2012) is providing design guidelines for future EMR systems, by understanding how the electronic documentation lead to changes in work practices, and how these effects could be decreased. Although their work has not focused specifically in the risk assessment process, patient triage was one of the work situations who has been observed during their studies.

The work of Park, Lee and Chen address our second research sub-question, by stating that the use of the electronic notes led to an increased workload for residents. According to the authors, it happens due to the longer charting times and the shifted responsibility from workers, which enabled the inference that the design of electronic notes should follow the design adopted by professionals in their current physical notes. According to Park, Lee and Chen the implementation of an EMR system can hamper the social nature of clinical work if the specific documenting locations, the medium, and the information needed to complete tasks are not studied during design.

According to Glascow et al. (2014) optimal strategy for patient risk mitigation might be to prospectively identify risk at the individual level, as it would give enough time to engage in strategies to prevent specific surgical complications. However, few available decision support tools assess the patient risk variables for a broad group of operative procedures and surgical outcomes, and minimal knowledge exist on the accuracy of surgeon risk assessment with or without decision support tools.

Although no human factors and ergonomics concepts have been explicitly demonstrated in Glascow et al's work, the authors figured out that both the risk prediction models and surgeons could identify patients who were more likely to develop specific surgical complications, highlighting the importance of experience in this kind of decision making. Both the model and surgeons were also able to point out the risk for specific health complications for patients, which partially address our first and second sub-question.

4.4 Discussion

Among the 20 papers discarded after full reading, 11 of them did not match any of the research questions. Two publications were discarded due to low methodological quality according to the aspects we described. The other six discarded publications met other exclusion criteria. The two databases that presented more search results were the IEEE Xplore (614 publications) and Science Direct (403). However, this order have changed in the final selection of papers, as the PubMed database concentrated most of the selected publications (five publications), followed by Science Direct (four publications).

We believe that the broader range of the Science Direct database contributed to the big amount of references found, as well as to the fact that it remained as one of the top databases in the final selection. The Science Direct database collects publications from diverse fields, from physical sciences and engineering, life sciences, health sciences, and social sciences and humanities. The PubMed concentrates publications from life sciences and biomedical – it uses the Medical Subject Headings (MeSH) controlled vocabulary (BODENREIDER, NELSON, *et al.*, 1998).

Furthermore, our research topic is interdisciplinary, although our research questions have narrowed the final results. We could infer that the medical field shows interest in the importance of gathering knowledge about work performance in patient risk assessment, as well as the contributions that cognitive engineering can give to this subject. Although other fields like engineering and computer science have also shown some results towards our research questions, these areas present broader focus, e.g. the risk assessment for multiple domains in complex systems, or contributions from the human factors discipline to multiple processes – rather than risk assessment - in health care.

Among the papers discarded due to unmet research questions, two of them proposed human factors methods for coping with complexity in risk assessment, but were not directly applicable to health care. This finding points out the significance of studies about judgment and uncertainty in risk assessment in multiple domains. It also shows that the risk assessment in health care presents many opportunities for the use of human factors and ergonomics in improving work situations, even though their applications might not be specific in the design of support devices or modeling work performance, as stated in our research questions.

Moreover, although most selected papers describe that problems in the representation of the domain hamper the implementation of improvements, the final amount of papers selected for data extraction represents less than 1% of the papers retrieved. This shows that the implications of lack of understanding about actual work performance in the design for complexity in risk assessment in health care need further research. This also highlights the specificity of the topic we explored in this review. However, it’s important to notice that we did not assess the **intensity of suitability** of a study to our research questions, e.g. some papers might be more or less suitable than others.

Regarding outcomes, we see that most of selected papers are related to recommendations of improvements (six publications), decision support tools (four publications), and design methods (four publications), while two publications explore the impacts of new technologies and processes. This shows that most related research explores the potential of cognitive engineering in providing tools to improve the design for complex work situations like risk assessment in health care work environments, although the impacts of these applications in human performance have not been extensively assessed.

We can also see that most PubMed publications focused on proposing improvements to risk assessment work situations in health care environments, which supports the idea that the medical area is focused on improving risk assessment work situations rather than exploring the potential of clinical decision support technologies. However, the selected studies show that, while different approaches have been taken, the associations between lack of knowledge about actual work and failed attempts in improving work situations or employing support technologies are similar in all research areas.

4.5 Conclusions

This literature review gathered recent contributions to multiple areas, from engineering to biomedical, on the contributions that cognitive engineering gives to the design for health care risk assessment, especially by contributing with the increase of knowledge about real work performance in such settings. In this paper we present information about how this research topic has been approached, results, accomplishments, and opportunities for further research.

Papers selected for review were very diverse in terms of the aims of the study, the underlying theoretical frameworks and methodologies used, reflecting how interdisciplinary our research topic is, and the wide range of research backgrounds employed in finding answers to our research questions.

The selection criteria we adopted in this review imply that relevant studies may have been excluded. Relevant papers published before 2011, or in conferences are not presented in our review of the literature, as well as publication in other languages rather than English. Moreover, the search terms, combined with the inclusion exclusion criteria, narrowed the results, which might also have left relevant studies out of the reviewed articles.

Furthermore, results included studies from several areas like medicine, engineering, and computer science. We did not present specific research questions associated with each area, therefore some papers might have been excluded for not addressing the research questions, although they might have explored our research theme in some extent. This aspect has also influenced the assessment of the quality of the papers and their suitability to the research questions, which wasn't also performed according to specifics of different research fields.

Regarding the stratification of papers according to their outcomes, it has been useful to point out which kinds of results have been expected from research in the topic we explored. However, it might also limit the range of some publications, which, sometimes, presented more than one kind of outcome. Moreover, some ambiguity about which class an outcome should be under might occur.

An opportunity for further studies would be to expand the search to include other contributions of human factors and ergonomics to the design for health care – rather than specific contributions to patient risk assessment - as well as the contributions of other areas to the risk assessment in health care. This could address important aspects, for example, which areas have made recent contributions to the improvement of health care services, and subsequently to the risk assessment in health care environments.

5 Results

In this thesis, we present three research questions. We wrote four scientific papers to address such research questions – two articles addressed the third research question. In the next subsections, we present the four mentioned papers. All papers have been either published or submitted, thus, we present citation info for all of them in the corresponding section's foreword.

5.1 Article 1: Designing for Patient Risk Assessment in Primary Health Care: a case study for ergonomic work analysis

5.1.1 Foreword

In this chapter we study the importance of a consistent description of actual work in patient risk assessment in the primary health care domain. Through a case study in the context of primary healthcare, we address the research problem of finding ways to build consistent work descriptions of the patient risk assessment system in the primary health care domain, in order to foster the design of improved work situations and support devices.

This is a qualitative field study based on ethnographic observation and semi-structured interviews carried out among professionals involved in the risk assessment process in a primary health care facility. The objects of ergonomic work analysis were work places and work situations with focus on human activity, as well as surrounding aspects.

The analysis identified elements in the work domain with high cognitive demand and operations that could increase mental workload, providing elements for the earlier stages of the design of work situations and support devices to improve the risk assessment in primary health care,

Here, we demonstrate the usefulness of actual work descriptions in the design for complex situations like the risk assessment in health care, as well the impact of poor descriptions in generating harmful situations for both the patient and health care practitioners in the explored domain.

This chapter resulted in one scientific article, with the following citation information:

Jatoba, A., Bellas, H. C., Bonfatti, R. J., Burns, C., Vidal, M., & Carvalho, P. (2016). Designing for Patient Risk Assessment in Primary Health Care: a case study for ergonomic work analysis. *Cogn Tech Work , 18:215-231*

5.1.2 Introduction

Health care systems are struggling to respond to multiple challenges in a complex and constantly changing world, while high levels of inequity in health status still exists, both globally and within nations. To improve the quality of services, health care systems must use multifaceted approaches integrated with local context, involving sustained action and engagement across multiple levels (REID, COMPTON, *et al.*, 2005).

One of the major processes in health care is the evaluation of patients’ risks and the corresponding triage according to their conditions. This process involves the identification of symptoms, listening to the patient’s complaints and expectations, and evaluating the patient’s vulnerabilities. It’s a dynamic and singular process, and patients and professionals are both responsible for the decisions made. These decisions can be critical as they involve the possibility of harmful situations both for the patient and the health care workers.

Furthermore, the risk assessment process encompasses organizational practices and procedures that may not be fully disseminated, as well as clinical traditions and practices, presenting singular combinations of knowledge. This hampers the use of an algorithmic approach, limits the usefulness of currently available support tools, and challenges the design of support tools.

Thus, we propose that an ergonomic approach can be useful in this case, as modeling can help to understand the knowledge structures and cognitive demands that can occur in these situations. Ergonomic work analysis (EWA) is one possible method to understand organizational constraints and affordances and reveal the way organizations manage complex knowledge structures and contributing to the design of new support systems.

In this paper, we present a case study of the execution of a EWA in a primary health care facility responsible for providing assistance to people from a poor community in Rio de Janeiro, Brazil.

5.1.3 Research Problem and Questions

In health care, one of the major barriers in designing suitable medical devices is the prevailing idea that safety and success in clinical procedures depend mostly on the abilities and training of health care workers. Not only does this create an attitude that problems can be trained away, it reduces the motivation to closely examine the tools that people use in their work or the understanding of how they use them (NORRIS, WEST, *et al.*, 2014).

In any sociotechnical systems work is underspecified and humans adapt their behavior to cope with the system's inherent complexity, and such a fact makes it difficult for analysts to build descriptions of work performance (CARVALHO, 2011). Traditional approaches that are common in healthcare like standardization and division of labor look effective under normal conditions. However, they may create gaps and increase risks for hazardous situations under abnormal conditions (NEMETH, WEARS, *et al.*, 2011).

Moreover, the dynamic behavior of complex systems is also influenced by human characteristics like fatigue, mood, and emotions, as well as interaction with other people and with the environment, the influence of the past experiences and culture of the people working within the system (NORMAN, 1980). In some ways, human decision makers strengthen systems due to human flexibility and ability to adapt to changes that face the system (AHRAM e KARWOWSKI, 2013).

Thus, in this paper we address the problem of finding ways to build consistent descriptions of the actual work performed on patient risk assessment system in the primary health care domain, in order to foster the design of improved work situations and support devices. We suggest that EWA might be one approach to capture the richness of human work in this environment. The analysis of how workers actually perform rather than describing how work has been prescribed to be performed, and the study of differences between these aspects provides a range of design opportunities.

We present a case study using EWA as an approach for the analysis of work situations in complex systems like health care, as means to address the following questions:

- How can work situations be enhanced and support devices be designed in order to improve the risk assessment process in primary health care?
- What are the contributions from ergonomics to the design of improved work situations and support devices for risk assessment in health care?

We believe that the results we present in this paper have the conceptual and practical significance of helping designers to understand the implications of work descriptions in the design for complex situations like risk assessment in health care. Our results also aim to minimize the impact of poor descriptions in generating harmful situations for both the patient and health care practitioners in the explored domain. Furthermore, the case study of ergonomic work analysis we described here contributes with transformations of complex, dynamic, and high-demanding work situations, like patient risk assessment.

5.1.4 Research Setting

This study was carried out in a primary health care facility in Rio de Janeiro, Brazil. According to the Brazilian health care policy, access to health care services must be universal, including actions for promotion, protection and recovery, with priority given to preventive activities. Thus, primary health care turns out to be the major strategy in the Brazilian health care system, as it is characterized by a set of actions, both individual and collective, in order to cover promotion and protection of health conditions, disease prevention, diagnosis, treatment, rehabilitation and maintenance of health.

Currently, primary health care in Brazil is mostly represented by the family health care strategy, developed through the performance of care practices by health care teams in delimited territories, considering social aspects of the locations in which patients live. In the family health care strategy assistance occurs both in primary health care facilities and in people’s residences. In Figure 5-1 we can see the basic structure of the reception of patients by the family health care strategy.

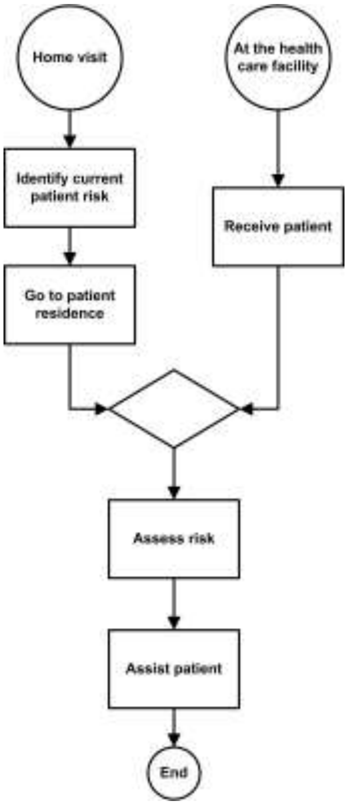

Figure 5-1: General structure of patient reception

Before visiting the patient‘s residence professionals become aware of patient’s current risk state. In the health care facility this is not possible, since patients arrive without appointments. Either way, all patients in the primary health care system must undergo risk assessment before getting assistance. The risk assessment process consists in the evaluation of patients’ severity and vulnerability, resulting in the prioritization of care actions. This process is based on the protocol described in Manchester Risk Rating Scale (MANCHESTER TRIAGE GROUP, 2005), in which colors are assigned to patients according to the severity of their conditions. The original protocol consists of five colors (black, red, yellow, green, and blue, considering black the worst patient conditions and blue the best patient conditions), however, the primary health care facility in which our study was carried out uses a modified version of the risk scale in which the color black is not present, and the worst patient conditions are represented by the color red.

5.1.5 Methods

Primary data is based on a qualitative field study carried out with ten professionals directly involved in the risk assessment process, along with two managers who were indirectly involved with the risk assessment process in a health care facility. The objects of analysis are work places and work situations with focus on human activity. The context is the workplace and its surrounding aspects.

Data collected by means of ethnographic observation (MYERS, 1999; NARDI, 1997) and semi-structured interviews through conversational action (VIDAL e BONFATTI, 2003) were recorded through photos, videos and notes. Through ethnography the observed group and its culture issues are understood by living in the same environment and making the things that the people make, trying to act the way they act while collecting empirical data. This way it is possible to understand how and, mainly, why the activities are done in one determined way, because the phenomenon is studied inside the social, cultural and organizational context. This strategy of gathering data allows grasping social scenes with its conflicts, misunderstandings, negotiation processes, and creation of consensual arrangements to avoid prescriptive rules (SILVA JUNIOR, BORGES e CARVALHO, 2010).

From the point of view of the activity analysis, as the subjects are observed in actual work settings, the physical, organizational and cultural constraints provide background for inferences and hypotheses about cognitive activities, which are going to be and validated with the participants in further steps of the analysis.

This study is in accordance with the ethical principles of the Resolution nº 466/2012 of the Brazilian National Council of Health Care/Brazilian Ministry of Health regarding scientific research involving human beings, and has been approved by the ethics committee of the Sergio Arouca National School of Public Health/FIOCRUZ.

5.1.6 EWA as a Formative Work Analysis Approach

The human interaction with a physical system always consists of actions, i.e., changes of the spatial arrangements of things, i.e., the body and external objects. Actions have extensions in time, and decompositions of a current activity into a sequence of actions can be done in many ways (RASMUSSEN, 1979). Through the study of workers' behavior in work situations, EWA increases understanding about how workers actually see their problems, indicates obstacles for the accomplishment of activities, and enables these obstacles to be removed through ergonomic action (WISNER, 1995).

Activity is a system of human performance, individually and societally, whereby subjects work in order to achieve an outcome. Human activity is performed in a multifaceted, mobile, and rich way, presenting variations of content and form (ENGESTRÖM, 1999; HUTCHINS, 1994). Any activity carried out by a subject includes goals, means, the process of molding the object, and results. The goals of an activity appear as the foreseen result of the creative effort. Moreover, while performing the activity, the subjects also change themselves. Societal laws manifest through human activities that construct new forms and features of reality, turning material into products (DAVYDOV, 1999).

From the activity theory perspective, cognition is a set of unconscious mental operations automatically unfolding over time or voluntary conscious cognitive actions (KAPTELININ, KUUTTI e BANNON, 1995). These two levels of information processing are interdependent and mutually influenced.

Thus, activity is a goal-oriented system. The goal of activity is a conscious representation of a desirable result. As a system, task consists of cognitive and motor actions, cognitive operations, and processes required in order to achieving a goal. The complexity of the task is determined by the number of elements in the system, the specificity of each element, the manner in which they interact, and the modes in which the system can function (BEDNY, KARWOWSKI e BEDNY, 2014).

Like other activity-centered approaches such as the course-of-action analysis framework, the EWA approach can also be useful for the analysis of both computerized and non-computerized work situations, and it's also focused on the analysis of workers' actual work situations, aiming for the design of improved new work situations. Inspired by the some critics of early human-centered systems design approach based on human factors instead of human actions and in the French traditional ergonomics (NORMAN e DRAPER, 1986; OMBREDANE e FAVERGE, 1955; WISNER, 1995), the course-of-action approach (THEUREAU, 2003) proposes the study of the human-system by the human interaction with the environment through tasks, cultural differences, behavioral acts, performance and learning. The EWA approach takes a similar path, and provides a structured set of phases and tools that simplify the data collection and the construction of models.

Both approaches give high emphasis in the transition between the analysis and the design of intervention projects, however, the EWA approach focuses on the definition of recommendations and their validation with workers.

Relationships are very important for EWA. The main idea is that ergonomists must be as close as possible to work situations, observing the activity from as close as they can, and validating recommendations directly with workers. In order to accomplish that, the EWA approach provides tools to define and describe groups and explicit responsibilities for workers and ergonomists during the analysis. The aim is to reduce tensions during the ergonomic intervention, as workers become part of the group that builds the solution, and help keeping the flow of information about how work situations are going to be transformed (CARVALHO, 2006).

EWA is also involved with musculoskeletal disorders caused by work posture, wrong movements, inadequate furniture or other work-related because these issues are important factor to be considered in ergonomic projects, however, psychosocial, cognitive, and individual factors also contribute to the development of work-related injuries (NIOSH, 1997; CORLETT e BISHOP, 1976). Therefore, understanding work activities using EWA enable investigations about physical disorders and discovering of socio-cognitive implications to work, and it is compatible with other frameworks and tools for cognitive analysis and modeling.

Both EWA and cognitive work analysis (CWA) (VICENTE, 1999) give emphasis in the identification of intrinsic work constraints and how these constraints affect the behavior of workers. However, EWA also takes into account the influence of physical components of the work environment in workers’ mental and physical distress, and the impacts of changes in the workplace settings – not only through the inclusion of new technology - but also transforming the overall work setting, influencing workers' moves, postures, processes, tools, and equipment.

Difficulties of the work situation, perception of the worker, the strategies workers adopt to satisfy work demands, and potential risks of hazards involved in work performance lead to differences between the prescribed work (task) and the actual work (activity). In order to describe social relation in health care environments, we must have a deeper understanding of social relations that involve multiple teams with overlapping or competing interests (JIANCARO, JAMIESON e MIHAILIDIS, 2014). Thus, EWA is centered on activity analysis, opposing the study of workers' motion on tools or devices, focusing on observing how workers actually perform their activities.

Moreover, especially in complex work situations, situated cognition is the basis for activity. In general, organizations develop work systems and support technologies imagining a system that is supposed to be constant in terms structure, time, and demands. However, in the real world, to cope with variations, there is the need of continuous adjustments in the operational performance, and sequences of tasks may vary enormously and quickly, both individually and among groups of workers. In these cases the hazards of performance may occur due to the high degree of indetermination of the demands of the task (OMBREDANE e FAVERGE, 1955), and the high degree of performance adjustment needed to cope with variations (HOLLNAGEL, 2012).

Thus, as the systems do not enable workers to be aware of important signals which could be used as basis for their decisions, the work analysis must focus on cognitive issues in a broad sense, rather than only on humans as processing information units, or in physical constraints in work performance. To access workers' situated cognition and, hence, the intelligence of the workers, we must perform detailed observation of their behavior (WISNER, 1995).

5.1.7 A Four-phase Approach to Ergonomic Work Analysis

In this paper we propose the use of a four-phase approach to EWA as can be seen in Figure 5-2. This representation of EWA as a spiral process indicates that phases might be performed iteratively until the final results are obtained. Iteration is the act of repeating the process in order to achieve the expected goal (PRESSMAN, 2014; SOMMERVILLE, 2010).

Figure 5-2: Phases of EWA

In ergonomics, the operation comprises observable parts of work (movements, postures, communication), and non-direct observable issues such as the cognitive functions like perception, attention, memory, problem-solving, and decision-making. These are the essentials of activities descriptions, i.e. the true working conditions. In the next subsections we explain the four phases of the proposed approach for EWA.

5.1.7.1 Framing

The expected result of the first phase of EWA is the elicitation of the initial objectives, i.e., the general idea workers and organization (represented by the managers) have about problems that affect work situations and the solution they initially desire. In subsequent phases, this initial objectives shall be confirmed (or not), turning into the description of actual ergonomic needs for both sharp end workers and managers.

For example, workers might be complaining about a specific tool, saying that it is not appropriate for the work that is being performed. However, the tool might not be the actual problem. Problems might be organizational, involving the processes in which the tool is being used, like the way the tool is being used. This investigation will be performed iteratively during subsequent phases and will be essential for the elicitation of the ergonomic needs in the global analysis phase.

In the framing phase we also describe general aspects of the organization, such as its history, location, relation with its surroundings, and context. Deeper relationships are also established to facilitate observations and interviews during fieldwork. In order to enhance the exchange of general and specialized knowledge, mobilizing the professional competencies available requires engagement to deepen relationships between workers, managers and ergonomists (VIDAL, CARVALHO e SANTOS, 2009). During this research we use three major groups of people:

- Support group: professionals that work in the organization and are meant to support fieldwork. They are stakeholders. This group comprises directors and managers responsible for the initial demand, as well as giving access to the organization, enabling the ergonomic action;
- Focus group: this group comprises the subjects of the analysis. This group must indicate which work situations will be analyzed and why (more representative, critical, more time consuming, with more cognitive demands) and, therefore, which professionals will be observed and interviewed;
- Accompaniment group: professionals that work in the organization and will join ergonomists as part of the analysis team. They can be recommended by the support group, but must definitely have strict relations with the focus group, as they will be the ones to reveal essential aspects of how workers perform their tasks, enable observations, put ergonomists in contact with professionals at work, arrange meetings between ergonomists and workers, validate results, etc.

Professionals can be members of more than one group and there’s no limit for the amount of professionals in each group.

5.1.7.2 Global Analysis

The objective of the global analysis phase is to describe, by means of context analysis and operation, which work situations actually deserve intervention. In order to accomplish this phase's objective, the functional context of the organization must be described, e.g. its population, work organization, work processes, and scope.

Among all work situations studied during the framing phase, in order to focus on the situation that actually needs intervention and define the ergonomic needs, we suggest the use of an analytical tool called EAMETA (RICART, VIDAL e BONFATTI, 2012). The EAMETA tool is used to evaluate six aspects in work situations as follows:

- Space: includes physical features of the workspace;
- Environment: comprises workspace elements, circumstances or conditions and their parameters in means of how they interfere in work performance;
- Furniture: includes furniture and objects people use to perform their activities and the way those objects are disposed in the workspace;
- Equipment: includes tools professionals use to perform their activities;
- Task: comprises rules, regulations, procedures and objectives that determine the workers' functions;
- Activity: includes the necessary steps workers must perform to accomplish their objectives.

A set of workers must be selected for interviews in which they will give their opinions about work situations, scoring each one of the aspects from 1 (very bad/very high demanding) to 5 (very good/very low demanding). The ergonomist responsible for the analysis also observes and evaluates the work situation and provides a score. The final score is calculated by averaging the scores given by workers and by the ergonomist. An aspect which final score is below 3.0 is potentially a candidate for intervention.

This phase is meant to describe a pre-diagnosis of work problems and define the focus of the analysis, as the starting point is the initial objective, mainly characterized by worker's complaints. However, worker's impressions about causes of distress might not be actual problems, especially when dealing with cognitive issues. Thus, it's important to keep in mind that results of further phases of EWA might bring the analyst back to this phase and new applications of the EAMETA tool can be necessary to find out actual problems.

5.1.7.3 Operation Modeling

Operation modeling consists of collecting evidence on actual activities, making possible a preliminary diagnosis of work situations. This is obtained by delimiting and measuring observable aspects of work and enables the description of how people work.

Focused on the opportunities for intervention detected during the global analysis, this phase aims the understanding of workers' behavior, operating strategies, processes and interactions. It implies the description of workers' activity, including their postures, efforts, information recovery and flow and decision making.

It's also important to delimit the determinants of work, that might be organization-related (design of the workstation, formal work organization, time constraints, etc.) or operator-related (age, anthropometrical characteristics, experience, etc.) (GARRIGOU, DANIELLOU, *et al.*, 1995).

This phase must be carried out by observations at the workplace, along with interviews with workers. Flowcharts are used to represent workers' activities and the operation model must be complemented by:

- A set of problems;
- A set of recommendations;
- An outline of possible improvements.

The set of problems must contain their descriptions, causes, consequences, and evidences found during fieldwork. In the set of recommendations, each one of them must be related to the problems they intend to solve. After that, the expected improvements must be listed.

5.1.7.4 Validation

Validation is the discussion about the ergonomic diagnosis with the EWA support group. It consists in presenting the results of EWA to the support group and discussing the final operation model and its complementary material (problems list, recommendations and outline of possible improvements). In this phase, results of analysis and recommendations are verified and negotiated, resulting in an intervention project.

5.1.8 Results

Field work sessions have been organized in four groups, one for each phase of EWA as follows: four sessions for framing, eight sessions for global analysis, ten sessions for operation modeling and one validation session. Participation in a team meeting completes the fieldwork as shown in Table 5-1.

Table 5-1: Fieldwork effort

	Sessions	**Time/Session**	**Total time**
Framing	4	1 h	4 h
Global analysis	8	2 h	16 h
Operation modeling	10	1 h	10 h
Validation	2	2 h	4 h
Participation in team meeting	1	4 h	4 h
		Total	**38 h**

The framing phase took one session with the general manager, one session with an assistant manager and two sessions with risk assessment teams. All eight sessions in the global analysis phases were used to apply the EAMETA tool. Four sessions were used to carry interviews and four sessions were for general work observations.

Operation modeling comprised work observation sessions focused on the problems described in the ergonomic needs. We can see in the following sections that they were necessary to describe cognitive issues involved in decision making inherent to the risk assessment process. Two validation sessions with both the support and accompaniment group were necessary to present the intervention project. In this section we show the results of the EWA carried out in the primary health care facility.

5.1.8.1 Framing

The general administrator of the primary health care facility accompanied the first visit, and the relationships necessary to carry out the field work were defined as follows:

- Support group members:
    - General administrator of the primary health care facility, responsible for coordinating all areas, from infrastructure to medical assistance. During interviews, the person in this position pointed out which workplace should be the focus of the analysis due to complaints from workers about work situations, and designated the professional who would accompany the ergonomic action.
- Focus group members:
    - Five orderlies and five nurses whose workplace is a room in the primary healthcare facility entitled “the risk assessment room”. According to the support group, those two groups of professionals are the ones directly involved in patient triage and risk assessment processes.
- Accompaniment group members:
    - Assistant manager of the primary health care facility. We called assistant manager one of the four assistants to the general manager. The one that has been designated for the accompaniment group is responsible for supporting professional continuing education in the primary health care facility, and his/hers background includes concepts, processes, workflows and tools that are used in the risk

assessment workplace that has been pointed out by the support group.

Figure 5-3 shows the representation of the group relations.

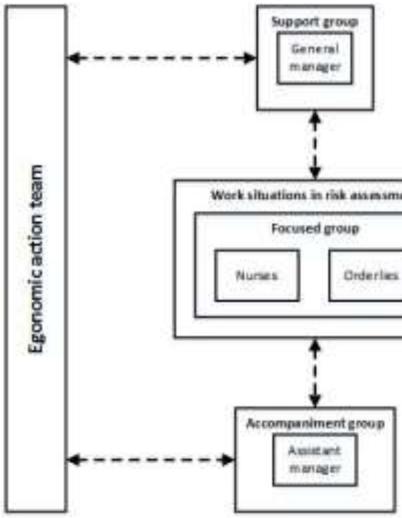

Figure 5-3: Group relations in the primary health care facility

This phase started with an interview session with the general manager in which for the definition of the focus and accompaniment groups members. In this interview, the general manager pointed out the risk assessment room as a focus of complaints by workers, therefore a potential high-demanding work place. Pictures of the risk assessment room can be seen in Figure 5-4 and Figure 5-5.

Figure 5-4: Desk of the risk assessment room

Figure 5-4 shows the desk with the computer and we can see in a small sink in the back. There are also two chairs: one for the patient and the other for one member of the risk assessment team. We can see that the desk has two small drawers, used to store medical equipment, paper, etc.

Figure 5-5: View of the weighing machines and the stretcher in the risk assessment room

The room has also an exam table and two weighing machines, one for adults and one for kids. A second chair, which cannot be seen in Figure 5-4 and Figure 5-5, is used for the second member of the risk assessment team. The layout of the risk assessment room can be seen in Figure 5-6.

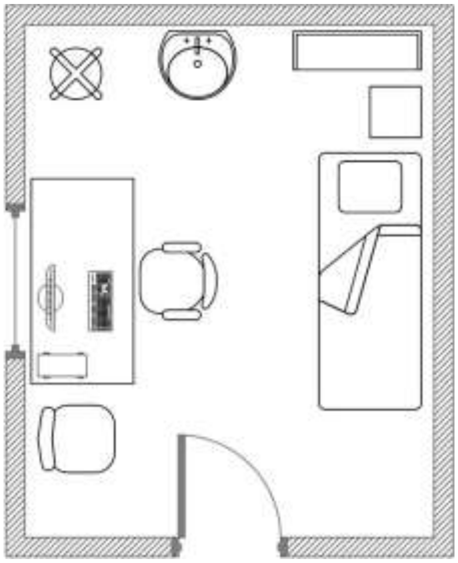

Figure 5-6: Basic layout of the risk assessment room

The accompaniment group has also been designated. According to the general manager, the professional and continuing education assistant manager would be the best person to join the ergonomists due to knowledge about work processes as well as proximity to the professionals that should be analyzed.

Thus, a second interview session has been carried out with the assistant manager which is member of the accompaniment group. The assistant manager confirmed that performing risk assessment is stressful and wearing due to the amount of aspects of the patient that the professionals must be aware of, as well as importance of the decisions that are made. The assistant manager testimonial can be seen below:

- "The risk assessment is the major cause of distress in the clinic. Professionals don't like to perform it and when they do, they end up their shifts very exhausted".

During these first sessions we have been informed that the relation between scheduled and emergency consultations is an index for tracking and evaluation of success rates in medical procedures. It is an important index as patients arriving spontaneously looking for care must pass through the evaluation of risk and vulnerability process which includes biological and socioeconomic aspects.

On data extracted from the information system used on the primary health care facility, analyzing 2,800 consultations in November 2013, 53% of the nursing care visits are not scheduled. In the case of medical care visits, this number rises to 76.6%. Only in dental care visits that number is below half, and still reaches 23.4%. The foundations of primary healthcare lie on health promotion and disease prevention. Therefore, as most patient receptions are happening spontaneously, i.e. without booked appointments, the primary health care assistance service loses its major characteristics.

The two remaining sessions of this phase have been carried out with the focus group. Five orderlies and five nurses participated in non-structured interviews about essential aspects of their activities, to describe principles, relations, work organization, and harmful situations.

Both nurses and orderlies stated that they have to keep attention in many aspects, not only of the patient, but the work environment, such as patient's physical conditions, patient records and history, as well as be aware of the amount of patients in the waiting rooms, routing patient to the correct treatment, etc. According to the members of the focus group interruptions are very common, as other teams must communicate with them all the time, but sometimes patients who are supposed to be in the waiting room also interrupt them, seeking for information or assistance.

Based on data collected during the interview sessions in this phase, we defined the initial objective as follows:

> *"The ergonomic evaluation of risk assessment workplace, due to distress it causes on workers and its potential for generating harmful work situations".*

5.1.8.2 Global Analysis

At the end of this phase, we were able to describe a pre-diagnosis of the risk assessment work in the primary healthcare facility and, thus, to define the ergonomic need, i.e. the actual harmful work situation faced by workers that should be mitigated.

Focusing With the EAMETA Tool

Work in the risk assessment room is performed by five teams of two professionals (one nurse and one orderly). For the application of EAMETA four teams have been interviewed and observed while performing their activities, of the ten members of the focus group, one nurse and one orderly could not be interviewed neither observed due to lack of availability. Four interview sessions and four observation sessions have been carried out. Results can be seen in tables Table 5-2 to Table 5-8 where T1 to T4 represent the teams that were interviewed and observed.

Table 5-2: Evaluation of the criteria "Space" with the EAMETA tool

	SPACE					
	T1	**T2**	**T3**	**T4**	**Ergonomist**	**Score**
Ceiling height	4	5	4	4	4	4.13
Circulation	4	1	1	2	1	2.5
Workplace area	4	4	4	4	1	2.5
Windows	5	5	4	4	4	4.25
Visibility	4	5	4	4	4	4.13
Communication	2	1	1	2	1	1.25

Average	3.13

For the “space” criteria problems related to circulation and workplace area were detected, once the risk assessment room is located in a small space in the corner of the primary health care facility. It causes also communication problems since workers must seek information about the patient outside the room. Circulation is also hampered by crowding in the waiting area.

Table 5-3: Evaluation of the criteria “Environment” with the EAMETA tool

	ENVIRONMENT					
	T1	**T2**	**T3**	**T4**	**Ergonomist**	**Score**
Natural lighting	4	4	4	4	2	**3**
Artificial lighting	4	5	5	5	4	**4.36**
Noise	4	4	4	2	4	**3.75**
Smell	4	5	4	5	4	**4.25**
Temperature	4	4	4	2	4	**3.75**
Ventilation	4	5	5	4	4	**4.25**
					Average	**3.89**

For the criteria “environment” we can see in Table 5-3 that the risk assessment room doesn’t have serious lighting or ventilation problems. It has good windows and natural lighting and ventilation as well as a silent air conditioner.

Table 5-4: Evaluation of the criteria “Furniture” with the EAMETA tool

	FURNITURE					
	T1	**T2**	**T3**	**T4**	**Ergonomist**	**Score**
Chair	1	1	4	4	4	3.25
Desk	1	1	1	1	1	1
Drawer	1	1	1	1	1	1
Closet	1	1	1	1	1	1
					Average	1.56

As we can see in Table 5-4, the furniture aspects present low average value. During observations, we could see that although the chair workers use is good, the desk has not enough space to dispose documents, notes and the computer. During interviews, workers stated that desk is too small and there’s no drawer and closet for personal belongings, and this could be confirmed during observations. However, most of the interviewed professionals also said that’s not a big problem, because their shift in the risk assessment room is only three hours a week. Therefore, the furniture aspect is not the first priority for the ergonomics action in the primary healthcare facility.

In Table 5-5 we show that the equipment is suitable, as workers have good computer and available medical instruments.

Table 5-5: Evaluation of the criteria "Equipment" with the EAMETA tool

	EQUIPMENT					
	T1	**T2**	**T3**	**T4**	**Ergonomist**	**Score**
Computer	4	4	4	4	4	**4**
Medical instruments	5	5	5	5	5	**5**
					Average	**4.5**

Table 5-6: Evaluation of the criteria "Physical demands" with the EAMETA tool

	PHYSICAL demands					
	T1	**T2**	**T3**	**T4**	**Ergonomist**	**Score**
Laying	5	5	5	5	2	3.5
Physical strength	5	5	5	5	5	5
Visual	5	5	4	4	4	4.25
Listening	5	5	5	5	5	5
Speaking	4	2	4	2	4	4
					Average	**4.35**

Regarding tasks and activity performance, data on Table 5-6 shows that no serious physical demands could be detected in work performance. Moreover, as we could see before, workers do not stay in the workplace for long periods of time.

Table 5-7: Evaluation of the criteria "Cognitive demands" with the EAMETA tool

	COGNITIVE demands					
	T1	**T2**	**T3**	**T4**	**Ergonomist**	**Score**
Attention	1	1	1	1	1	**1**
Focus	1	1	1	1	1	**1**
Memory	1	1	1	1	1	**1**
Reasoning	1	1	1	1	1	**1**
Awareness/Interpretation	1	1	1	1	1	**1**
Decision	1	1	1	1	1	**1**
					Average	**1**

However, cognitive demands are very high in the risk assessment as shown in Table 5-7. Along with high memory usage, workers must remember a large amount of information about patient’s conditions and current clinical conditions such as vital signs, temperature, blood pressure, etc. Although they have adequate computers, the software they used doesn’t have functionality to store all variables they use, making them use very volatile tools like sheets of papers and post-it stickers. Therefore, this information is not stored and can’t be reliably transmitted.

We could observe that during the diagnosis process, which can take about ten to fifteen minutes, workers must keep in mind not only the protocol to be followed in each case, but information like blood pressure values, current weight and height, eventual fever status, as well as patient history and values previously stored in their records – recovered sometimes electronically and sometimes on physical paper records.

During observations, we could also see that interruptions are common, as other professionals interrupt them to get information and sometimes they must go outside the risk assessment room to get information themselves. Talking with other workers in other teams is an important activity in risk assessment, especially because much information about patients are tacit and can only be obtained by talking to other teams that have previously given those patients assistance.

Interviews and observations let us infer that most information seeking occurs to make workers aware of as much aspects as they can about patients’ conditions, which are influenced not only by their current clinical status, but by the conditions of their families, and social conditions like employment, residence situation, safety, etc. Being aware of all these aspects without adequate support is very difficult, making awareness a very high demanding element in performing risk assessment. Attention is also a very high demanding element, as workers must be fully concentrated.

We could see that constant interruptions make it difficult to keep their focus on the evaluation of patients’ conditions and to all protocols that must be followed to evaluate patients’ clinical and social conditions. We must also point out the pressure that is imposed by the importance of correct diagnosis, which means life or death of patients as well as other problems as overcrowding of emergency rooms or increase on waiting times.

Table 5-8: Evaluation of the criteria "Organizational demands" with the EAMETA tool

	ORGANIZATIONAL demands					
	T1	**T2**	**T3**	**T4**	**Ergonomist**	**Score**
Time pressure	1	1	1	1	1	1
Division of tasks	5	5	5	5	5	5
Interruptions/Interferences	1	1	2	1	1	1.13
Cooperation	4	4	4	4	1	2.5
Procedures	1	1	1	1	1	1
					Average	**2.12**

Shift hours, interferences, and interruptions increase time pressure, as show in Table 5-8. The lack of standard procedures to perform assessments also increases organizational demands. The primary healthcare managers made some effort in establishing some procedures and protocols for risk assessment. However, they are not followed by all teams. During interviews, we could see some workers complaining about the lack of training on such protocols.

We could also notice that even when the team knows the protocols and procedures, some situations prevent them from applying such procedures, which makes them workaround. Only two evaluations (workplace area, for the space and cooperation, for the organizational demands) show discrepancy between the opinion of workers and result of the observation by the ergonomist. There hasn't been significant discrepancy among the opinions of workers either. In the case of the discrepancy in the workplace area criterion we could infer that workers are used to the size of the risk assessment room.

During field research we could notice that most rooms in the primary health care facility are the same size, so workers might be resigned about it. From our point of view the room should have more space, enabling workers to perform their tasks more comfortably. The discrepancy in the evaluation of the cooperation criterion might have a similar reason.

We believe that the fact that the workers must share important information with lots of other professionals without appropriate support, making them go outside of the room or being interrupted many times, is a harmful situation. However, the results of the EAMETA indicate that they don't see any harm in this situation. Observations of work situations were very important to capture and describe stressors, specifically cognitive ones which couldn't be diagnosed only by asking workers what they're feeling. To understand cognitive functions, we have to appreciate the context in which they are carried out.

Pre-diagnosis and Elicitation of the Ergonomic Needs

The risk assessment process is a sub-process of the primary care triage. Triage is the first contact between health care professionals and patients, and is the act of receiving and listening to patients' complaints. It is considered the fundamental process in performing primary health care actions. As part of triage, the purpose of risk assessment is to deepen the evaluation of demands that patients present to health care professionals.

Data collected during fieldwork indicated that bad risk assessments were mischaracterizing the primary health care system in the clinic where this work was carried out, as most of the assistance provided in the clinic was emergency care rather than preventive action. Primary care should prioritize preventive care and the promotion of health.

The results of the global analysis also indicate poor standards for risk assessment and difficulties that workers have in applying the existent protocols due to problems like variability, pressure, work overload etc. In this case, workarounds unsettle the risk assessment process. We could see during observations that similar patient conditions received completely different risk scores. This issue makes workers uncomfortable, as can be seen in the following testimonials:

- "When a patient is assisted by the nurse that made his assessment, we do not assign a color to him".
- "Sometimes I forget to assign a color and assist the patient anyway".
- "Sometimes we receive a patient complaining of a symptom and we are not aware that this is not his first visit, but rather a return to the clinic".

At the end of this phase, we defined the ergonomic needs as follows:

"The standardization of the risk assessment process, making criteria more visible, reducing the need of memorize data already available may minimize variations in activity

and the needs of performance adjustments enabling a more reliable application of the risk assessment and facilitating practitioners decision-making"

5.1.8.3 Operation Modeling

In the primary health care facility in which this study was carried out, risk assessment is performed by a team of two people (a nurse and orderly) in a once-a-week three hour shift. The Assignment of risk scores is performed according to the model suggested by the Brazilian Ministry of Health, in which colors are assigned to patients according to how severe their conditions are. This model is based on the Manchester Risk Assessment Scale (MANCHESTER TRIAGE GROUP, 2005), which was adapted to the Brazilian health care strategy, and can be seen in Figure 5-7.

Figure 5-7: Risk assessment color scale

Task Modeling

To describe the procedures and steps workers follow while performing the risk assessment, two teams have been observed and task flows have been built as shown in Figure 5-8 and Figure 5-9.

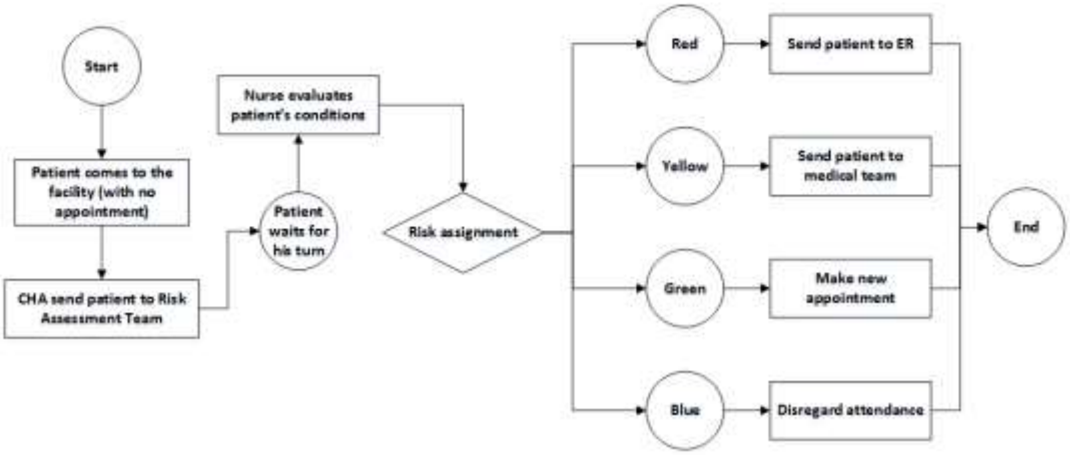

Figure 5-8: Risk Assessment Tasks

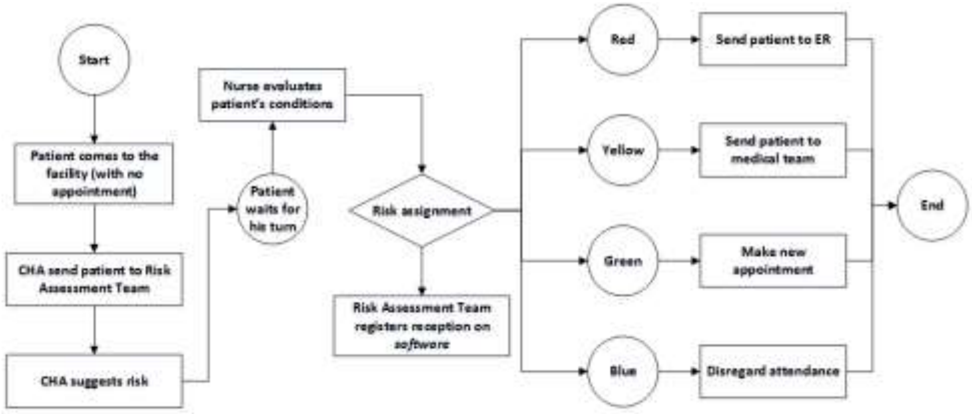

Figure 5-9: Variation on Risk Assessment Tasks

In Figure 5-9, we see that before waiting for his turn, the patient is previously evaluated by the Community Health Care Agent (CHA). Sometimes, after this evaluation, the patient is assisted by the team or sent home.

Concerning the activity of assigning risk to patients, variation also occurs. In Figure 5-10, we see a scenario in which a patient is presented to Team 1 with a set of symptoms and in the end is assigned the color Red.

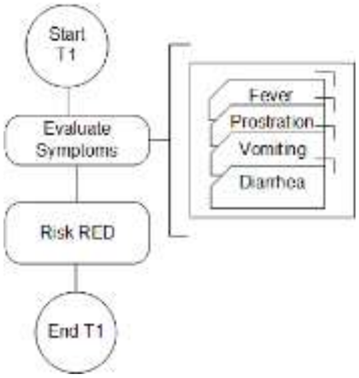

Figure 5-10: Assignment of Risk by Team 1

In Figure 5-11 we see the same symptoms being evaluated by Team 2 that, in this case, attributes the color yellow to the patient.

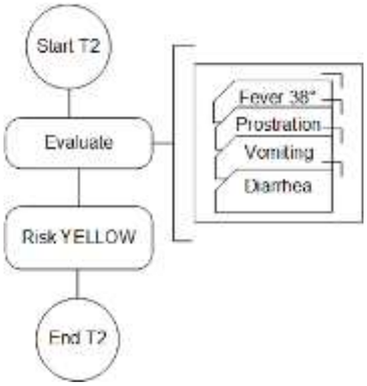

Figure 5-11: Assignment of Risk by Team 2

These cases illustrate how the process varies with context and scenarios, once it is impossible to predict all possible situations. In these scenarios, even though patients present similar symptoms, we could observe different contexts. Moreover, transferring knowledge across contexts is cost effective, since such knowledge may refer to training, procedures and regulations, and features of the work environment (PARUSH, KRAMER, *et al.*, 2012).

In our observations we could highlight that patients in the represented cases live in different locations, and in the case presented in Figure 5-10 the health care facility was not as crowded as in the case presented in Figure 5-11. Moreover, the two cases represent different teams, in different moments, thereby different situations.

Problems List

In this section we present the list of problems detected and described during the past phases of EWA. Each problem is entitled and related to collected evidence. In this paper we list in Table 5-9 three major problems related to the ergonomic needs – the reduction of unwanted variations of the risk assessment process, making criteria visible and their application more uniform, reducing the use of memory, and enhancing the possibility to use other cognitive resources.

Table 5-9: Problems list

Title	Description	Evidence
Lack of standard procedures	Although the clinic has established a set of protocols for risk assessment, they are hard to follow, especially by unexperienced workers. These protocols are related to the clinical practice or to the use of the risk assessment color scale.	Although managers state that the clinic has procedures for risk assessment (see Global Analysis in section 5.1.8.2) EAMETA indicates that procedures are not followed. Pre-diagnosis also shows testimonials where professionals state that procedures are not followed. Operation models show that sometimes variation in the reception process that affects the way risk assessments are performed. Moreover, we can see in activity flows that similar situations are evaluated differently. It could be not only a demonstration of the lack of standards, but also of variability (see section 5.1.8.3, figures Figure 5-8 to Figure 5-11).
Large usage of memory	Workers must remind the protocol for capture patients' conditions and, once conditions are captures, must remember the values of the variables related to such conditions. There are no tools to store those variables and workers make use of paper notes, post-its and other material to keep such information.	Testimonials collected during the analysis show that workers forget aspects of protocols sometimes (see Pre-diagnosis in section 5.1.8.2). Cognitive demands evaluated with EAMETA also show the large usage of memory.
Attention	Workers must pay attention to patients' conditions while being interrupted and coping with interference. As much of information about patient history and social conditions is tacit, workers must interrupt their work themselves to look for that information	EAMETA shows many interference and interruptions. Furthermore, it also shows that workers state that they have high needs of cooperation with other teams. Although we couldn't detect significant communication problems between teams, we could observe that it sometimes affect the level of attention workers have during their activities. Operation models show that situation (see section 5.1.8.3, figures Figure 5-8 and Figure 5-9).

From this list of problems we could propose a set of recommendations that aimed to mitigate their impact on work conditions, as we see in the following subsection.

Recommendations

Along with recommendations related to transformation of the physical space, new furniture and others, the development of a decision support tool with the features listed in

Table 5-10 have been submitted to the support group of the EWA as suggestions to mitigate workers' cognitive overload.

Table 5-10: List of recommendations

Recommendation	Features
Development of a decision support tool showing information about patients and option selection in assign risk scores	• As access to information about patients' conditions is not centralized, workers make decisions based on the information they collect by their own means. • An information system could gather the necessary information about patient's conditions, and display it properly to workers, helping them make decisions. The following aspects must be observed: • The decision support tool must enable the communication between risk assessment teams; • It must support the registration of the variables workers evaluate during diagnosis; • The tool must represent the workflow of risk assessment and its protocols; • It must be able to retrieve information on patient history. • It must incorporate the criteria of assignment of risk scores

In the following subsection we explain the possible improvements that could be accomplished with the implementation of an intervention project containing this recommendation.

Outline of possible improvements

As the result of EWA, complementing the list of problems and recommendations, we presented a set of assumptions about achievable work improvements to the support group, as shown in Table 5-11:

Table 5-11: List of achievable improvements

Reduce usage of memory	Variables and respective values should be stored and retrieved from the system and workers won't have to keep them in mind.
Stabilization of the risk assessment process	As the information system should represent the risk assessment workflow it will be more difficult for workers to perform the risk assessment their own way.
Reduce tacit information flow	Data collected during communication between teams can be registered and incorporated to patient's history, becoming explicit information
Help using the risk assessment protocol	The information system will incorporate the criteria that the clinic's managers have determined as a protocol for the assignment of risk colors to patients. This increases the stabilization of this process and help workers apply such criteria, specially the inexperienced ones.

The discussion and validation of those results are presented in the next subsection.

5.1.8.4 Validation

Among all presented problems, clinic managers have not recognized the one entitled "Lack of standard procedures". They state that the clinic has made many staff meetings to discuss procedures and rules and that many protocols are inherent to clinical practice. However, they agreed that less experienced professionals have more difficulties in following protocols and that the clinic does not have verification procedures to assess how those protocols have been effective.

Thus, it was common sense that an information support system could incorporate the risk assessment protocols. This could reduce the gap between the performance of experienced and novice professionals. The support system may also improve cognitive performance, reducing the need to memorize information already available, and managers' worries about how the protocols have been followed or not.

Regarding how the information system could support decision-making, the EWA support group state that the risk assessment is accomplished taking into account many chaotic variables. Thus, we agreed that any support algorithm must consider the opinions of experts and variations in the activity itself.

Moreover, regarding the retrieval of information about patient's conditions, members of the support group agreed that there is much tacit and dispersed information, but argued that the most important information is centralized and retrieved by the current information system, although its displays may not be suitable to the operation.

We agreed that the future information should provide multiple visualisations of the information in order to increase suitability, although the implementation of these kinds of displays imply some cognitive costs as well (JUN, LANDRY e SALVENDY, 2013), affecting human performance especially in safety-critical systems (DING, LI, *et al.*, 2015). Moreover, the new system interface must represent the constraints of the work environment in a way that people who use it could clearly perceive them (BURNS e HAJDUKIEWICZ, 2004; VICENTE e RASMUSSEN, 1989; RASMUSSEN, 1986).

5.1.9 Discussion

There were three core findings from this study. First, that context can have a significant effect on decision-making. Second, high information requirements can add significantly to demands. Finally, we found the EWA was a useful approach to identify these problems and to generate ideas to help redesign future support tools.

Context effects decisions: In our case study, we could highlight the importance of the context in the way health care workers make decisions. For example, how crowded the facility is influences the perception the health care team has about patient’s conditions and, subsequently, in the risk score the patient will be assigned. Furthermore, integration of health care service systems depends on the quality of coordination processes and efficient communication among workers, as well as communication between workers and patients (NYSSEN, 2011).

High information access requirements add demands: Results also demonstrate that the retrieving of information about patients is high demanding to workers. There is a large amount of documents to be retrieved on each patient reception, and workers must deal with lots of information on a computer screen and paper, as well as seek for information from other teams, most of the times transmitted verbally. The combination of environmental and contextual settings, information retrieving, and patient examination is a large set of issues that workers must be aware in order to assess patients’ risks. This entails the increase of the probability of inadequate assessments, waste of resources, and harmful situations.

EWA was an effective method to identify redesign points: To support the design of new support tools, the EWA approach highlights points of tension in work performance, i.e., elements in work situations that cause harm or discomfort for workers. This element is important in the extent that it helps delimiting the boundaries of the intervention, that is, which parts of the work situation should actually be transformed or supported.

Moreover, as the EWA approach can be combined with other work analysis frameworks and processes, as it provides important incomes to initial design phases. The results of the EWA, rather than simply providing a list of factors that should be considered in the design, provided descriptions of interactions between the elements of the system as a whole, which enables a human-driven approach to design. Systemic approaches like EWA facilitate understanding the domain and identification of the problems considering diverse points of view. The capability of comprehending problems assumes sensitivity to particularities of the context and readiness to acquire knowledge from domain experts (NORROS, 2014).

A concern presented by the support group during validation sessions is that no matter how sophisticated the technological support may be, the final decision must be made by the health care professional. This could denote that health care professionals distrust technological support to automatize or as substitute of humans in their activities. However, the technological support can be used in way to facilitate work augmenting action possibilities and inserted in the work environment as naturally as possible.

Although there has been some effort by software experts in involving users in the development of health care information technology, this has not been enough to ensure proper understanding of the users' needs and many failure cases remain. Thus, the participation of ergonomics and human factors specialists can be useful to reduce the distance between users' expression of their needs and the proper formalization of requirements for design purposes (NIÈSA e PELAYO, 2010).

Furthermore, the way professionals interact with the new system must not be too different than the way they interact with other tools. We suggest that an ecological approach should be adopted in the design of the interface of the decision support tool, as the organization and presentation of information are essential in designing displays for safety-critical system.

Although during validation sessions professionals had agreed that workers could take advantage of multiple visualizations providing different perspectives on the data, there are also some costs associated to this kind of displays. It involves design costs (i.e. additional computation time to render views), spatial and temporal harms of presenting multiple views, and cognitive costs like learning time.

5.1.10 Conclusions

Health care workers' rules, mental models and use of clinical information are much more complex than meets the eye. Although some repetition of tasks can be noticed, there is enormous variability, as occurrences always have different characteristics. These factors demonstrate the great cognitive effort of health care workers while performing their activities and how critical the decisions made in such environments are.

The application of EWA during field work in a primary health care facility in Rio de Janeiro, Brazil, let us highlight a set of problems in the risk assessment process, a decision making process in the family health care strategy which imposes high cognitive effort to workers due to its complexity and criticality.

Moreover, the major recommendation to improve work situations was the development of a decision support tools. We must emphasize that the computerization of work processes without considering workers' current information requirements produces gaps between workers and their devices. When developing support tools, information technology professionals must be aware of the variables and constraints involved in such complex work in order to design and implement tools that reduce cognitive effort instead of increasing it (JATOBA, CARVALHO e CUNHA, 2012).

EWA results pointed out that risk assessment workers have to remember a large set of variables, protocols and tacit information, and such situation must be mitigated. However, more specific cognitive engineering techniques may be applied to deepen the analysis and result in more detailed work descriptions, as decision making in such settings is difficult.

Therefore, we suggest that future work could bridge the gap between EWA and the design of support tools both in the human factors and software engineering area, or bringing together elements of both areas to result in information systems that meets the needs of workers in complex systems like health care.

5.2 Article 2: Contributions from Cognitive Engineering to Requirements Specifications: a case study in the context of health care

5.2.1 Foreword

This chapter aims at presenting a case study on the use of human factors and ergonomics to enhance requirements specifications for complex sociotechnical systems support tools through the increase of the understanding of human performance within the business domain and the indication of high-value requirements candidates to information technology support.

This work uses methods based on cognitive engineering to build representations of the business domain, highlighting workers' needs and contributing to the improvement of software requirements specifications, employed in the health care domain.

As the human factors discipline fits between human sciences and technology design, we believe that its concepts can be combined with software engineering in order to improve understanding of how people work, enabling the design of better information technology.

This chapter resulted in one scientific article, with the following citation info:

Jatoba, A., da Cunha, A.M., Burns, C.M., Vidal, M.C., de Carvalho, P.V.R. (in press). The role of human factors in requirements engineering in health care: A case study in the Brazilian health care system. *Human Factors and Ergonomics in Health Care, vol 4, no. 1, 6-11*. doi:10.1177/232785791504100.

5.2.2 Introduction

Failures in software development projects are usually related to the misunderstanding of client needs and desires, or inappropriate knowledge about the domain. Although requirements documents, architecture models, and design descriptions are effective deliverables in most software engineering processes, ensuring IT projects meet their technical requirements still remains difficult (DERAKHSHANMANESH, FOX e EBERT, 2013).

If we consider the context of health care, effective evaluations of health care information systems are necessary in order to ensure that systems adequately meet the requirements and information processing needs of users and health care organizations (KUSHNIRUK e PATEL, 2004).

To improve requirements specifications in situations with high cognitive workload, we believe that software engineering can benefit by using concepts of human factors and ergonomics, which fits between human sciences and technology design and brings techniques to improve the understanding of how people work, by providing services and tools that can be used to conceive better IT.

Human factors and ergonomics are recognized as a discipline that enables the redesign health care systems in order to accomplish better quality of care. Thus, our research presents a case study on the application of human factors concepts to enhance software requirements specifications, making contributions to the design of IT.

5.2.3 Research Problem and Objective

According to the 2012 Standish Group's[1] CHAOS Report (THE STANDISH GROUP, 2013), there has been an increase in software development project success rates in comparison to the previous two years, but the failure rates of projects (that is, projects cancelled prior to completion or delivered and never used) and the number of challenged projects (projects that are late, over budget, or contain less than the required features and functions) are still very high.

As can be seen in Figure Figure 5-12, failure rates in 2012 were at 18% while challenged rates reached 43%. Notably, there has been a slight increase in both cost and time overruns. Cost overruns increased from 56% in 2004 to 59% in 2012, as can be seen in Figure 5-13.

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[1] The Standish Group is a privately held company that evaluates risks, value and failure rates in IT projects performance. It is responsible for the CHAOS Report, a biannual evaluation of software development projects.

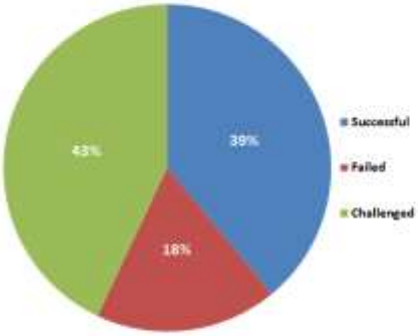

Figure 5-12: Software development projects resolution according to the 2012 CHAOS Report

The development of features (i.e., sets of related requirements, domain properties, and specifications that allow users to satisfy a business objective or need (ROBERTSON e ROBERTSON, 2006; CLASSEN, HEYMANS e SCHOBBENS, 2008)) went down, with 69% of specified requirements completed, in comparison to 74% in 2010. This suggests that organizations are focusing on high-value requirements rather than completing 100% of the requirements. Similarly, when looking at software products' features (as opposed to requirements), we can see in the CHAOS Report that it seems that 20% of features are used often, while 50% of features are hardly or never used.

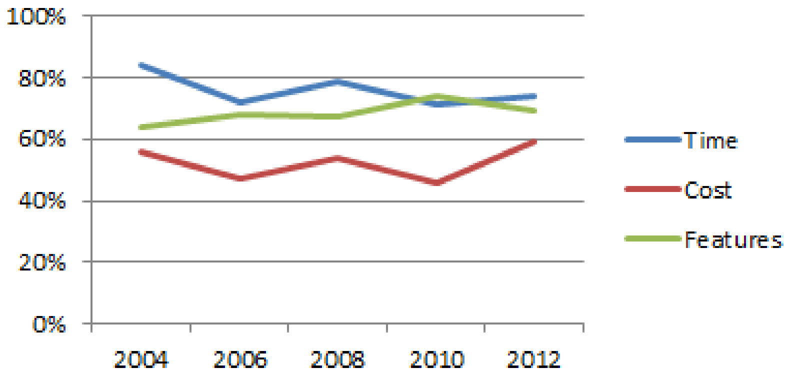

Figure 5-13: 2012 CHAOS Report Overruns and Features

These numbers support the idea that effective requirements engineering remains the most difficult task in developing software. Focusing on the 20% of features that provide 80% of the value of the software could maximize investment in software development and increase user satisfaction (THE STANDISH GROUP, 2013). The main question, then, is how do we determine which requirements or functionalities provide the most value? This situation leads us to the following research problem:

- How to find high-value requirements and improve quality of information about work performance in order to enhance software requirements specifications, making them more reliable, reducing failure in IT projects, and enabling the design of more suitable software to support people's work in complex systems like health care.

The premise of sociotechnical thinking is that systems design should be a process that considers social and technical factors that influence the functionality and usage of computational systems. The misuse of human factors and sociotechnical approaches can increase the risk that systems will not reach their expected objectives (BAXTER e SOMMERVILLE, 2011; LAUGHERY JR. e LAUGHERY SR., 1985).

The volatility and unpredictability of the operational environment; the heterogeneity, autonomy, and uncontrollability of participating actors; and the social dependencies that emerge between participating actors are important factors that must be considered in design (DALPIAZ, GIORGINI e MYLOPOULOS, 2011; KARWOWSKI, 2012).

Due to these characteristics we cannot expect consistent, complete, understandable, verifiable, traceable, and modifiable requirements. In other words, the idea that requirements can be characterized by traditional attributes is no longer valid (KATINA, KEATING e JARADAT, 2014). Thus, in order to address this problem, the objective of this paper is stated as follows:

- Present a case study in the context of health care to demonstrate how the human factors discipline can contribute to the design of more suitable IT for complex systems by enhancing software requirements specifications.

We believe that the case study presented in this paper contributes with the design of computer-enabled work support for complex systems as it meets the following challenges:

- Increased understanding of the problem: the approach presented delimits scope and boundaries of the system and describes details about the problem domain;

- Determination of high-value requirements: focusing on the definition of key processes and high cognitive workload activities, we propose ways of indicating major candidates for technological support, and techniques to determine proper requirements specifications by identifying human performance concerns and using them as drivers of the requirements elicitation process;
- Increased reliability of requirements specifications: through work analysis, the approach proposed in this paper helps avoid lack of user input, a common issue on challenged projects (THE STANDISH GROUP, 2013), and unspoken or assumed requirements. It recognizes workers as domain experts, increasing user confidence that the system will meet their needs;
- Structured representation of information: the ability to represent information in a structured form is often seen as a prerequisite for processing it in software (WEBER-JAHNKE, PRICE e WILLIAMS, 2013). In complex sociotechnical systems the information is distributed among many spaces and agents, making modeling difficult. The approach we propose in this article embeds tools to build descriptive models of how the sociotechnical system actually behaves.

Concepts and methods are needed that are capable of tackling the functions of a complex system in detail. From this perspective the technological and human elements become automatically inseparable, and technology should be seen as a tool that people take advantage of in their various activities (NORROS, 2014). If we want to support complex work, real world knowledge of the complex work world needs to be obtained to efficiently design appropriate information systems, as organizations require knowledge to be easily accessed and shared in order to cope with work effectively (GREENSPAN, MYLOPOULOS e BORGIDA, 1982; WANG e CHEUNG, 2015; COLOMBO, KHENDEK e LAVAZZA, 2012).

5.2.4 Research Questions

Sociotechnical systems are a complex interplay of humans, organizations, and technical systems that must satisfy the requirements of multiple stakeholders. Complex entities adapt in a changing environment as its properties also work as single entities. These emergent properties make the entity as a whole more than the sum of its parts. Moreover, in order to provide work support, one must first understand the nature of the system that will be supported, since the way we see the system defines what it counts to support it (CHECKLAND, 1999).

Thus, the design for complex systems like health care must emphasize the interactions between the systems properties, even though the satisfaction of requirements depends not only on the independent performance of the individual subsystems but also on the success of the interaction among all subsystems. It’s virtually impossible to reduce the system’s parameters and features without losing global functional properties (AYDEMIR, GIORGINI e MYLOPOULOS, 2014; PAVARD e DUGDALE, 2006).

Therefore, the research topic of this paper addresses what concepts, tools and techniques the human factors discipline provides for indicating high cognitive-demanding work situations, building representations of human work, and increase knowledge about the domain in complex sociotechnical systems. By addressing this topic, we believe we will be able to answer the following research questions.

- How the design of computer support for complex work situations can be more effective and result in more adherent, robust, and resilient software solutions?
- How can software engineers enhance their requirements specifications in order to design better IT for complex systems?

Although improving the physical design of a medical device or the cognitive interface of health IT is important, without understanding the organizational context in which technology is used, workers may develop workarounds, making the tools unsafe, ineffective, and not useful.

5.2.5 Material and Methods

In this paper we suggest an approach to handle variability and cope with emerging factors in work performance in complex situations to build more accurate representations of the resulting system behavior. The approach we propose in this paper helps transform informal knowledge into formal representations in the early stages of requirements engineering, increasing the completeness of specifications. The approach is divided into three phases, which can be split into steps, as shown in Figure 5-14.

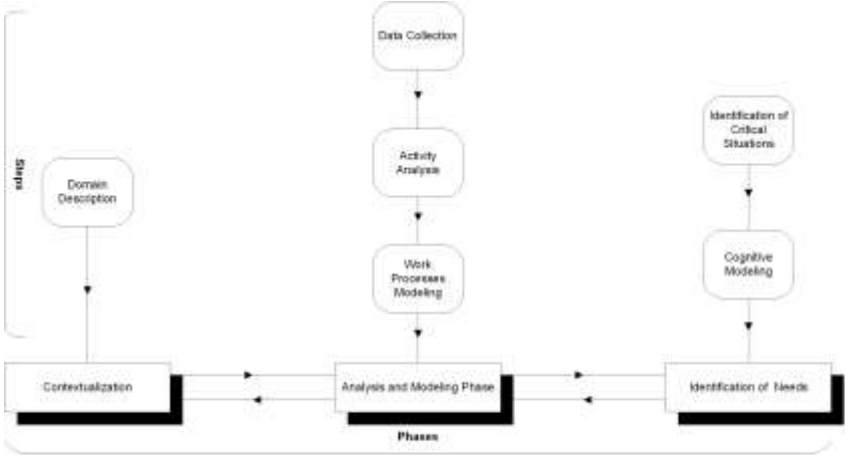

Figure 5-14: The proposed method's structure

Usually, people involved in the beginning of the requirements engineering process have many roles, experiences, and expectations. Thus, each person has a personal view of how the software should perform. Many informal representations are used in the initial stages of requirements engineering in order to express the variety of views about the system.

Though informal representations have some advantages (they are usually based on natural language, they are well known because they are used in daily life, etc.), they can be dangerous, as they sometimes generate discrepancies on specifications and present opaque views of how the software should work, especially in complex sociotechnical systems, which rate highly on uncertainty, variability, and are hard to describe completely (POHL, 2013).

It is also important to consider that some professionals are not necessarily advanced computer users, especially in complex sociotechnical systems like health care. As a result, the development project has to consider expert and novice users, and must seek to reconcile their points of view. Requirements analysis in conventional development practices usually assumes a use case-based approach, which tends to focus on user interaction with the software without analyzing the details of user work (SUTCLIFFE, THEW e JARVIS, 2011). This can make the conciliation of multiple stakeholders’ points of view difficult and result in incomplete requirements specifications.

The problematic nature of changing requirements is another issue potentially increased by aspects of complex sociotechnical systems. In complex environments, in order to make the IT system satisfy its goals, and to determine what could be expected during the software’s lifetime, designers must be able to anticipate emergent behaviors of the system and its components (JARKE, LOUCOPOULOS, *et al.*, 2011).

The phases of the approach must be performed iteratively (i.e., it is not necessary to complete a step for the next one to begin). The number of iterations at each stage is not determined, and, in this paper, we show the results of the completion of each phase.

5.2.5.1 Contextualization Phase

The objective of this phase is to gather initial knowledge about the organization. This knowledge should describe the work environment and make aspects of that environment, such as its influence on people’s work, comprehensible, as well as define key work processes.

The concept of key business process in an organization is the complete set of activities that are executed to receive the customer order, build the product or service, deliver the product or service, and receive the payment that corresponds to the product or service (CUNHA e COSTA, 2004).

The contextualization phase comprises a single step, called *domain description*, in which the expected result is the identification of essential characteristics of work, such as services provided, customer profiles, and a listing of operators, and the organization of that work, including leading labor relations and team structures.

In order to perform this phase, analysts should formulate a plan to gather general domain information using contextual inquiries in order to find out interpersonal dimensions in cross-functional teams (BEYER e HOLTZBLATT, 1998). This phase is focused on making explicit things that designers usually do implicitly, like gathering informal data about how workers perform their tasks or talking to professionals while they work to gain visual information about their performance.

The first thing to do is to set the scope of the analysis. IT projects tend to be business-driven (i.e., focused on the needs of the client, or what the client believes their needs are), and usually center on immediate problems, such as client feelings (BEYER e HOLTZBLATT, 1998). Thus, this step should include conducting interviews and collecting artifacts, such as the documents, regulations, and tools people use while performing their work.

The results of this phase can be materialized into diagrams, maps, plans of physical space, field notes, etc.

5.2.5.2 Analysis and Modeling Phase

Modeling is important to improve certain properties of the product, such as quality or maintainability, or of the processes, such as cost-efficiency and predictability (FRANCE, RUMPE e SCHINDLER, 2013).

The goal of this phase is to describe and then represent work in the organization. This will be achieved by collecting and analyzing data in the field and building process models to represent the basic structures of people’s work. This is the beginning of the design stage and during this phase, the analyst should shift focus from the system to understanding how the work is really performed.

There has been significant effort in simplifying the constructions of models or eliminating the need for learning a modeling language. However, this comes at the cost of limiting the task displays and controls that can be modeled to a limited set of tasks and processes, which lack the capabilities required for modeling complex cognitive tasks such as learning, decision making, and sentence comprehension and the confusion generated by discrepancies between human performance and model tests (CAO e LIU, 2012).

As the key processes and their objectives have been discovered in the domain description, what professionals do to achieve those objectives is described as their work. Steps and the expected results of this phase are described in the next subsections.

Data Collection Step

Data collection is expected to result in a set of field notes containing details about the organization and its work strategies. Data collection is achieved by interacting with, and observing the behavior of, workers through conversation, interviews, and the collection of artifacts used in performing their tasks.

Its major input is the domain description, used to identify the operator roles that should be observed. In addition to the professionals involved, clients can also be observed in order to deepen knowledge about them and properly identify user demands.

Activity Analysis Step

The activity theory and concepts (ENGESTRÖM, 2000) has inspired this step. Activity analysis aims to find the constraints and contradictions, which emerge as a result of tensions within or between the elements (object, rules, subjects, tools) of an activity system. Therefore, this step should provide elements about how workers think while performing tasks. Thus, its results should be important in describing the execution flow, the skills and competencies employees should possess, and the tools employees must use to accomplish their tasks.

In the health care domain such contradictions manifest in the form of deviations from standard scripts, thereby threatening its coherence and, sometimes, making task performance inadequate. According to Engeström, although activity systems are driven by a deeply communal motive, they are inherently contradictory. However, in order to achieve the goals/objectives of the activity people must find ways to resolve contradictions using the available resources, which in many cases are not designed accordingly.

Activity analysis step was based on direct observation of work activities and on Cognitive Task Analysis (CTA) techniques used for knowledge elicitation of workers. It aims at helping analysts to express and represent knowledge in a way that others can understand, and such representations will be discussed and validated during the next steps (CRANDALL, KLEIN e HOFFMAN, 2006).

The results of this phase are presented by concept maps as seen in Figure 5-15. Concept mapping is a procedure for knowledge elicitation that can be conducted with individual workers or with small groups of domain practitioners (CRANDALL, KLEIN e HOFFMAN, 2006).

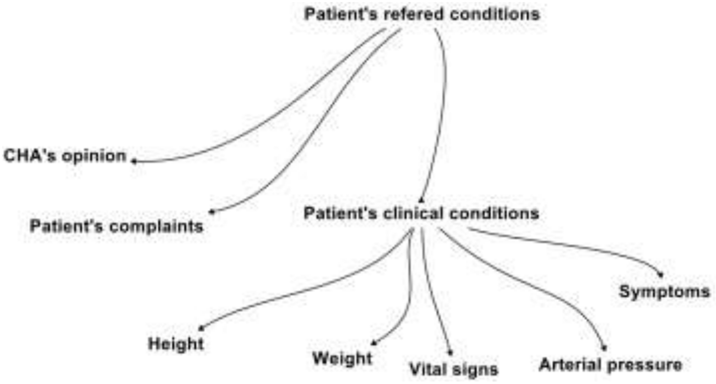

Figure 5-15: An example concept map

This step provides a visual interpretation of workers' mental states, their "states of knowledge", as they work. This information will be important in the cognitive modeling step. Once these results have been produced and reviewed, the modeling step can be performed, as will be demonstrated in the next subsection.

Work Processes Modeling Step

A process is a set of structured activities and measurements that should result in a specific product for a particular customer or market. Describing work processes requires emphasis on how work is done within the organization, instead of focusing on determining what the organization produces (DAVENPORT, 1994). This definition can be viewed as an operational one, although it serves as a basis for workflow-based approaches (BIDER e PERJONS, 2014).

In this step, we try to describe a process by defining its boundaries. The initiation boundary of this particular process is characterized by an activation message sent by an external entity called a starter. This message can load the work process with the necessary inputs for its effective start. The completion boundary of the process is characterized by the transmission of closing messages. These messages provide the customer with the results of the work process (CUNHA e COSTA, 2004).

A process is described when its boundaries are fully identified (i.e., when all types of customers, all types of starters, all types of triggers, all types of inputs, all types of closures, and all types of results have been determined). If any of these elements has not been identified, the work process is not correctly set.

Consisting of logically linked activities, process models built in this step should demonstrate the results of each process the organization performs. Therefore, each process activity must have its inputs and outputs properly identified. If an activity does not have these elements properly identified, it is not a viable activity; thus, it is a candidate for elimination and may be disregarded (CUNHA e COSTA, 2004).

The notation we adopted to build the diagrams is similar to the one established by the Object Management Group (OMG) with the Business Process Model and Notation (BPMN).

The primary goal of BPMN is to provide an understandable notation for creating models that can be read by business analysts who create the initial drafts of the processes, developers who are responsible for implementing the technology that will perform the processes, and business people who manage and monitor the processes. Thus, BPMN creates a standardized bridge for the gap between business process design and process implementation (OBJECT MANAGEMENT GROUP, 2011; LÓPEZ-CAMPOS, MÁRQUEZ e FERNÁNDEZ, 2013). Basic elements of BPMN can be seen in Figure 5-16.

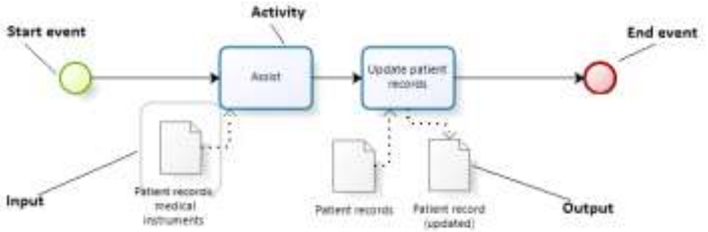

Figure 5-16: The basic elements of Business Process Management Notation

In order to support workers by providing them with skill-enhancing computerised tools, the work process must be seen as the primary element and users must be made partners in the development of systems. Thus, users are enabled to help discover knowledge gaps and make suggestions on how their work could be improved. This involves commitment and mutual dialogue between users and designers to acknowledge each other’s competencies and inadequacies (MARTI e BANNON, 2009).

5.2.5.3 Identification of Needs Phase

As the goal of this phase is to provide recommendations of technological support for specific activities or sub-processes within the organization, ergonomic approaches are useful in that the design of work systems necessarily make some assumptions about the nature of individuals, since the human work is often not replaced (HOLLNAGEL, 1997; MAYER, ODENTHAL, *et al.*, 2014).

Building on the process models created in the analysis and modeling phase, the identification of needs phase must report a set of work situations that could be enhanced through the use of information systems. After these situations have been identified, they should receive further cognitive modeling.

Identification of Critical Situations

Critical situations are those related to cognitive or environmental constraints on work performance. Cognitive constraints are work demands that originate with the human cognitive system, like workers' subjective preferences, mental models, or experiences. Environmental constraints are work demands that originate from the context in which work is located, such as the social or cultural reality of the workplace, which does not depend on what workers might think about it (VICENTE, 1999).

The expected result of this step is to highlight a set of activities - or groups of activities - in the work process models that should be assisted by IT. These activities are called *candidates*.

Vicente's CWA framework does something similar when it indicates the c*ontrol tasks* to be modeled. Although the analysis of these control tasks is unable to identify specifically which technological support the work process needs, it allows analysts to identify high-value requirements and constraints associated with the work to be performed. In this paper we suggest the following criteria to choose candidates:

- Complaints: situations in which workers' complaints are many and compelling;
- Consequences: situations in which the events exert greater consequence on professionals;

- Centrality: situations that depend on many others;
- Modernity: situations that require urgent modernization;
- Stability: situations that are variable or ephemeral and remained so throughout the study.

Cognitive Modeling

Cognitive modeling is an approach to cognitive science that emphasizes building representations of cognitive theory applied to human work. Cognitive models represent human capabilities and limitations and their influence on task performance.

A general premise of cognitive models and a cognitive approach for man-machine interaction is that the human being can be seen as an information processor or an input/output system. As with software models, cognitive models are simplified representations built to predict and understand a particular phenomenon.

The models produced as a result of this step should represent structural and functional conditions that retrieve the information used throughout the human cognitive process. For example, the amounts of information workers receive and use to perform their tasks, or situations that should be perceived so that a certain mental or cognitive action can be performed.

To achieve this level of representation, we adopted tools and methodologies recommended by Vicente (VICENTE, 1999) in the Control Task Analysis phase of his CWA framework: the Decision Ladder (DL) (RASMUSSEN, 1976; RASMUSSEN, 1986), which describes what tasks must be done to achieve the final purposes of the work domain. DLs are comprised of information-processing activities and states of knowledge. Information-processing activities are the cognitive activities that workers should perform to complete a task; states of knowledge are the outcomes of these activities (VICENTE e RASMUSSEN, 1989).

In the DL notation, information-processing activities are represented as boxes and states of knowledge are represented as circles. Directional arrows are used to represent relations between elements in the model. These relations can be *shunts*, which connect information-processing activities to states of knowledge in non-sequential order, or *leaps*, which represent links between two states of knowledge.

The elements of the model are disposed in alternating order according to the progression of the task. The basic structure of the DL is shown in Figure 5-17.

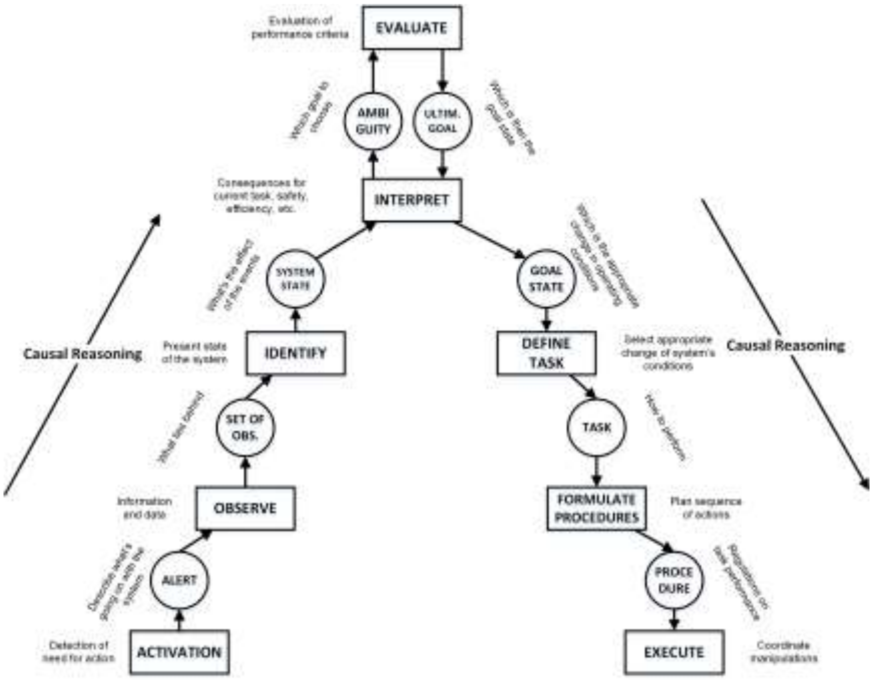

Figure 5-17: Basic structure of Rasmussen's Decision Ladder

The DL is flexible enough to describe how professionals behave, allowing analysts to identify shortcuts that can induce more skilled performance. It should be noted, though, that DL is not itself a model, but a template that represents the basic structure of the model (VICENTE, 1999) – like a meta-model.

5.2.6 Results

In this paper we present a case study in the context of health care. Health care information systems design that does not address cognitive, cooperative, and organizational aspects can introduce new forms of complexity. This problem space provides a good testing ground for our ideas as it involves the following:

- Uncertainty: providing care does not relate only to performing routine procedures as unpredictable scenarios happen frequently. As a result of this uncertainty, workflows are dependent on the context of the problem at hand.

- Variability: many symptoms are qualitatively assessed or rely on patient reports, which can be highly variable. More quantitative measures, such as imaging and diagnostic tests, can often be interpreted in different ways.
- Interdependency: in the health care system, people (i.e., patients, physicians, nurses, and others) and technology (e.g. labs, decision support, and electronic records) cooperate and exhibit emergent behaviour.

Information and information exchange are crucial to the delivery of care on all levels of the health care delivery system—the patient, the care team, the health care organization, and the encompassing political and economic environments. However, most health care technology investments have concentrated on the administrative side, rather than on clinical care, resulting in little progress toward meeting the actual needs of patients, providers, medical facilities, and addressing the regulatory, financial, and research environments in which they operate (REID, COMPTON, *et al.*, 2005). Fieldwork was carried out in a primary health care facility in Rio de Janeiro, Brazil, for 142 hours, as shown in Table 5-12.

Table 5-12: Research effort

		Sessions	**Time**	**Total**
Interviews	**Administration professionals**	4	1 h	4 h
	Health care professionals	12	30 min	6 h
Observation	**General**	10	2 h	20 h
	CHAs	15	4 h	60 h
	Nurses & orderlies	5	4 h	20 h
	Dentists & Assistants	1	2 h	2 h
	Home visits	4	4 h	16 h
Validation		6	30 min	3 h
Deepening		3	3 h	9 h
Total				**142 h**

The field research has been carried out in accordance with the ethics precepts established in resolution nº 466/2012 of the Brazilian National Health Council/Brazilian Ministry of Health on research related to human beings, and has been approved by the ethics committee of the Sergio Arouca National School of Public Health/FIOCRUZ, Rio de Janeiro, Brazil.

Interviews have been carried out with the following professionals:

- Administration professionals: general manager, assistance manager, continuing education manager, and administration officer
- Health care professionals: two physicians, three nurses, 10 CHAs, and two orderlies
- Health care professionals have been interviewed both individually and in groups, in a non-structured manner, for no longer than 30 minutes each.

General observation is related to time spent in the clinic's lobby, where we could observe the way professionals relate to patients inside the facility. In these observations we could also describe aspects of the physical space, equipment, territory, etc.

No physicians could be observed during appointments due to medical ethics regulations. However, doctors could be observed during medical visits, along with the rest of the health care team.

5.2.6.1 Contextualization Phase

The execution of this phase resulted in details about the operation of the facility, the scope of the health care and work organization, as well as a brief description of the information systems that workers regularly use. The contextual inquiries and the discussions in the interview sessions were based on guide questions, and presented the results shown in Table 5-13. The answers given are testimonials from workers. For this phase, four professionals were interviewed: the general manager, the assistance manager, the continuing education manager, and the administration officer.

Table 5-13: Results of the Contextualization phase

Guide Question	Answer	Additional material
What is the geographical area served by the facility?	"We cover the district of [RESERVED], divided in four areas, each one with approximately 4,000 people" "There are plans of expanding the coverage to three or four extra areas" "I don't know for sure the dimensions of the	Maps

	covered area in this district, but the clinic has 5,000 m^2”	
What are the services offered by the health care facility?	General medical appointments (Pediatric, Obstetric, Dermatologic, etc.); Dentist; Clinical exams; Medicine supply; Vaccines; Monitoring of chronic patients	Internal policies, Regulation documents
How many people are living in the serviced area?	“Approximately 22,000 people” “We perform almost 40,000 medical visits and 11,000 medical appointments per year”	Field notes
How are teams organized?	“We have five teams, each one providing care to one area with approximately 5,000 people” “Each team has: an M.D; a Nurse; two Orderlies; a Dentist; a Dentist assistant; 6 Community Health care Agents”	Maps of each area; Regulations regarding Family Health care teams
How does the facility building reflect the organization of work??	“The building has the following rooms: Lobby; 11 medical offices Three dentist offices; One pharmacy; One vaccination room One procedures room One room for the collection of exams material; One meeting room; One management office; One health care agents’ office.”	Clinic’s floor plan
What information technology is currently used in the facility?	“We use two software. One is old and will be discontinued soon. The other one is being tested” “The new software has all patients’ records.”	Observation of software during use
How is this information technology used by workers?	“We use the old software to confirm patients’ data during registration, but once these data are in the new software, we don’t have to use it anymore.” “To each patient’s reception, we have to use the software to obtain medical records. Once an appointment or a medical visit or any other procedure is performed, the software must be updated.” “The software doesn’t really support our procedures, but should provide information to help us.” “We use the software to gather information about the number of receptions performed. This information will be passed to the Ministry of Health and it’s related to our funding.”	Observation of software during use; Regulations regarding Family Health care funding; Regulations regarding Family Health care work processes

The most important clue provided by the results of this phase reveals the purpose of family health care: to provide preventive health care services to families in delimited territories. According to its regulations, the clinic gets funding from the Ministry of Health to operate in a determined geographic area. Its operation is based on a set of health care actions (in peoples' homes or in the clinic), which we called *reception*.

This process could be seen in two levels. The first, and highest, level addresses how the clinic becomes operational (i.e., the government decides that a specific area needs family health care for reasons included in primary health care policies). At this level, we can consider the starter of the reception process to be the government when it deploys the family health care strategy.

The second level addresses the assistance of patients after family health care has been deployed and the clinic is operational. At this level, the starter of the reception process is normally an event: the needs of a particular family, the schedule of a FHS team, a patient attending the clinic spontaneously, etc. Figure 5-18 illustrates the reception process, its starter, and the expected result. According to the data we collected, the reception process is the only key process in this phase. No other key process was discovered.

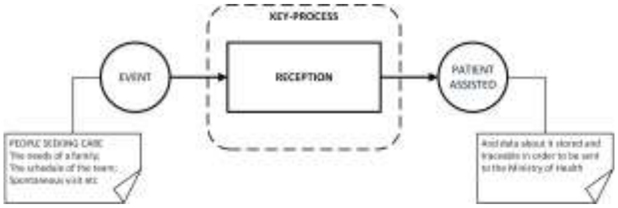

Figure 5-18: Definition of the Key process and its boundaries

5.2.6.2 Analysis and Modeling Phase

The following subsection shows how the analysis and modeling phase has been performed and what results have been obtained. As only one key process has been defined, reception will be analyzed and modeled. While performing this phase, we must keep in mind that the reception process begins with an event and ends with the patient being assisted. The contextualization phase has provided high level aspects of these boundaries, which will be deepened in this phase.

Data Collection Step

The entire observation has been conducted in a non-participatory way, without interfering in work performance. In the time between observations, workers have been interviewed in order to answer questions and establish further details about how activities were performed.

Aspects of the patient/clinic relationship have been highlighted, such as how patients arrive and enter the facility, how they collect passwords for assistance, how they are accommodated in the clinic lobby, and the path that they follow from the entrance of the facility to the attendance room.

Thus, the work process and all its activities have been described, as well as inputs and outputs of each activity in the process, and the artifacts used for the process in its entirety.

The storage media of the artifacts workers use have been described and classified according to volatility, that is, the durability of the information container. For example, it has been registered whether the artifacts remain stored as historical data or if they are destroyed after use. Table 5-14 shows data on Community Healthcare Agents (CHA) collected in the first observation iteration.

Table 5-14: Data collected in the first observation of the Community Health care Agent

Actor	Activities	Artifacts
CHA 1	Get patient records: go to the archives and get patient's profiles and medical records (it happens once a day) Call for patient: according to the passwords shown in the panel, patients are called Register reception: received patients have their attendance registered in the Reception records Schedule visit	Patient records (SGBD)[Persisted] Reminders (Paper)[Destroyed] Reception records (Paper) [Stored] Exam application (Paper) [Stored]
CHA 2	Get patient records: go to the archives and get patients profiles and medical records. He picks the records up when each patient comes to his booth. In this step, the CHA verifies if the patient is registered or not. Call for patient: according to the passwords shown in the panel, patients are called Schedule visit Update patient records	Patient records (SGBD)[Persisted] Reminders (Paper)[Destroyed] Reception records (Paper) [Stored] Exam application (Paper) [Stored]

In this step we did not describe relations between activities and specific artifacts or the flow of activities, we described the roles played by each actor and highlighted elements that will be detailed in the next steps.

Activity Analysis Step

To execute this step, some rules have been followed:

Preparation for Analysis

Data collected during observation had its accuracy and completeness evaluated. Field notes and cognitive artifacts were reviewed.

This comparison indicates to analysts the possibility of missing elements and refers to the need for new sessions of fieldwork, as, through comparison, it is possible to determine whether all operators involved in the activities were identified and their roles sufficiently described.

Structuring Data

The data contained in the notes field was sorted into six categories: role and activity; standards; use of prior knowledge; use of experience or intuition; use of the runway; problem.

Elicitation and Representation of Knowledge

This phase of the activity analysis step can be summarized as a second level of analysis, in which a way to represent elicited knowledge about the structure of the collected data is defined. Figure 5-19 shows a concept map built in this step.

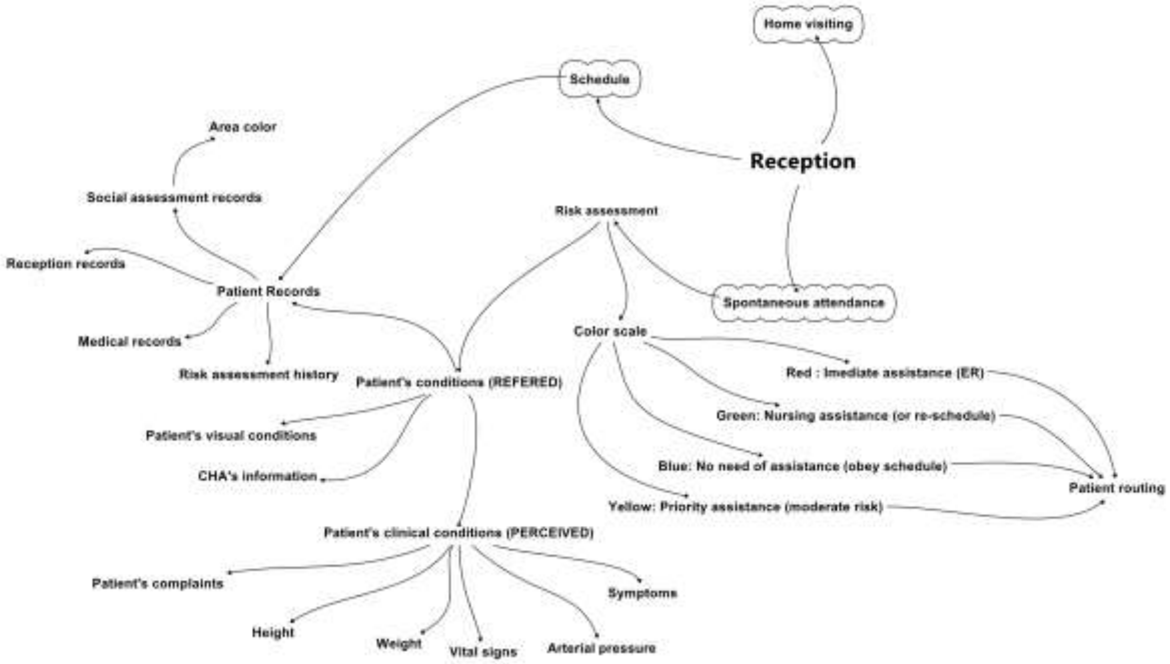

Figure 5-19: Concept map representing elicited knowledge about the Reception key process

Using the knowledge that has been obtained, it is possible to characterize a set of states of knowledge that will be transposed to cognitive models.

Work Processes Modeling Step

As was described in the contextualization phase, the clinic has five teams. All five teams were analyzed, resulting in five process models. Once each model was validated, their activities and respective boundaries were compared with one another. These five models have been merged, resulting in the s*ynthesis model,* which can be seen in Figure 5-20.

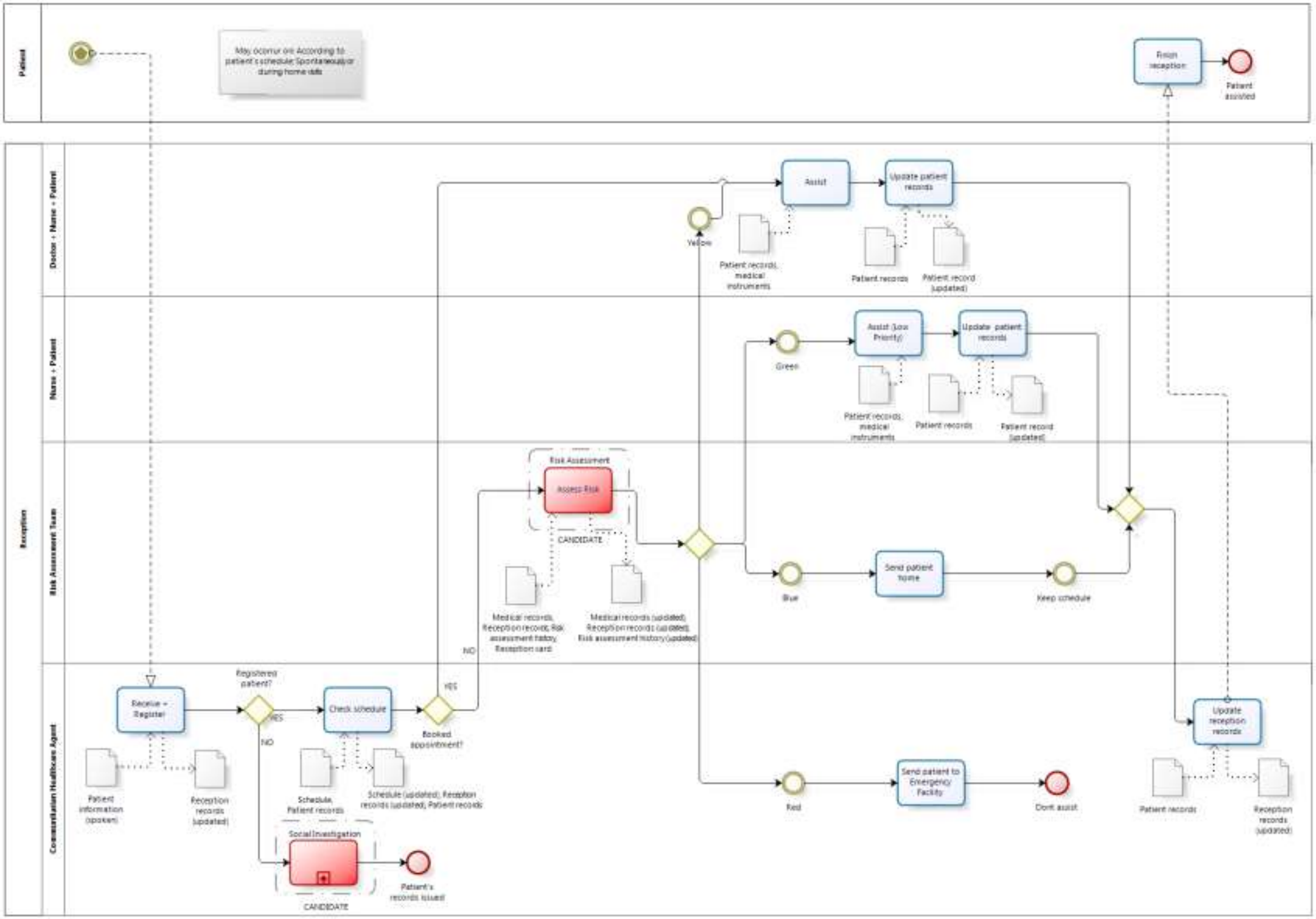

Figure 5-20: Synthesis Model of "Reception", the key process

Data collected in previous phases provided the elements for the construction of business models. For example, the activity “Get records” appears in the synthesis model. This activity, and its boundaries (i.e., the CHA as its main actor, the action of obtaining and updating the “patient record” artefact, and the decision that follows), can also be seen in the collected data.

5.2.6.3 Identification of Needs Phase

To determine which activities deserve the support of information systems and high-value requirements, a set of candidates for IT support have been identified, as shown in the following subsections.

Identification of Critical Situations

Using the criteria mentioned in subsection 5.2.5.3, the following results have been obtained:

Complaint: The clinic manager pointed out a set of activities that have higher demands on workers. Practitioners also indicated the activities that demand complex mental reasoning and the ones that require more elaborate models or use a larger amount of artifacts.

Consequence: During the observation a set of process activities that took more time to be executed and thus had more impact on the process, causing it to end unexpectedly or causing inadequate variations was identified. Analyzing these activities, we determined a set of artifacts that, because of the complexity involved in either producing or obtaining them, makes work heavier.

Centrality: Observing the health care professionals, we could highlight activities, or sets of activities, that play a central role in the process. These activities are significant in decision making, especially about assisting or not assisting patients, and result in different terminal points for the key process.

Stability: During observation we could see that at some point in the process, two groups of activities were being performed in many different ways. These variations depended on who was performing them, as well as on contextual issues. These two sub-processes, which were given the titles “Social Investigation” and “Risk Assessment,” have been highlighted for further analysis. Both sub-processes followed protocols; however, these protocols were applied differently by each team. This discrepancy pointed out important variability in the process.

Figure 5-21 shows one of the candidates highlighted in the process model.

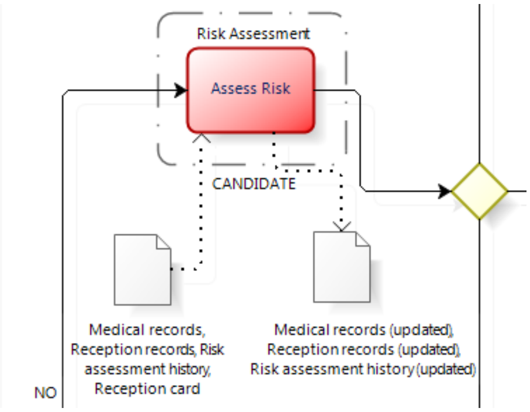

Figure 5-21: Highlighting the Candidate entitled “Risk Assessment”

Cognitive Modeling

As shown in in Figure 5-20, two candidates have been highlighted in the identification of needs phase: “Social Investigation” and “Risk Assessment”. Figure 5-22 shows the decision ladder for the risk assessment candidate.

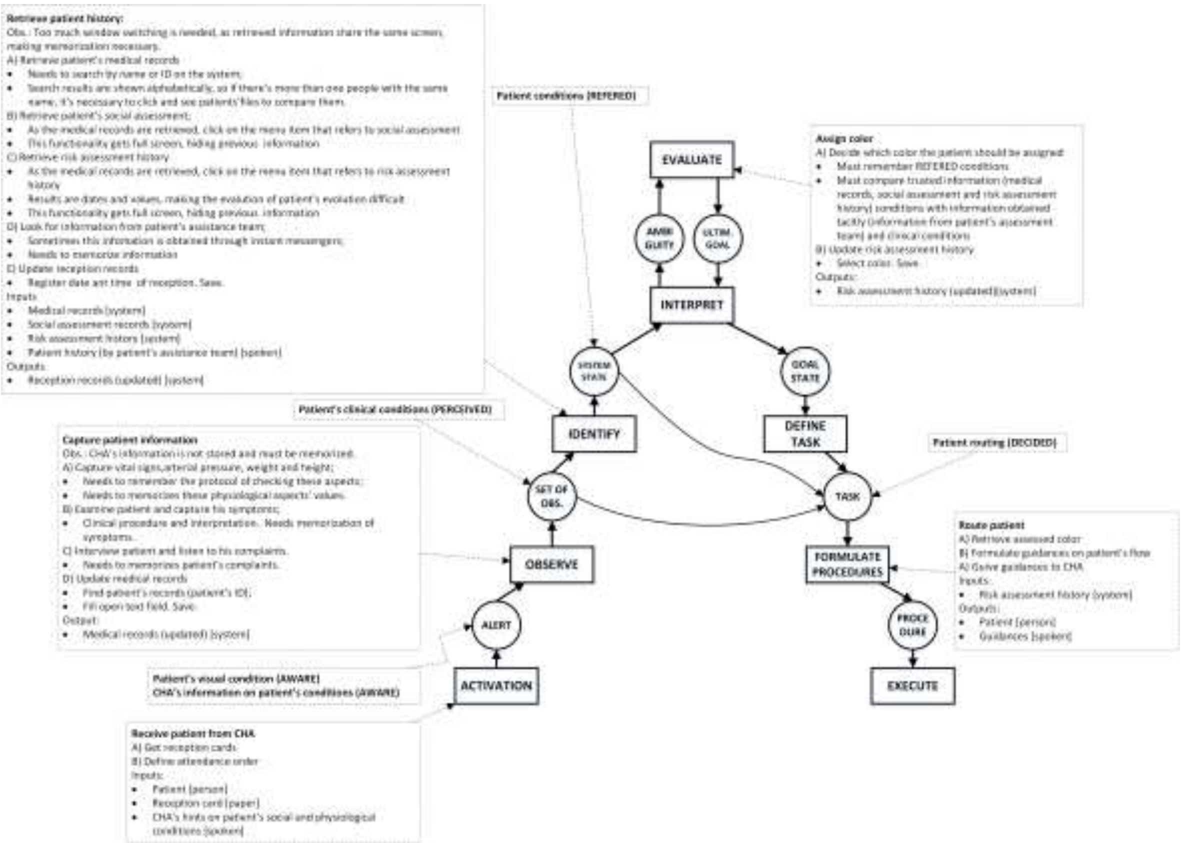

Figure 5-22: Decision Ladder for the Risk Assessment Candidate

The decision ladder displays information obtained in all phases of the approach, as well as the results of the cognitive analysis. States of knowledge shown in Figure 5-22 can also be seen in the concept map shown in Figure 8. However, in the decision ladder the states of knowledge are described as results of the information-processing activities that enable them. As we made clear in the process model shown in Figure 5-20, the decision ladder indicates inputs and outputs that are used by each information-processing activity, in order to point out the information needs inside the entire risk assessment activity. Those inputs and outputs are provided either by the computer system, which supports the entire process, or by any other informal memory method that workers use (e.g., papers or information obtained in conversations).

5.2.7 Towards Requirements Specifications

Requirements engineering should provide mechanisms to understand what the client desires through the analysis of his needs, the evaluation of viability, and the negotiation used to find a reasonable solution (PRESSMAN, 2014). In this section we show how

Software Requirements Specifications (SRS) can be enhanced by incorporating results from the approach we propose in this article. SRS shown here follow the IEEE recommended practice for writing requirements specifications, which describes good practices for SRS content (IEEE COMPUTER SOCIETY, 1998 (Reaffirmed 9 December 2009)).

In this paper we focus on section 3 of the IEEE 380 SRS, which relates to specific requirements. Moreover, we have focused on the specification of functional requirements. This section of the SRS should contain all of the software requirements at a level of detail sufficient to enable the design of a system that can satisfy those requirements, and be used by testers to test that the system satisfies those requirements. Throughout this section, every stated requirement should be externally perceivable by users, operators, and other external systems.

Although we show IEEE 380 SRSs, the approach we suggest in this paper provides elements for the beginning, or first iteration, of the requirements specifications no matter which requirements engineering methods or techniques are adopted. This method offers specifications that can be incremented in further iterations or stages of requirements engineering, as they are already focused on high-value requirements. Figure 5-23 shows the simplified diagram in which the actor “Risk Assessment Team” accomplishes the use case “Supporting Risk Assessment”.

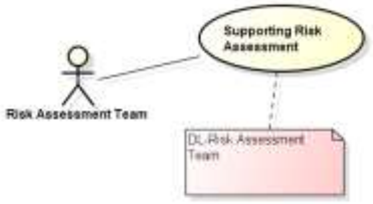

Figure 5-23: Simplified use case diagram

The use case show in Figure 5-23 is considered accomplished if the entire Risk Assessment decision ladder (see Figure 5-22) is complete. Thus, if we consider that human performance is made of both computer-supported and non-computer-supported activities, we should consider appropriate requirements as those that would help in the achievement of all expected states of knowledge.

Therefore, requirements that can be extracted from the information-processing activities, and their inputs, outputs, constraints, and processing rules are described in the decision ladder as well. We have explored the three following functional requirements:

- REQ1: Capture patient information
- REQ2: Retrieve patient history
- REQ3: Assign color

These requirements are defined in the OBSERVE, IDENTIFY, AND EVALUATE information-processing activities, respectively. In the case explored in this paper the ACTIVATE and FORMULATE PROCEDURES information-processing activities do not deserve functional requirements because they are not supported by the computer system, and are thus not described in SRSs.

Some specifications, such as user and hardware interfaces, should be made in further stages of design and are not explored in this article – these specifications are stated as NOT APPLICABLE (N/A) in the SRS, as is seen in Table 5-15. Moreover, all data handling has been related to a Relational DBMS, due to the fact that this is the way some of the current inputs and outputs have been built. Display specifications shown in this paper focus on simple inferences and should be deepened in further stages of design.

Table 5-15: SRS for the “Risk Assessment” Candidate

Specific requirements for **Risk Assessment**

User interfaces
N/A
Hardware interfaces
N/A
Software interfaces
N/A
Use cases
“Supporting Risk Assessment”
Functional requirements
REQ1

Description	Capture patient information
Input	Medical records [system]

Display	Capture vital signs, arterial pressure, weight and height according to Family Health care Strategy (FHS) protocol: Put checkboxes to assure evaluation of all aspects. Put text fields to enter the corresponding aspects values. Fields must be displayed in the FHS protocol following order: vital signs, arterial pressure, weight and height. Enable the capture of symptoms on patient's examination: Put check boxes organized by colors (risks). Each one of the four colors shows a set of check boxes for its assigned symptoms. If a suitable symptom does not have an appropriate check box, enable a text field to insert it. Register the patient's complaints: Create a section to register patient's complaints (supposed to be symptoms). Put check boxes organized by colors (risks). Each one of the four colors shows a set of check boxes for its assigned symptoms. If a suitable symptom does not have an appropriate check box, enable a text field to insert it. Enable "Save" button.
System Processing	Capture vital signs, arterial pressure, weight and height, according to FHS protocol: Once aspects are checked, save them. Also save the corresponding aspects values. All fields are required in the FHS protocol order. Enable the capture of symptoms on patient's examination: Once symptoms are selected or typed, save them. These fields are not required. Register the patient's complaints: At least one check box is required. Save information on "Save" button click.
Output	Medical records (updated) [system].
Constraints	Patient must have been identified and records must have been retrieved.
Data Handling	Data must be stored in relational DBMS.

REQ2

Description	Retrieve patient history
Input	Medical records [system] Social assessment records [system] Risk assessment history [system]
Display	Screen must be divided into three frames: Medical records, Social assessment and risk assessment history. All frames must be simultaneously visible in the same screen. Display patient's medical records: Show evolution graphs to represent existing numeric scales (body temperature, weight, height, arterial pressure etc.). Must occupy no more than a portion of the screen. Display patient's social assessment: Show patient's residence on the map and his area's color (risk grade).

	Must occupy no more than a portion of the screen. Display risk assessment history: Show line graph with patient's risk evolution. Must occupy no more than a portion of the screen. Enable the capture of information from patient's assistance team: Enable text field to store information from patient's assistance team. Enable check box to indicate that assistance team has been consulted. Enable the update of reception records: Enable calendar (date and time). Enable "Save" button.
System Processing	Display patient's medical records: Generate the corresponding graphs. Display patient's social assessment: Generate the corresponding map. Display risk assessment history: Generate the corresponding line graph. Enable the capture of information from patient's assistance team: Once information has been typed in the text field, save it. Once check box has been checked, save it. Enable the update of reception records: Compare date and time selected with system's current date and time. If different, alert user. On "Save" button click, save.
Output	Reception records (updated) [system] : occasionally including information from patient's assistance team
Constraints	Patient must have been identified and records must have been retrieved.
Data Handling	Data must be retrieved from relational DBMS; Data must be stored in relational DBMS.

REQ3

Description	Assign a color
Input	Patient records [system]
Display	Display suggestion of which color the patient should be assigned: Must occupy no more than a portion of the screen. Show suggestions of risk assessment (probability of occurrence of each color) in a graph. Show consolidated data, explaining how each color probability has been calculated. Show option "agree with systems suggestion" to the user. If not agreed, enable combo box for color selection. Enable the update of risk assessment history: Enable "Save" button.
System Processing	Display suggestion of which color the patient should be assigned: Retrieve stored data. Retrieve patient's records from database (see REQ2).

	Based on retrieved data, an algorithm should suggest risk rates. Generate graph. Enable the update of risk assessment history: On “Save” button click, save.
Output	Risk assessment history (updated)[system].
Constraints	Patient must have been identified and records must have been retrieved; Patient’s records must be visible on the screen.
Data Handling	Data must be retrieved from relational DBMS; Data must be stored in relational DBMS.

A software requirement may exist because of the nature of the task to be supported or because of a special characteristic of the project. However, the SRS should not describe any design or implementation details. The SRS limits the range of valid designs, but does not specify any particular design and, most of all, should not impose additional constraints on the software.

As the decision ladder shows how people actually work (i.e., “as is”), the SRS should describe how the system should perform in order to help workers accomplish their objectives (i.e., “to be”). Therefore, we can see that specifications are described in accordance with information processing activities, but they are deepened to show how the software should work and what it must provide the user. We used the steps that professionals follow as described in the DL to guide the writing of specifications that point out how the system should perform. The same is done to describe the computerized form of inputs and outputs.

5.2.8 Discussion

There is recognition that design flaws in health information technology lead to increased cognitive work, impact workflows, and patient harm, and the human factors and ergonomics discipline can help in increasing the knowledge to redesign the systems and improve patient safety and quality of care (CARAYON, XIE e KIANFAR, 2013). In some cases the lack of information about the system’s performance generates usability issues that contribute to disparities in the utilization of technology and patient safety concerns, particularly among non-typical users (GIBBONS, LOWRY e PATTERSON, 2014).

At the end of the fieldwork, all five Family Health care assistance teams underwent new interviews designed to evaluate the effectiveness of the proposed approach. As each team had eight professionals directly involved in the Reception process, these structured interviews collected answers from 13 professionals from diverse categories. In these interviews, health care professionals saw all of the models that were produced and the resulting specifications.

The following questions were presented to the professionals:

- How completely do the models represent your work?
- How adequately do the models represent your activities?
- How correctly do the models represent your flow and sequence of activities?
- How correctly do the models represent the inputs and outputs of your activities?
- How correctly do the models highlight high-demanding work situations?
- How can you benefit from technological support to the highlighted candidates?

Interviewed professionals could answer “completely”, “very”, “moderately”, “poorly”, or “inadequately” to each question. All professionals interviewed stated that the models “very” or “completely” represented their work. There were no claims that the work was “poorly” or “inadequately” represented. The same was stated for the representation of the sequences of activities.

Regarding the identification of inputs and outputs of activities, more than half of the respondents stated they were represented “moderately”. This may indicate lack of understanding about the results of the activities. In interactions with professionals during observation, we found that many of them have poor understanding about the results of their own activities as they relate to the persistence of relevant information.

The first point of discussion is the indication of high-demanding work situations, as all of the answers pointed out that the approach had highlighted the right candidates, especially the risk assessment – always referred as an intellectual, physical, and cognitively overloaded set of activities. Although right candidates to IT support have been pointed out, some professionals have stated during interviews that some candidates might be more important than others, which makes us to infer that prioritization of candidates might me important.

When asked about how they could benefit from the adoption of IT to support specific candidates on their domain, only one of the interviewed professionals answered “poorly”, suggesting that the approach did not point out clearly which parts of their work should be assisted and which ones should not.

Another discussion point regards limitations of the models used. Classical workflow management systems and their supported languages like BPMN are better for structured processes rather than complex, dynamic, and unpredictable systems, which require much flexibility (VAN DER AALST, PESIC e SCHONENBERG, 2009). Despite this limitation, multiple process models have been built in order to represent multiple views of work performance. Moreover, process models have been used to represent the boundaries of the process, providing means for deeper analysis and modeling with adequate tools.

Considering the basic structure of SRS stated in the IEEE 380, we can see how it reflects data collected and presented in other artefacts built while applying the proposed methods. For example, the decision ladder reflects and deepens information represented in the synthesis process model, while SRSs also show information modelled in previous phases.

Although we highlight the importance of experts’ evaluations of the results, presenting the methods to software engineers, and comparing the results of the proposed method with the results of regular software engineering techniques might bring important extra evaluations. However, we must take into consideration that traditional software engineering modeling techniques are based on static views of the context and domain, and as we stated in previous sections of this paper, aspects of complex systems hamper these techniques.

5.2.9 Conclusions

In complex systems several factors are added to people’s work, such as unpredictability, variability, and constant decision-making. In these systems, work does not always go as planned, requiring operators to make constant use of improvisation. The difficulty of understanding work in complex sociotechnical systems, given that it is often influenced by a large number of factors, makes it difficult to adopt support devices.

Thus, in this paper we propose a case study in the context of health care to explore the contributions that the human factors discipline could give to address major issues in the development of support tools in complex work environments. Fieldwork has been carried out in a primary health care facility to demonstrate the use of an approach that brings together human factors concepts and software engineering tools to improve requirements specifications for complex sociotechnical systems IT.

This three-phase approach uses cognitive engineering to increase understanding about how professionals perform complex work, taking into account the cognitive effort made by those workers in performing their activities. Furthermore, we define the parts that could best benefit from computer support – the high-value requirements candidates – which will then be described in cognitive models.

Information obtained during the execution of the proposed approach can be used to increase the reliability of requirements specifications, as the high-value candidates have been defined and information about how people work has been gathered and organized in structured representations. Results obtained point out that the requirements engineering process could benefit from the concepts, tools, and techniques suggested in this paper.

This work is influenced by cognitive ergonomics, which contributes to the design of computer-based systems by supporting aspects of interaction that depend on the knowledge usually required by humans in order to use IT to improve the effectiveness of their work.

As IT support increases to meet new and diverse types and levels of complexity, this work could be useful in helping information systems to not only meet their technical requirements, but also to deliver anticipated support for real work in complex organizations.

5.3 Article 3: Supporting Decision Making in Patient Risk Assessment Using a Hierarchical Fuzzy Model

5.3.1 Foreword

In this chapter we present a hierarchical fuzzy model to support the assignment of risk scores in the patient triage and risk assessment process in primary health care. This approach uses triangular fuzzy numbers under the AHP framework in order to illustrate the inherent imprecision in the evaluation of patient risk. Fieldwork was conducted in a primary health care facility in Brazil to demonstrate the applicability of the proposed approach.

The proposed approach enabled the weighing of sub-criteria and the establishment of relative importance of each criterion in the formation of patients' risk scores. Using this approach we also provided fuzzy representations of patients' conditions, appropriately weighted according to the relative importance of each criterion.

The AHP framework enabled the definition of relative importance of criteria, which contributed to more suitable and approximate definitions of patients' conditions. Furthermore, fuzzy numbers enabled the representation of membership functions of patients' conditions to each alternative in the risk scale, which had been proved a useful support to health care workers' decision making.

Citation information for this chapter's resulting paper can be seen below:

> Jatoba, A., Bellas, H.C., Burns, C.M., Grecco, C.H.S., Vidal, M.C., de Carvalho, P.V.R. (under review). Supporting Decision Making in Patient Risk Assessment Using a Hierarchical Fuzzy Model. *IIE Transactions on Occupational Ergonomics and Human Factors*

5.3.2 Introduction

Judgements in complex systems like health care are usually made under uncertainty and subjectivity. In health care, risks are very high due to criticality, complicated processes, hazardous environments, and the very dynamic behaviour and health conditions of patients. Some common constraints in these workplaces, like time pressure, ambiguous information, make it impossible to apply traditional methods to support decision-making (KLEIN, 1997). Particularly in a public decision-making situation, workers prefer not to express their preferences explicitly, or the alternatives have imprecise, uncertain values for criteria measurements (OKUL, GENCER e AYDOGAN, 2014).

The risk assessment process in primary healthcare often consists of the assignment of a risk score – illustrated by colors – that should represent the severity of the patient's conditions and potential to develop illnesses. Risk assessment is an important process since it affects patients' triage to services and treatment. In order to assign a risk score that truly represents a patient's conditions, health care workers must consider a large set of subjective and imprecise variables, such as sewerage conditions, neighbourhood security, family resources and capability and the current symptoms presented by patients.

Thus, in this paper we present a hierarchical fuzzy model to support the assignment of risk scores in the patient triage and risk assessment process in primary health care. In this approach we used the Analytical Hierarchy Process (AHP) to define the relative importance of criteria and sub-criteria that workers use to assign risk scores to patients in primary health care. Furthermore, we have adopted triangular fuzzy numbers to illustrate the imprecision in the evaluation of patient risk through the definition of membership functions to represent patients' conditions and decision alternatives.

5.3.3 Motivation

In this paper we focused our attention in decision makers – health care professionals – facing uncertainty about the outcomes of their decision. In health care facilities workers are affected by many aspects such as time pressure, missing information, poor resources, etc. These aspects, along with personal preferences, opinions and expertise, affect the behavior of workers, thus, the way they make decisions is also affected.

In the specific case of patient risk assessment, there are protocols in which criteria for decision making are described. We present a case study carried out in a Brazilian health care facility that uses the Manchester Triage Protocol (MANCHESTER TRIAGE GROUP, 2005) as the basis for the patient risk assessment process. The Manchester Triage Protocol presents a set of colors used to classify patients according to their risk of evolving into a dangerous health situation.

Although criteria present different importance according to the context, the relevance of criteria in relation to each other is not precise. For example, we know that a patient with a red assignment shows evidence of a more dangerous condition than a patient with a yellow assignment. However, the same symptoms can be used both in red and yellow assignments, showing that the risk assignment is not a simple evaluation of symptoms. Furthermore, expert decision makers at patient risk assessment show not only analytical skill but also effective use of intuitive decision making, exploiting their deep experience and skills (SAAY, 1987; SAATY, 1990).

Fuzzy logic has been used extensively in the health care field. For example, we can see applications of fuzzy reasoning in knowledge-based expert applications for pattern matching and decision analysis in the diagnostic process (BARTOLIN, BOUVENOT, *et al.*, 1982). Fuzzy logic has also been used in the framework of medical diagnosis, with applications that define relationships between signs and diagnoses by means of fuzzy relations showing how diagnoses can be derived from soft matching processes (SANCHEZ, 1998). More recently, we can see the use of fuzzy logic in the assessment of the intensity of signs and symptoms of typhoid fever (SAMUEL, OMISORE e OJOKOH, 2013), as well as in the assessment of requirements of health care services (LEE, RU, *et al.*, 2015), along with many other kinds of medical applications.

The sectors of medical activities can be organized in a hierarchy according the procedure, i.e. methodologies, relationships and demands are correlated. Therefore, this situation substantiates the hypothesis that a successful application in one sector of health care can lead to a successful application in close sectors (ABBOD, VON KEYSERLINGK, *et al.*, 2001).

Thus, we believe that workers performing the patient risk assessment would benefit highly from the concepts present in the Fuzzy Sets Theory (ZADEH, 1965; ZADEH, 1975; GRECCO, CONSENZA, *et al.*, 2014), which provides methods to tackle human cognition during decision making with multiple criteria, imprecise outcomes, and under inherent uncertainty that comes with this kind of reasoning.

This study has the conceptual and practical significance of increasing the comprehension of how the fuzzy logic can be used to represent the decision making of primary health care workers during the evaluation of patients' conditions, enabling the design and development of decision support devices for the patient risk assessment.

Moreover, multiple criteria are usually organized in hierarchies where each sub-criterion has its own importance for a main criterion and traditional Multi Criteria Decision Making (MCDM) approaches are generally not effective for multi-level hierarchy of criteria, lacking description of relations and interdependency of criteria and their sub-criteria. As decision criteria are usually dependent to each other, evaluating them individually disregarding such dependency may lead to inadequate results (RAMÍK e PERZINA, 2010; YANG e LI, 2013)

Thus, this is the major contribution of this paper, which uses relative weights to rank criteria and determine the importance of each criterion for the definition of the most suitable alternative for decision. We use triangular fuzzy numbers in the AHP framework (SAATY, 1990; SAATY, 1977) in order to take advantage of both AHP and fuzzy logic principles and methods. Therefore, we develop a model, based on the MCDM principles, to represent the decision problem of the assessment of patient risk in the context of primary health care. We demonstrate the potential of the proposed approach by employing it in a primary health care facility in Brazil.

5.3.4 Research Problem and Question

Decision making in complex systems is hampered by the fact that the object of choice always involves context variables that bring uncertainty and unpredictability to the outcomes. Complex systems comprise causal processes and agents whose interactions lead to unpredictable outcomes and consequences, and the agents adapt themselves, interacting in complex ways that reshape their collective future (AXELROD, AXELROD e COHEN, 2001).

The health care domain proved to be a good candidate for computer support to decision making due to the high cognitive demands, increased by aspects like unpredictability regarding the amount and severity of patients, concurrent management of multiple individuals requiring timely responses, and a need to cope with limited resources. The complexity of health care facilities includes the functions of the work, the implementation of technology, activities and workflows performed by the people and the technology, as well as the social, physical, cultural, and organizational environment. Managing the cognitive, physical, spatial, and temporal resources in such systems is crucial for patient safety and quality of care (FRANKLIN, LIU, *et al.*, 2011).

In this paper we explore the research topic of the decision making in patient triage and risk assessment in primary health care, addressing the problem of providing a decision support model capable of tackling the inherent uncertainty and imprecision of human evaluation of patients' conditions in order to assign them risk scores. We suggest that fuzzy logic might be one approach as means to address the following question:

- How can health care workers' practices, protocols, mental models, and decision making be embedded into an inference machine capable of providing a decision support tool in order to improve work situations in patient risk assessment in primary health care?

A big challenge is presented when one wants to provide computer support to decision making in health care, as it's necessary to design better sociotechnical systems, enabling better interaction between humans and computers (DELANEY, FITZMAURICE, *et al.*, 1999).

5.3.5 Materials and Methods

This research follows qualitative principles and data collected in has been codified according to recognized analytical tools (STRAUSS e CORBIN, 1998). All participants agreed with consent terms and their names had been kept confidential. Primary data been collected by means of non-participative ethnographic observation and semi-structured interviews during field study carried out among 15 professionals involved in the risk assessment process in a primary health care facility in Rio de Janeiro, Brazil.

This study is in accordance with the ethical principles of the Resolution nº 466/2012 of the Brazilian National Council of Health Care/Brazilian Ministry of Health regarding scientific research involving human beings, and has been approved by the ethics committee of the Sergio Arouca National School of Public Health/FIOCRUZ.

5.3.5.1 Fuzzy Logic as a Behavioral Model to Support Decision Making Under Uncertainty

A decision problem is defined by the available options, the possible outcomes or consequences of the chosen option, and the contingencies or conditional probabilities that relate outcomes to options. The perception the decision maker has about the available options is controlled partly by the formulation of the problem and partly by the norms, habits, and personal characteristics of the decision-maker (TVERSKY e KAHNEMAN, 1981). Moreover, when there are multiple decision makers and multiple criteria are available, situations of conflict among workers always arise as each expert has his own opinion under each criterion an alternatives (HSU e CHEN, 1996).

There are essentially two approaches to modeling human decision making: the normative approach, which is outcome-oriented, based on the idea that if one can correctly predict the outcome of the decision making, then the decision process can be understood; and the behavioral approach, which is process-oriented, based on the assumption that if one understands the decision process, than it’s possible to predict the outcome. According to behavioral theories (sometimes called descriptive, prescriptive, or cognitive) understanding how decisions are made can help defining how they actually should be made.

Normative decision theories have their foundations on concepts surrounding the rationality of the decision maker and the optimality of the decision. According to these concepts, when decision makers don’t follow certain rules supposed to describe their behaviour, they are being suboptimal or irrational, disregarding the fact that behavior is purposing and goal-oriented, even though some ways to get to the goal are better than others (EINHORN e HOGARTH, 1981). One of the major normative approaches to the decision theory is the expected utility model.

Furthermore, judgment and choice are also affected by the way contextual aspects are represented by decision makers. Any contextual changes, even the lesser ones, affect the cognitive representation of the problem by people making decisions, affecting people's behavior and, thus, its predictability. Another aspect that must be considered is that, while making decisions in complex sociotechnical systems, people must cope with many contextual factors like ill-structured problems, uncertain variables, competing goals, time pressure, etc.

Although the foundations of the theory of decision making under uncertainty come from the expected utility model, the idea that the choice can be described in terms of the utilities of the outcomes for the decision maker has been subject of long time criticism. Tversky and Kahneman state that people's choice process by framing and evaluating acts, outcomes and contingencies, expressing the outcomes of the decision as gains or losses (KAHNEMAN e TVERSKY, 1979; TVERSKY e KAHNEMAN, 1974).

For Tversky and Kahneman, people's behavior while making decisions under uncertainty can violate principles of the expected utility model. For example, in normative models, the utilities of outcomes of the decision are weighted according to their probability of occurrence. However, people can overweight specific outcomes considered certain, when compared with other outcomes considered only probable.

Moreover, the subjective assessment of probability is based on data of limited validity, processed according to heuristic rules. Although these rules have some validity, reliance in this rule alone may lead to errors in estimations they want to present (TVERSKY e KAHNEMAN, 1974). Therefore, as the reliability analysis is constantly undetermined by the unpredictable behavior of operators at work in complex systems the probabilistic approach is not the most appropriate one for solving such problems. Lack of experience data, entangled cause-and-effect relationships and imprecise data hamper the choice process using probability models (ZADEH, 1965; SHANG e HOSSEN, 2013).

However, although behavioral decision models like prospect theory are based on descriptions of observed workers' behaviors, they still rely on the assumption that the decision-makers perform under consistent rules (BELL, RAIFFA e TVERSKY, 1988). Furthermore, traditional paradigms compare the quality of the decision with rational standards that might be appropriate for typical tasks, but don't consider contextual aspects that join decision making in the real world.

Although decision-making is a structured process, it is very dynamic, involving complex search for information, getting feedback from all directions, gathering and discarding information, coping with constant uncertainty, conflicting concepts, and multiple attributes. Moreover, humans are reluctant decision makers. Human decision-making is an organic process, made on pre-decision and post-decision stages loaded by numerous contextual aspects (ZELENY e COCHRANE, 1982). Humans evaluate alternatives by means of their consequences. If there is uncertainty, there is not one clearly defined consequence for each alternative, and there's not much information about the likelihood of specific consequences (COMES, HIETE e SCHULTMANN, 2013).

According to Klein (KLEIN, 1997; KLEIN, 1999), the way people make decisions is naturalistic, i.e. decision makers are more concerned about increasing situation awareness through feedback, rather than developing multiple options compare to one another. The Naturalistic Decision Making (NDM) approach is concerned about understanding the way people user their experience to make decisions and the cognition involved, rather than comparing the available options, since most of the time, there are typically multiple conflicting criteria that need to be evaluated in making decisions. Furthermore, human reasoning is not precise in its nature. Only a small fraction of human thinking relates to reasoning in precise logical or quantitative terms.

The Multiple Criteria Decision Making (MCDM) discipline is suitable to these situations, since it provides concepts and methods for structuring and solving decision and planning problems involving multiple criteria. The purpose of MCDM is to support decision makers facing problems where there is not a unique optimal solution (ASHTIANI e ABDOLLAHI AZGOMI, 2014).

When dealing with conflict, decision makers start searching for new suitable alternatives to reduce ambiguity or uncertainty. However, during this process, the ideal image can be displaced and the conflict might be increased rather than reduced. The evaluation of alternatives becomes systematic as the dominance of one choice among the existing alternatives becomes clearer to the decision maker. However, this is not linear, but a dynamic process of careful interpretation and reassessment of alternatives (ZELENY e COCHRANE, 1982).

However, classical MCDM methods require perfect decision information, like assigning precise weights to criteria and intensively involving a decision maker, which makes it difficult to cope with decision making under uncertainty. Moreover, in these cases there is a need to model the way humans actually think and reason with information described in natural language, for which the fuzzy logic brings many contributions (ALIEV, PEDRYCZ, *et al.*, 2013).

Thus, fuzzy logic (ZADEH, 1975; ZADEH, 1965) contributes to MCDM by providing methods to represent and cope with approximate reasoning, fitting in the inherent uncertainty in human cognition. Differently from the standard logic, fuzzy rules of inference are approximate rather than exact, making it suitable to multiple criteria problems when human evaluations are needed, and, therefore, modeling the human knowledge is necessary. The purpose of fuzzy logic is to provide ways to reason with vague, ambiguous and imprecise knowledge, enabling the computational representations of decision problems in a complex system in a similar way it supposed to be represented by people. It has been considered as a modeling language to approximate situations in which fuzzy phenomena and criteria exist (GRECCO, CONSENZA, *et al.*, 2014).

One of the disadvantages of the traditional decision theories is the lack of attention to interaction among the aspects involved in decision making. Variables to represent environmental and contextual factors can be placed in a decision model, but usually disregard the way these factors interact (ALIEV, PEDRYCZ e HUSEYNOV, 2013). As the prospect theory and other behavioral approaches to decision making are developed for precise and complete information, the behavioral decision making discipline benefits of fuzzy logic concepts, since behavior and environment are qualitative and described in natural language.

One of the main advantages of using fuzzy logic to support decision making is the use of linguistic variables rather than numeric ones. This makes fuzzy representations of decision problems more understandable and similar to human thinking, as preferences as human judgments are often described in natural language and cannot be described by exact numerical values. However, we must highlight that fuzzy systems require more tuning before becoming operational than regular systems. Furthermore, fuzzy logic can be combined with other models to enhance its results and increase effectiveness through the description of imprecise values in membership functions (MCNEILL e THRO, 2014; LEE, 1996).

5.3.5.2 Application of the Proposed Model

The application of the fuzzy model we propose in this paper followed three basic steps:

a) **Scenario selection:** The clinic manager presented six real patient receptions that have been performed in the health care facility. Among these, three have been selected randomly for the application of the model. We can see the selected scenarios in section 5.3.5.4.

b) **Interview professionals:** workers have been argued about risk assessment procedures, criteria, and decision alternatives. Data collected in the interviews populated the fuzzy model as can be seen in section 5.3.5.5. Workers also discussed the scenarios in order to figure out whether the rates given to patient in the selected situations were correct. Opinions of workers were used subsequently as expert opinions for comparison with the results provided by the fuzzy model as can be seen in the discussion section.

c) **Run scenarios through model:** data from the selected scenario were included in the fuzzy model, resulting in patient risk assessments as can be seen in section 5.3.6. Results were compared with expert opinion in order to assess how good the fuzzy model was at matching good risk assessment according to the experts

5.3.5.3 Participants

Participants were selected according to their relations with the risk assessment process in the primary healthcare facility. As this process is collective and ubiquitous, all health care professionals that work in the clinic participate of the risk assess process one way or another. Either by directly applying it for patient spontaneous demands, in the risk assessment room – like nurses and orderlies – or "longitudinally" like formulating procedures, assigning risks to families, evaluating conditions of locations etc. – like physicians and community health care agents.

Therefore, the selected participants were all nurses, orderlies, physicians and community health care agents of the primary healthcare facility in which this study was carried out. All professionals have been invited but their participation was voluntary. Fourteen workers agreed to participate and were interviewed.

All interviews were conducted individually and lasted approximately 30 minutes. The interview guidelines had both multiple-choice and open questions and participants could speak freely about different aspects of their work. Interviews began with an inquiry about the professional profile of interviewees, followed by AHP pairwise comparisons of risk assessment criteria. Participants could also talk about the criteria, pointing out their relevance as well as suggesting inclusions and exclusions of criteria.

Subsequently, three scenarios of patients seeking health assistance have been presented to participants. To each scenario, they could tell what risk grades patients could receive, as well as what risk grades they should not receive. They could also speak freely about the features of scenarios and were argued about some aspects involved in those scenarios, like amount of information, quality of information, workload, time constraints, etc.

5.3.5.4 Scenarios

Scenarios are based on real work situations and have been built with data collected from the information system used in the primary health care facility and in observations from previous studies. Risk assessments of six patients have been collected and three of them have been randomly chosen to construct scenarios for the application of the proposed approach as shown in Table 5-16.

Table 5-16: Scenarios for the application of the proposed approach

Scenario 1	An approximately 45 years old male patient comes to the risk assessment team, complaining about ear ache and presenting fever. The patient lives with his wife and two kids (5 and 7 years old respectively) in a house made of recycled wood, located in an area with no sewerage. Although this patient is unemployed he gets governmental allowance. He doesn't have any history of referred illnesses
Scenario 2	A 28 years old female patient is received by the risk assessment team, presenting high degree of fever and coughing. The patient has no kids, and lives with her parents in a brickwork house, in an area with proper sewerage and city water. The patient is unemployed and doesn't get any government allowance. Her father, a 60 years old man with a heart condition, has a history of tuberculosis.
Scenario 3	A mother comes to the risk assessment team with her 8 month baby girl which, according to her, cries incessantly and refuses breastfeeding. She also states that the baby presents diarrhea, which has not been confirmed by the risk assessment team. In preliminary exams, they could see that the baby presents cough and runny nose, but no fever. The family dos not receive government allowance, but the baby's parents are married and her father is employed. The family lives in a brickwork house, although the neighbourhood in which their home is located presents some areas with exposed sewerage. None of them have history of referred illnesses.

Three workers have been chosen randomly to be represented in the proposed fuzzy model: one physician, one nurse, and one orderly, with different levels of expertise, experience, and background. Their profiles can be seen below:

- P1: Physician, graduated approximately one to three years ago, and has only worked in primary health care since then. In the last five years he/she has taken between two and four extracurricular courses. He/she is not part of the team that performs the risk assessment for patient spontaneous demands;
- P2: Nurse, graduated for more than five years, has worked as an orderly before graduation, and works in primary health care for more than 10 years.

In the last five years, has taken between two and four extracurricular courses. He/she performs the risk assessment process both for spontaneous demands and in the longitudinal form, and has been performing risk assessment for approximately three years;

- P3: Orderly, doesn't have college education but has taken between two and four extracurricular courses through the last five years. He/she has been working in primary health care for more than 10 years and has worked as a community health care agent before being an orderly. For approximately three years, he/she has been performing the risk assessment process both for spontaneous demands and in the longitudinal form.

5.3.5.5 Fuzzy Modeling of Patient Risk Assessment

The first step was defining the structure of the risk assessment problem. Work analysis performed during previous work (JATOBA, BELLAS, *et al.*, 2015) pointed out that the assignment of risk rates to patients were made upon three kinds of criteria:

- Current clinical conditions: symptoms the patient presents by the time of his attendance to the clinic
- Family social conditions: financial and housing conditions of the patient's family
- Patient individual social conditions: patient's financial, educational and historical health situation.

According to data collected during fieldwork, these main criteria are divided into sub-criteria, resulting in the representation of the hierarchy and suitable alternatives shown in Figure 5-24. Each sub-criterion has a relative importance weight in the formation of its corresponding main criterion. These criteria, used by teams to assess patients' and their families' social a health risk, reflect the potential of developing illnesses and vulnerabilities each family has (SAVASSI, LAGE e COELHO, 2012; SAVASSI, CARVALHO, *et al.*, 2012).

The decision alternatives are the risk scores of the Manchester triage protocol, represented by five colors: blue, green, yellow, red, and black. Each main criterion has a relative importance in the formation of the patient's risk. Thus the patient risk could be enunciated as "the sum of relative-weighed sub-criteria, and weighed by the relative importance of the corresponding main criterion".

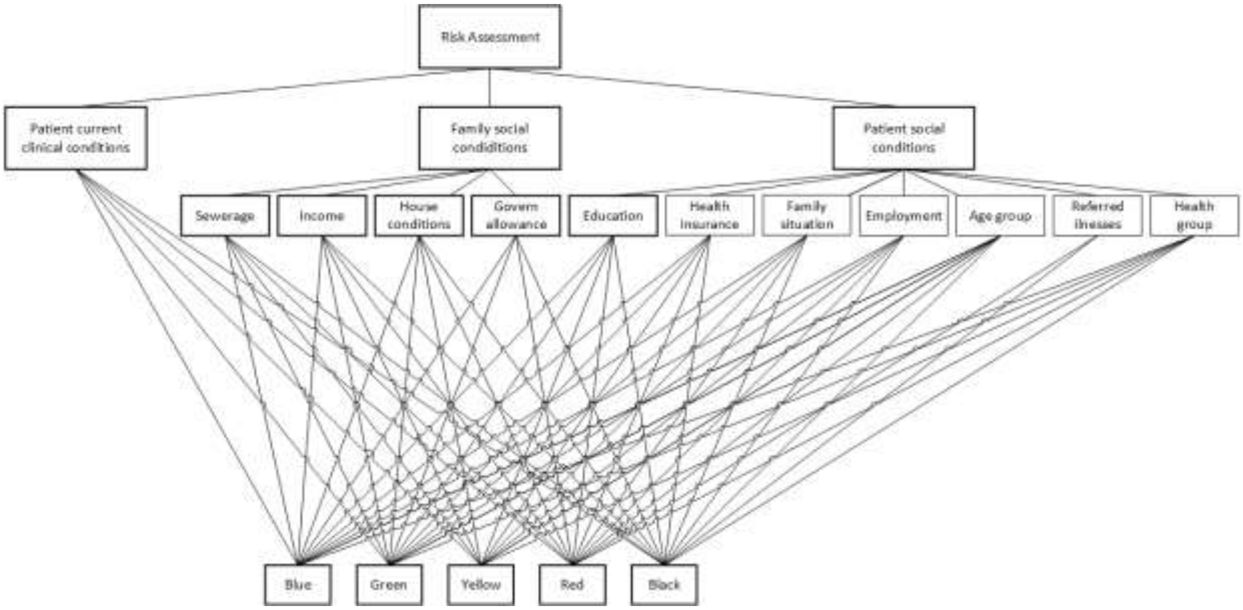

Figure 5-24: Problem hierarchy and decision alternatives

In order to express values of variables in real-life situations humans use natural language. For example, the same way workers could use a degree value to express how much fever a patient is experiencing, they could simply say "high" or "very high". This notion is also important to the cases in which the context modifies the relevance of the variable, e.g. fever in patients with different sewerage conditions. Thus, to express the values of the variables explored in this paper we used linguistic variables (ZADEH, 1965; ZADEH, 1975) due to its suitability to human natural language and representation of imprecise values.

To describe the relevance of each criterion in relation to others, we used the following linguistic terms: equal importance (EI); moderately more important (MMI);

strongly more important (SMI); very strongly more important (VMI); and extremely more important (EMI).

To describe the patient conditions in each criterion we used the following linguistic terms: very bad (VB); bad (B); medium (M); good (G); and very good (VG). Following, we describe the fuzzy membership representation of linguistic terms as well as membership functions for the decision options for risk assessment

Membership functions allow the graphical representations of fuzzy sets. The membership value of an element X in the fussy set A defines its relevance to the fuzzy. First, we started by defining crisp values to each linguistic term according to the fundamental scale of absolute numbers (SAATY, 1977). For each of these crisp numbers, a fuzzy number has been related as we show in Table 5-17, as well as membership functions shown in Figure 5-25.

Table 5-17: Linguistic terms and fuzzy numbers for relative relevance

Linguistic term	Crisp value	Fuzzy value
EI	1	(1,1,3)
MMI	3	(1,3,5)
SMI	5	(3,5,7)
VMI	7	(5,7,9)
EMI	9	(7,9,9)

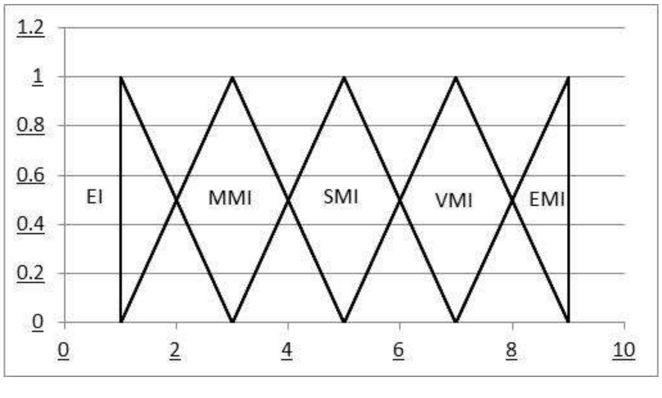

Figure 5-25: Membership functions for relative relevance linguistic terms

The same has been done for the linguistic terms used to describe the rates of criteria, which we show in Table 5-18 and Figure 5-26.

Table 5-18: Linguistic terms and fuzzy numbers for criteria rates

Linguistic term	Crisp value	Fuzzy value
Very bad	9	(7,9,9)
Bad	7	(5,7,9)
Medium	5	(3,5,7)
Good	3	(1,3,5)
Very good	1	(1,1,3)

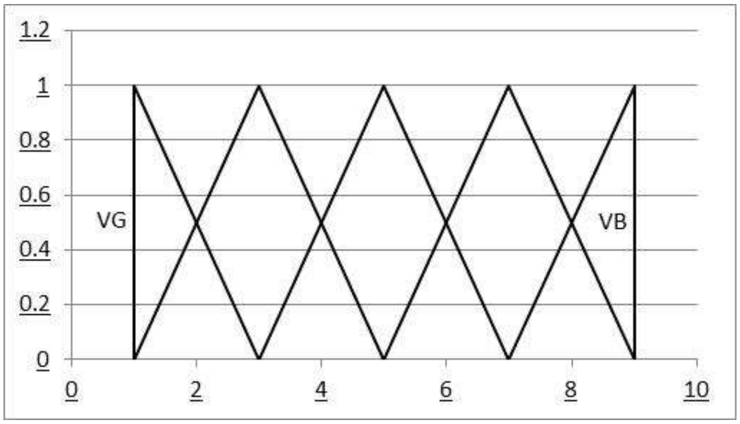

Figure 5-26: Membership functions for criteria rating

The alternatives for decision making in risk assessment are represented by the five colors defined in the Manchester Triage Group color scale. Fuzzy numbers and membership functions for each of these risk grades are show in Table 5-19 and Figure 5-27.

Table 5-19: Fuzzy numbers for risk grades

Variable	Crisp value	Fuzzy value
Blue	1	(1,1,3)
Green	3	(1,3,5)
Yellow	5	(3,5,7)
Red	7	(5,7,9)
Black	9	(7,9,9)

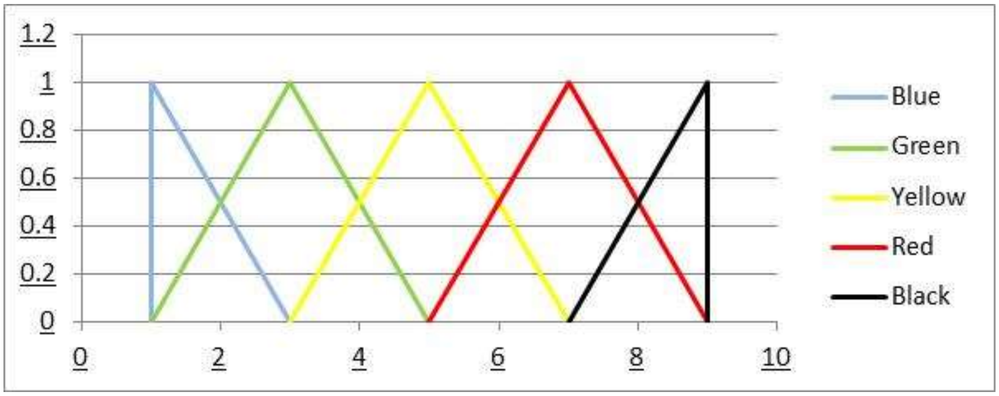

Figure 5-27: Membership functions for risk grades

Although we have defined a specific set of linguistic terms to describe criteria rates, equivalencies and reductions can be used. For example, “very high” might be more useful than “very bad” for a symptom like fever. Similarly, for some symptoms only “bad”, “medium” and “good” might be suitable.

The second step was focused on weighing workers’ opinions. Workers’ opinions are weighed according to a set of professional features considered relevant to the performance of risk assessments. During interviews managers stated that three professional features are the most important in risk assessment: feeling and ability to listen to patients’ complaints; technical expertise; and mastery of risk assessment processes and workflow.

Workers have been classified according to their professional features. In order to classify workers and assess their technical expertise the following aspects in their profiles have been counted:

- Physicians or Nurses: 1 point;
- Orderlies which completed college graduation: 1 point;
- Directly involved in the risk assessment process: 1 point;
- Working years since graduation: 1 point per year;
- Extra courses related to working area in the last three years: 1 point per course;

The same principle was followed to assess workers' mastery of risk assessment processes and workflows, taking into account the following aspects in their profile:

- Nurses and orderlies: 1 points;
- Worked in some other position in primary health care: 1 point;
- Years of experience in health care: 1 point per year;
- Years working specifically in the primary health care: 1 points per year;
- Years performing the risk assessment process: 1 point per year.

According to managers interviewed during fieldwork, workers relate differently to the risk assessment process. For example, physicians rely more in their technical expertise since they perform risk assessments mostly during normal work conditions like booked appointments or home visits in which they are able to gather information previously and make plans. On the other hand orderlies rely more on their mastery of the risk assessment process, since they are responsible for performing risk assessments in spontaneous demands, which are abnormal conditions. Thus, in order to weigh workers differently according to their profile, we assigned them one point for each matching profile feature, counted and normalized the total points, and obtained the indexes shown in Table 5-20.

Table 5-20: Obtaining skills and experience relative indexes

	Points		**Normalization**	
	Technical expertise	**Mastery of processes and workflows**	**Expertise index (X)**	**Mastery index (M)**
Worker 1	12	6	0.22	0.09
Worker 2	24	29	0.44	0.45
Worker 3	19	29	0.35	0.45
∑	55	64	1.00	1.00

Following, feeling and ability to listen to patients' complaints have been assessed according to the results of the observation of workers performing their tasks, as we show in Table 5-21.

Table 5-21: Evaluation of the criteria "Feeling"

	F			**F^2**			**i**	**Feeling index (F)**
	P1	**P2**	**P3**					
Worker 1 (P1)	EI	SMI	MMI	3.00	10.33	51.00	64.33	0.68

Worker 2 (P1)		EI	EMI	3.40	3.00	18.60	25.00	0.26
Worker 3 (P1)			EI	0.69	1.89	3.00	5.58	0.06
∑							**94.91**	**1.00**

In Table 5-21 we see the pairwise comparisons according to the AHP framework (*F*), which defines the squaring of the pairwise matrix (F^2) and the normalization (*i*) in order to obtain an eigenvector, which, in this case, refers to the feeling index (*F*) (SAATY, 1990).

Following, once the importance indexes of all professional features were defined, workers gave their opinions about the relevance of each professional feature when compared to each other, resulting in the pairwise comparison matrixes shown in Table 5-22.

Table 5-22: Pairwise comparison of professional characteristics

	Participant 1			**Participant 2**			**Participant 3**		
	Feeling	**Technical expertise**	**Mastery of processes/ workflows**	**Feeling**	**Technical expertise**	**Mastery of processes/ workflows**	**Feeling**	**Technical expertise**	**Mastery of processes/ workflows**
Feeling	EI	EI	MMI	EI	MMI	SMI	EI	EI	EI
Technical expertise		EI	MMI		EI	MMI		EI	EI
Mastery of Processes/workflows			EI			EI			EI

The matrixes were averaged (A^2), squared and normalized, resulting in the aggregation index eigenvector (AI), as shown in Table 5-23.

Table 5-23: Obtaining the aggregation index eigenvector

	Average (A)			**A^2**			**i**	**Aggregation index (AI)**
Feeling	1.00	1.67	3.00	3.83	5.00	9.89	18.72	0.48
Technical expertise	0.78	1.00	2.33	2.75	3.59	7.00	13.34	0.34
Mastery of Processes/workflows	0.51	0.56	1.00	1.45	1.96	3.83	7.25	0.18
∑(i)							**39.31**	**1.00**

Based on the feeling (F), technical expertise (X), and mastery of processes and workflows (M) indexes, the relative weights of each worker are calculated by Equation 5-1, where *i* represents each worker. Results are shown in Table 5-24.

Equation 5-1: Relative weights of workers (*W*)

$$W_i = \sum_{i=1,..,n} (F_i \times X_i \times M_i) \times AI_i$$

Table 5-24: Calculation of relative weights of workers

	Feeling (F)	**Expertise (X)**	**Mastery (M)**	**Aggregation index (AI)**	**Weights (W_i)**
Worker 1	0.68	0.22	0.09	0.48	0.41
Worker 2	0.26	0.44	0.45	0.34	0.36
Worker 3	0.06	0.35	0.45	0.18	0.23
∑					**1.00**

Following, workers were asked to evaluate the relative importance of sub-criteria to the formation of each main criterion (current clinical conditions, family social conditions, and patient social conditions). This generated fuzzy normalized eigenvectors for each sub-criterion. Then, main criteria had been pairwise-compared generating the fuzzy normalized eigenvector of relative importance of main criteria. The evaluation of the importance of family social conditions by the worker 1 and the respective normalized eigenvector can be seen in Table 5-25.

Table 5-25: Pairwise evaluation of the importance of family social conditions by worker 1

Family Social Conditions (C1)					
Worker 1	**Linguistic term**				**Normalized eigenvector λ_{SE1}**
	C1.1	**C1.2**	**C1.3**	**C1.4**	
Sewerage (C1.1)	EI	SMI	SMI	SMI	(0.55, 0.57, 0.55)
House conditions (C1.2)		EI	MMI	MMI	(0.16, 0.24, 0.24)
Income (C1.3)			EI	EMI	(0.23, 0.15, 0.15)
Government allowance (C1.4)				EI	(0.05, 0.04, 0.06)
				∑	**(1.00, 1.00, 1.00)**

The operation was reproduced for each worker. Following, the resulting eigenvectors have been multiplied by the relative weights of respective workers, providing weighted eigenvectors. The average of weighted eigenvectors is normalized resulting in the relative family conditions criteria eigenvector (λ_{S1}) as shown in Table 5-26.

Table 5-26: Obtaining the family conditions sub-criteria weights eigenvector

W_i	**0.41**	**0.36**	**0.23**	**Average**	**Normalized eigenvector λ_{S1}**
Sewerage (C1.1)	(0.23, 0.23, 0.23)	(0.10, 0.12, 0.14)	(0.09, 0.09, 0.09)	(0.14, 0.15, 0.15)	(0.42, 0.45, 0.46)
House conditions (C1.2)	(0.07, 0.10, 0.10)	(0.08, 0.09, 0.10)	(0.03, 0.03, 0.03)	(0.06, 0.07, 0.08)	(0.18, 0.22, 0.23)
Income (C1.3)	(0.10, 0.06, 0.06)	(0.10, 0.08, 0.06)	(0.09, 0.09, 0.09)	(0.10, 0.08, 0.07)	(0.29, 0.24, 0.21)
Gov. Allowance (C1.4)	(0.02, 0.02, 0.03)	(0.08, 0.06, 0.06)	(0.01, 0.01, 0.01)	(0.04, 0.03, 0.03)	(0.11, 0.09, 0.10)
∑					(1.00, 1.00, 1.00)

This procedure is reproduced to the other set of sub-criteria related to patient individual social conditions, giving the results demonstrated in Table 5-27.

Table 5-27: Obtaining the individual social conditions sub-criteria weights

W_i	**0.41**	**0.36**	**0.23**	**Average**	**Normalized eigenvector λ_{S2}**
Education (C2.1)	(0.08, 0.08, 0.08)	(0.06, 0.08, 0.09)	(0.06, 0.07, 0.08)	(0.07, 0.08, 0.08)	(0.20, 0.23, 0.25)
Employment (C2.2)	(0.06, 0.08, 0.09)	(0.05, 0.07, 0.07)	(0.07, 0.07, 0.07)	(0.06, 0.07, 0.08)	(0.18, 0.21, 0.23)
Family situation (C2.3)	(0.06, 0.05, 0.04)	(0.10, 0.10, 0.09)	(0.01, 0.02, 0.02)	(0.06, 0.05, 0.05)	(0.17, 0.16, 0.15)
Referred illnesses (C2.4)	(0.05, 0.04, 0.03)	(0.06, 0.05, 0.04)	(0.01, 0.01, 0.01)	(0.04, 0.03, 0.03)	(0.12, 0.10, 0.08)
Health group (C2.5)	(0.05, 0.04, 0.03)	(0.05, 0.04, 0.03)	(0.02, 0.02, 0.02)	(0.04, 0.03, 0.03)	(0.11, 0.10, 0.08)
Age group (C2.6)	(0.12, 0.13, 0.14)	(0.03, 0.02, 0.03)	(0.06, 0.05, 0.04)	(0.07, 0.07, 0.07)	(0.21, 0.20, 0.21)
∑					**(1.00, 1.00, 1.00)**

The current clinical conditions sub-criteria are related to the color assigned to the patient due to symptoms he presented. As it is made according to the Manchester triage protocol, the relevance of colors is already defined, thus it's not necessary to capture the opinions of workers (JATOBA, BELLAS, *et al.*, 2014). Table 5-28 shows the calculation of the normalized eigenvector for each color of the Manchester scale for patients' symptoms.

Table 5-28: Obtaining the normalized eigenvector for each color risk color

	Lingustic term	**Normalized**

	Blue	**Green**	**Yellow**	**Red**	**Black**	**eigenvector λ_{S3}**
Blue	EI	MMI	SMI	VMI	EMI	(0.50, 0.51, 0.46)
Green		EI	MMI	SMI	VMI	(0.26, 0.27, 0.28)
Yellow			EI	MMI	SMI	(0.13, 0.13, 0.14)
Red				EI	MMI	(0.07, 0.07, 0.09)
Black					EI	(0.04, 0.03, 0.03)
					∑	**(1.00, 1.00, 1.00)**

The next step is obtaining the relative weights of the main criteria. The procedure to obtain these indexes is the same performed before: Workers made pairwise comparisons of main criteria; matrixes are squared and normalized resulting in the main criteria relative weights eigenvector. Table 5-29 shows the evaluation made by each Worker.

Table 5-29: Pairwise comparison of main criteria according to Workers

	Worker 1			**Worker 2**			**Worker 3**		
	C1	**C2**	**C3**	**C1**	**C2**	**C3**	**C1**	**C2**	**C3**
Family conditions (C1)	EI	EI	EI	EI	EI	EI	EI	EI	EI
Individual conditions (C2)		EI	EI		EI	EI		EI	MMI
Current clinical conditions (C3)			EI			EI			EI

Converting linguistic terms in triangular fuzzy numbers, averaging, normalizing led us to the normalized eigenvector for the relative importance of the main criteria (λ_C) as shown in Table 5-30.

Table 5-30: Weighing main criteria

W_i	**0.414**	**0.357**	**0.229**	**Avarege**	**Normalized eigenvector** λ_C
Family conditions (C1)	(0.14, 0.14, 0.14)	(0.12, 0.12 0.12,	(0.08, 0.07, 0.06)	(0.11, 0.11, 0.11)	(0.34, 0.33, 0.32)
Individual conditions (C2)	(0.14, 0.14, 0.14)	(0.12, 0.12 0.12,	(0.08, 0.11, 0.11)	(0.11, 0.12, 0.12)	(0.34, 0.36, 0.37)
Current clinical conditions (C3)	(0.14, 0.14, 0.14)	(0.12, 0.12 0.12,	(0.06, 0.05, 0.06)	(0.11, 0.10, 0.11)	(0.32, 0.31, 0.32)
∑					**(1.00, 1.00, 1.00)**

Finally, Equation 5-2 shows the risk of the patient (R_p), obtained by the sum of each sub-criterion, multiplied by its relative weight (λ_s), and multiplied by the relative weight of its main criterion (λ_C).

Equation 5-2: Patient risk

$$R_p = \sum_{i=1,\ldots n}^{k} (S_{ik} \times \lambda_{Sik}) \times \lambda_{Ck}$$

5.3.6 Results

A total of 15 hours of fieldwork in a primary health care facility in Rio de Janeiro, Brazil has been conducted as shown in Table 5-31. Initial interviews with clinic managers have been carried out in order to define initial procedures like schedules, scope, and contents of invitation letters. The field research was completed with a validation session of two hours to present the process and its results, as well as discuss future developments. Two nurses and one manager participated in the validation session.

Table 5-31: Fieldwork hours

	Sessions	**Duration**	**Total**
Interviews with manager	4	1h 30 min	6 h
Interviews with workers	14	30 min	7 h
Validation session	1	2 h	2 h
Total			**15 h**

Once presented to the three scenarios seen in section 5.3.5.4, workers have been asked to represent each patient's conditions using linguistic variables. These patient conditions have been converted to triangular fuzzy numbers and Equation 5-2 has been applied to calculate the risk of patients for each scenario as shown in Table 5-32. Graphic representations of fuzzy numbers that represent the three patients' conditions are shown in figures Figure 5-28, Figure 5-29, and Figure 5-30.

Table 5-32: Patients' conditions and calculations of risks represented in fuzzy numbers

Criteria		**Scenario 1**	**Scenario 2**	**Scenario 3**
Family conditions	**Sewerage**	(2.95, 4.08, 4.13)	(0.42, 0.45, 0.46)	(2.11, 3.17, 4.13)
	Income	(1.23, 1.95, 2.06)	(0.18, 0.65, 1.14)	(0.18, 0.65, 1.14)
	Gov. allowance	(2.02, 2.14, 1.91)	(2.02, 2.14, 1.91)	(0.29, 0.71, 1.06)
	House conditions	(0.11, 0.28, 0.50)	(0.80, 0.83, 0.89)	(0.80, 0.83, 0.89)
	$\sum S_i$	(2.16, 2.79, 2.71)	(1.17, 1.35, 1.39)	(1.15, 1.77, 2.28)
Individual conditions	**Education**	(0.61, 1.17, 1.75)	(0.61, 1.17, 1.75)	(1.01, 1.63, 2.25)
	Employment	(1.29, 1.88, 2.06)	(1.29, 1.88, 2.06)	(0.55, 1.05, 1.60)

	Family situation	(0.17, 0.48, 0.75)	(0.51, 0.81, 1.05)	(0.17, 0.48, 0.75)
	Referred illnesses	(0.12, 0.10, 0.08)	(0.12, 0.10, 0.08)	(0.12, 0.10, 0.08)
	Health group	(0.34, 0.48, 0.58)	(0.11, 0.10, 0.08)	(0.56, 0.67, 0.75)
	Age group	(0.63, 1.01, 1.46)	(0.21, 1.01, 1.46)	(1.48, 1.82, 1.87)
	$\sum S_i$	(1.08, 1.86, 2.46)	(0.97, 1.84, 2.39)	(1.33, 2.09, 2.70)
Current clinical conditions		(0.41, 0.57, 0.79)	(0.08, 0.24, 0.44)	(0.12, 0.20, 0.32)
	R_{Pi}	(3.64, 5.22, 5.96)	(2.22, 3.43, 4.22)	(2.60, 4.06, 5.29)

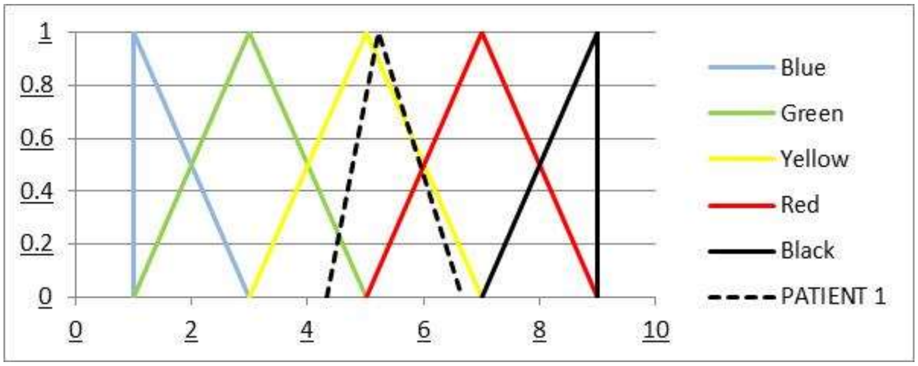

Figure 5-28: Graphic representation of patient 1's conditions

The dashed triangles in figures Figure 5-28, Figure 5-29, and Figure 5-30 are the calculated patient risks represented in a triangular fuzzy numbers. The areas occupied by the dashed triangles represent their memberships in the risks fuzzy sets, i.e. their potential to each color of the risk scale. For example, we can see in Figure 5-28 that the risk of the first patient is positioned between the green, yellow, and red fuzzy sets, but most of its area occupies the yellow space, which means that, according to the approach we propose in this paper, the patient should potentially be assigned the risk yellow.

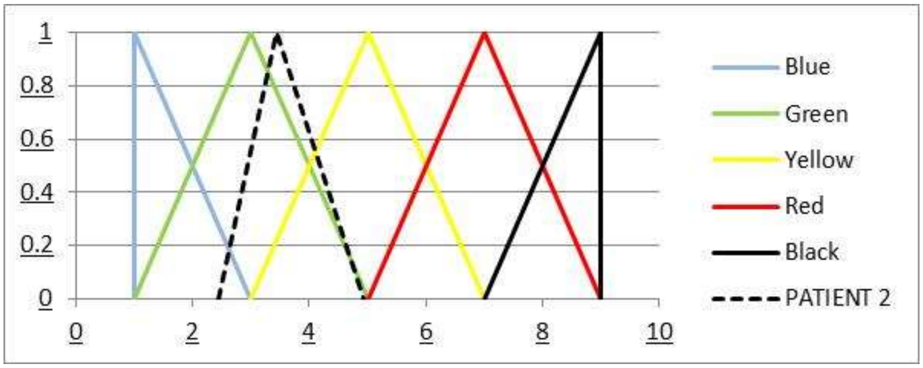

Figure 5-29: Graphic representation of patient 2's conditions

Similarly, we see in Figure 5-29 the conditions of the second patient, in which the calculated risk occupies mostly the green fuzzy set, demonstrating the potential for the risk green to this scenario. Furthermore, we see in Figure 5-30 shows slightly bigger potential for the color green rather than the color yellow, with little potential for the color red in the third scenario.

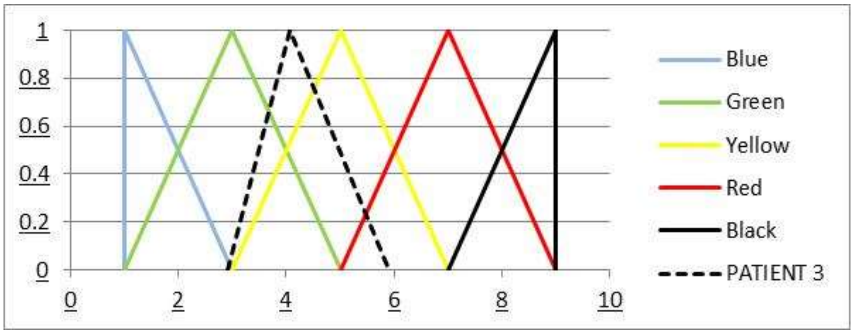

Figure 5-30: Graphic representation of patient 3's conditions

5.3.7 Discussion

When presented to the first scenario, 53% of interviewed workers stated that the patient one should be assigned the color green, while 33% stated that the patient should be assigned the color yellow. Moreover, 73% of interviewees stated that patient should not receive the color blue and 46% stated that the patient should never be assigned the color red. We can see in Figure 5-28 that according to the proposed model the patient represented in the first scenario holds membership among the colors green, yellow and red, with highest membership in the color yellow, followed by the color green, and slightly below, the color red.

Furthermore, in the second scenario, 60% interviewees stated that the patient should be assigned the color yellow and 33% the color green. 80% Interviewees stated that in this scenario the patient should not be assigned the color blue, while 33% stated that the patient should not receive the color red. In this case, we see in Figure 5-29 that our approach presents the patient conditions between the colors green and yellow, with higher – although not much -membership for the color yellow, matching the assessment suggested by interviewees. However, the approach presented in this paper shows potential – although very little – for the color blue in this scenario.

Regarding the third scenario, 60% interviewees stated that the patient should be assigned the color green, and 26% stated that the patient should be assigned yellow. Furthermore, approximately 20% interviewees stated that the patient should receive the color blue, although 60% stated that the color blue should not be assigned to the patient in any ways, as well as the color red with 53%. In Figure 5-30 we see that our approach puts the patient's conditions among the colors green and yellow – similar to what the interviewees suggested. However, it includes a very low membership in the color red, and no membership in the color blue.

We can see that despite minor differences the approach we present in this paper shows results that are similar to expert opinions in most cases, as we can see in the areas occupied by the dashed triangle in figures Figure 5-28, Figure 5-29, and Figure 5-30. It's important to highlight that half the interviewees stated that the presented scenarios lacked information for a more accurately risk assessment. For example, there was no information about patients' education status, which they consider important.

Also, some interviewees stated that other symptoms, as well as the time the patients have been presenting such symptoms are important information which could not be seen in the presented scenarios. Moreover, previous knowledge about the patient influences the risk and it was not possible to reproduce this feature in the scenarios. All those issues are potential causes of some discrepancies between the assessments suggested by our approach ant the opinion of workers.

It's also important to highlight that some interviewees stated that they didn't take the sewerage criteria into consideration while assessing the risk of the patients in the presented scenarios. They stated that the location of the primary healthcare facility is known for having bad sewerage conditions, thus if they took this into account, most patients would get the color red. We can see in figures Figure 5-28, Figure 5-29, and Figure 5-30 that except for the third scenario – in which the patient lives in represented as living in a location with good sewerage conditions – the color red has some membership.

Another point of discussion goes on who is responsible for assessing patient's conditions. Primary care processes occur in participatory and multidimensional ways, also having the patient himself responsibility for his own health. Aspects of shared decision making in the medical context, many of them emphasizing the patient-physician shared participation in the medical decision making process should be take into account in those cases (MOUMJID, GAFNI, *et al.*, 2007).

5.3.8 Conclusions

The patient risk assessment process in primary healthcare is performed under uncertainty and subjectivity, hampered by hazardous environment, workers' dynamic behaviour, and unpredictable patients' conditions, Moreover, workers in these environments are highly affected by time pressure, difficult communication, and traffic of ambiguous ant tacit information, among other issues that increase physical and cognitive workload. In cases like this, traditional methods to support decision making are not suitable.

Thus, in this paper we explore the decision making in patient triage and risk assessment in primary health care, providing a decision support model based on fuzzy logic that encompasses health care workers' practices, protocols, mental models, and decision making in order to cope with uncertainty and imprecision of human evaluation of patients' conditions.

Results of fieldwork carried out in a primary health care facility point out that the proposed approach presents recommendations of patients' risks that match workers suggestions in the presented trial scenarios. Some discrepancies that appeared in some cases might be resultant of the scenarios used for the experimentation and might be solved with few adjustments in the proposed approach. Thus, an interesting future work could be the deepening of the analysis to enable the inclusion of extra inputs, as well as the different combinations of the existing criteria.

One limitation of this study is that the proposed fuzzy model makes the evaluation of all criteria mandatory for all patients, although some cases could be seen during field work that workers do not take into account all the criteria defined in the patient risk assessment protocol. Therefore, another suggestion for future work is to enable the exclusion of criterion according to the patient whose risk is being assessed.

Other limitation regards the combination of criteria. According to some interviewees, the relative importance of some criteria might change due to combination of criteria. For example, the health group might be more important depending on house conditions. Thus, it would be interesting to implement such feature in the fuzzy model in order to support this issue and provide more consistent risk suggestions.

Moreover, we believe the approach we propose in this paper provides reliable information about patients’ conditions, improving the design of decision support tools, and enabling health care workers to perform the patient triage in a more stable, standardized, comfortable, and consistent way.

5.4 Article 4: A Hierarchical Approach for Triage on Family Health Care

5.4.1 Foreword

This chapter presents an approach to support decision making in assigning of risk rates for patients of spontaneous demands in the Brazilian Family Healthcare Strategy. This approach was elaborated based on concepts of the Fuzzy Set Theory and AHP - Analytical Process Hierarchy and implemented in a Primary Healthcare Facility in the City of Rio de Janeiro.

The proposed approach can be used as an additional tool to support the work of healthcare professionals, providing further criteria for their decision making. It is complementary to the latter paper, as it presents a model to support physical aspects of the evaluation of patients' conditions.

Citation information for this chapter's resulting scientific paper can be seen below:

Jatoba, A., Bellas, H.C., Vidal, M.C., de Carvalho, P.V.R. A fuzzy AHP approach for risk assessment on family health care strategy. In: Vincent Duffy;Nancy Lightner. (Org.). Advances in Human Aspects of Healthcare. 1ed.Danvers: AHFE Conference © 2014, 2014, v. 3, p. 470-480

5.4.2 Introduction

The increasing computerization of work processes without considering workers' current information requirements produces gaps between workers and the subjects of their work, resulting in urgent decisions without prior knowledge about the variables involved in the problem, and without adequate time for planning and selecting options. Thus, the adoption of assistive devices inevitably transforms the way people work.

If one considers the use of Information and Communication Technologies (ICTs), these devices may also entail the emergence of new possibilities of action and hence new types of process failures. These new possibilities for action increase the number of feasible variations in the process, making the system more complex, increasing the probability of new types of imperceptible faults. Such a fact occurs especially because in complex systems work is mostly underspecified, so operators make use of adaptations, improvisations, and creativity in tasks performance. In most cases these adaptations lead to expected results, but sometimes the results of their combination are unpredictable (WOODS e HOLLNAGEL, 2006).

Thus, the approach proposed in this work is inspired on Primary Healthcare Facilities (PHF) that perform the Family Healthcare Strategy in the City of Rio de Janeiro. Work in these environments has essential characteristics of complex socio-technical systems, like strong presence of variability and adaptability, and freedom in arrangement of work by professionals, in addition to cooperative joint in performing activities.

In this paper we suggest an approach to provide more inputs to the Risk Assessment Process in primary health care. We use of concepts of Fuzzy Logic and Analytical Hierarchy Process (AHP) to contribute to the standardization of this process, in order to minimize discrepancies on evaluations of patient risk between teams, improving the quality of decision.

5.4.3 Motivation

The Brazilian Constitution states that the Government has the duty to ensure "universal and equal access to healthcare services for its promotion, protection and recovery," adding "comprehensive care, with priority given to preventive activities, without prejudice to assistance services." If we consider that last part of the text, when it comes to "priority to preventive activities without prejudicing care services", the role of the Family Healthcare Strategy (FHS) as part of the healthcare framework proposed by the Brazilian Unified Healthcare System (SUS) becomes clear.

On Primary Healthcare Facilities (PHF) that perform FHS, work should be characterized in preventive care and thus presents a great distinction to Emergency Care. In PHFs, consultations must be scheduled. However, this is not what actually happens. On data extracted from the computerized system used on the PHF where this work has been performed, analyzing 2,800 consultations in November 2013, 53% of the nursing care visits are spontaneous statements, i.e., those in which the patient comes to the facility without an appointment, complaining of some symptoms, like pain or fever, for example. In the case of medical care visits, this proportion rises to 76.6%. Only in dental care visits that number is below half, and still reaches 23.4%.

Such information highlights the mischaracterization of the service provided by FHS, which departs from its fundamental principles of health promotion and disease prevention. It is also worth mentioning that patients in emergency situations undergo a process entitled "Risk Assessment" in which its severity is assessed and the decision to provide care or not is made. This article suggests a way to improve this process, increasing its stability, helping to standardize it and thus improving the accuracy of cases referred from spontaneous statements.

Developing devices to support work in complex systems, especially when it comes to collaborative team work, requires deep understanding of how people work, their principles, their shared processes and strategies. Given the set of decisions taken by professionals in the performance of their activities, the complexity of the system in which their work is performed, which involves, literally, life and death of people - the approach presented in this article can bring important contributions to the improvement of work conditions, providing more inputs to decision making.

5.4.4 Results

Risk assessment is a dynamic process for the identification of patients who require immediate treatment, according to their potential risk, health problems or degree of distress, giving priority to care according to the clinical severity of the patient, and not to the order of arrival at the facility. The evaluation of risk and vulnerability cannot be considered sole prerogative of healthcare professionals.

Moreover, patients and their social network should also be considered in this process. Assessing risk and vulnerability involves being aware of patient's both physical and mental suffering degree. For example, the user who comes walking without visible signs of physical problems, but very distressed, might be a priority, with a higher degree of risk and vulnerability than other patients with visible symptoms. It is also important to emphasize that on the assessments made in healthcare work, professionals of different levels of experience and different fields of activity need to solve problems of various levels of complexity. Also, according to the development of such expertise, practitioners are more dependent upon clinical experience, which is in turn dependent on the analogy between the cases that have occurred (PATEL, KAUFFMAN e AROCHA, 2002).

Evaluating the behaviour of a complex system through expert opinion and a basic set of attributes means representing the process of decision-making. It depends on several factors, like selecting among available alternatives. Whereas the reliability analysis is constantly undetermined by the unpredictable behaviour of operators in complex systems - like public healthcare system - the probabilistic approach is not the most appropriate one for solving such problems.

Moreover, making decisions is an essential and integral part of medical and nursing practice, as health care workers express clinical judgment about the patient care by intuition and reflection, based upon professional knowledge and skills (MANCHESTER TRIAGE GROUP, 2005).

In order to understand how work is carried out in the PHF, Ergonomic Work Analysis (VIDAL, 2008) has been performed, in which professionals involved in risk assessment were observed and interviewed at their workplace. The field study was done in a PHF that performs FHS in Rio de Janeiro. A survey was conducted through semi-structured interviews with 10 professionals engaged in the risk assessment process in the PHF. During these interviews, professionals should, from a set of symptoms indicated in the Reception Booklet of the Brazilian Ministry of Health (MINISTÉRIO DA SAÚDE, 2004), point which color should be assigned to each symptom if a patient attended the PHF.

Professionals were asked to assign a degree of importance for symptoms, starting from most important to least important, within the color scale that determines the risk rates.

5.4.4.1 Reception with Risk Assessment on Family Healthcare Strategy

Reception is considered the gateway that patients use to access the set of services provided by Family Healthcare Strategy. It is a process of human relations done by all healthcare workers in all sectors of care, not only receiving, but performing a sequence of attitudes and modes that make healthcare, listening to the needs of the patient (SILVEIRA, FÉLIX, *et al.*, 2004).

In summary, the result of a complete flow of reception means fulfilling a care agenda to the patient. Along the way, various health care activities are carried out. Because of that, the Reception is the key process of the Family Health Strategy.

The definition of levels of risk of patients follows a protocol in which colors are assigned to patients according to the severity of their symptoms, similar to Manchester Risk Rating Scale (MANCHESTER TRIAGE GROUP, 2005). Figure 5-31 shows the hierarchy of risk assessment used in PHF this work was carried out and their respective outputs.

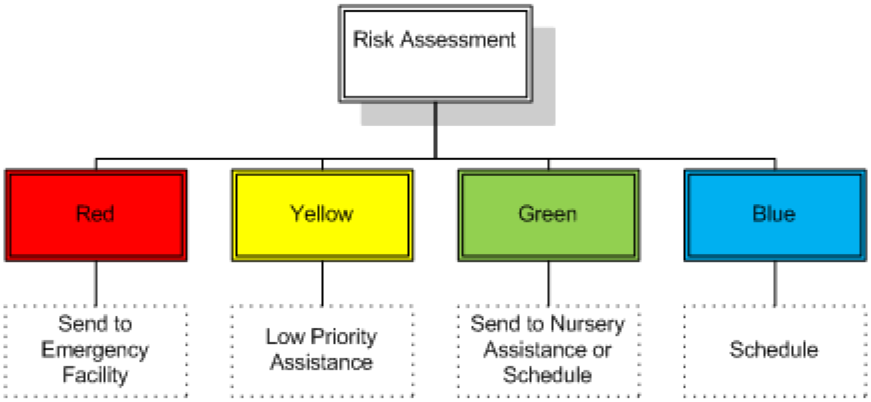

Figure 5-31: Risk Assessment Hierarchy

The same risk assessment scoring system is suggested for all the healthcare framework of SUS, not only for Family Healthcare. Therefore, Roncato, Roxo, & Benites (2012) suggest a set of criteria / symptoms that, when noticed, are related to each color of a family healthcare specific scale. This set of criteria / symptoms suggested by the authors was presented to the professionals working in the PHF.

Then, workers could suggest the inclusion and/or exclusion of symptoms as well as the correlation of symptoms with colors, according to the reality of the population they assist at the PHF, resulting in the set of criteria and respective colors shown in Table 5-33

During the fieldwork, there were no significant indications for symptoms to the Red color scale. Patients receive a Red rating when they have severe symptoms and need emergency care and are therefore referred to the nearest Emergency Facility.

Table 5-33: Symptoms and Respective Risk Rating. (mm Hg - mm Hg, mg / dL - milligram per deciliter)

	Yellow	Green	Blue
Criteria / Symptoms	Asthmatic crisis; Acute abdominal pain, nausea or Acute diarrhea with signs of dehydration; Vomiting; Low back pain with urinary symptoms or fever; Chest pain (> 2 hours) Fever (39 ° c); Pregnant women: pain in lower abdomen, loss of vaginal fluid; HGT> 300mg/dl or <50mg/dl; Symptomatic Hypertension: BP> 150/100 mmHg with headache vomiting; Blood pressure <80/40 mmHg.	Diaper rash in babies; Menstrual Cramp; Constipation; Chronic pain recently worsened; Ear pain; Headache or dizziness, without alteration of vital signs; Loss of appetite in children without change of vital signs; Red eye with conjunctival irritation; Blood pressure> 170/100 mmHg; Prostration in children; Urinary symptoms; Suspected pediculosis; Suspected chickenpox; Cough, nasal congestion, runny nose and fever < 38.5 ° C; Vertigo.	Attestations and awards; Menstrual delay (more than 30 days); Menstrual delay (less than 30 days); Routing-references; Problems or complaints for more than 15 days; Prescription refills; Request and / or return of exams.

Some testimonies made during interviews:

- "Of the symptoms that you listed as Red, most are actually Yellow for us";
- "Sometimes a patient appears with symptoms of a Red, but is assisted anyway, as he may have other symptoms".

At the PHF this study was conducted, risk rating is performed by a team of two people, on rosters - each day of the week the team has different formations. These teams interact freely with other professionals during the performance of their tasks, either to ask questions or to obtain new information that may be relevant for the assignment of patient risk.

Although the color system is used by all teams, each team applies the criteria its own way, making this process unstable. During interviews, it was possible to identify the need for standardization of this process, as can be seen in some testimonies:

- "The Risk Assessment process is the subject of the greatest suffering in our practice";
- "When the patient is assisted by the nurse who does the rating herself, many times she/he does not assign any color";
- "Sometimes I forget to assign color and just assist the patient";
- "Sometimes we receive a patient complaining of a symptom and we are not warned that it is not a first application but a return to the clinic."

5.4.4.2 Scenario

To illustrate the application of the approach suggested in this article, we present the results obtained in the case of a patient - a child - is welcomed at PHF complaining of abdominal pain.

Once received by the community health care agent – in his booth - that verifies that no appointment is scheduled, the patient is forwarded to the risk assessment team.

A preliminary evaluation performed by the nurse detected four symptoms

- Problems or complaints for more than 15 days;
- Depletion in children;
- Acute diarrhea with signs of dehydration;
- Inadequate breathing.

5.4.4.3 Assigning Degrees of Risk through Fuzzy Logic and AHP

The set of alternatives and output options is the center of decision-making. In the construction of a decision framework, we first need to organize the elements into hierarchically arranged groups according to their effects and influence on the context.

In this study, we used the Fuzzy Sets Theory (ZADEH, 1965) applied to the framework provided by AHP (SAATY, 1977), to bring this approach further the context of imprecision that involves decision making in the complex health care system in which the Family Healthcare Strategy is included.

In the case shown in this work, for each degree of risk represented by a color, there are a number of criteria. The importance of one color in relation to another is already determined - for example, the Yellow rating is less critical than Red - and thus the criteria for each color were not compared with criteria of each degree of risk. The relevance of a criterion at a given level of risk can be demonstrated by means of the Fuzzy Sets Theory, as shown in Figure 2.

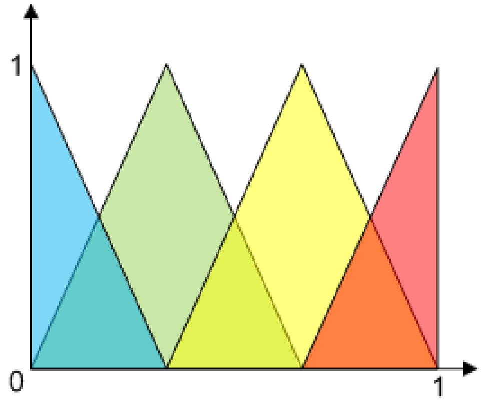

Figure 2: Relevance of Criteria / Symptoms to Degrees of Risk

Table 5-34 presents a matrix for all four criteria/symptoms used in this case study. The matrix shows the importance of criteria/symptoms, one compared the others, as determined by the risk assessment model. The results are used in the next steps for obtaining the cumulative rank in relation to output options.

Table 5-34: Pairwise matrix of assessment criteria.

	Blue Risk	**Green Risk**	**Yellow Risk**	**Red Risk**
Blue Risk	1/1	1/2	1/3	¼
Green Risk	2/1	1/1	1/2	1/3
Yellow Risk	3/1	2/1	1/1	1/2
Red Risk	4/1	3/1	2/1	1/1

Further, we obtain a ranking of priorities from the pairwise matrix. For this, fractions are converted to decimal numbers. Following, we square and normalize the matrix, resulting in the prioritization vector shown in Table 5-35.

Table 5-35: Obtaining de prioritization vector

				i	**i/∑(i)**
4.0000	2.4167	1.4167	0.8750	8.7083	0.0793
6.8333	4.0000	4.0000	2.5000	17.3333	0.1579
12.0000	7.0000	5.5000	3.4167	27.9167	0.2543

30.0000	13.0000	7.8333	5.0000	55.8333	0.5085
			∑(i)	**109.7917**	**1.0000**

The prioritization vector indicates that the highest value of the normalization is the most important criteria/symptom, and so on. However, this order has no surprises, as the patient has a criterion/symptom of each rating and the importance of each color is given by the scale used in the PHF. However, the index obtained – i/Σ(i) - is important to calculate the cumulative prioritization of outputs.

Criteria/symptoms are now compared with output options (decisions). The possible outputs in the case study are the degrees of the proposed Risk Assessment Scale Risk: Red, Yellow, Green and Blue. Opinions of healthcare professionals, expressed in natural language, are taken to relate criteria to output options.

The criteria are not expressed in exact terms, and thus, the evaluation of a symptom may have greater relevance to a given degree of risk in some cases when compared to others.

Thus, professionals were given the opportunity to assess the relevance of each symptom in relation to the risk degree. According to its incidence, the suitability of each color to a symptom was established. Table 5-36 illustrates this situation, the opinion of professionals for the symptom "prostration in children", ie, among the respondents, there were twice as many Green assignments than Yellow for this symptom. The columns with 0 (zero) mean that no professionals have indicated the related colors for the assessed symptom.

Table 5-36: Evaluation of the symptom "prostration in children" by professionals

Prostration in children				
	Blue	**Green**	**Yellow**	**Red**
Blue	0	0	0	0
Green	0	1/1	2/1	0
Yellow	0	1/2	1/1	0
Red	0	0	0	0

The same operation used to generate the prioritization vector should be repeated, creating pairwise matrices for each criteria/symptom as can be seen in Tables Table 5-36Table 5-40.

Table 5-37: Prioritization for "Problems or complaints..."

Problems or complaints on more than 15 days					
				i	**i/∑(i)**
2.0000	0.6667	0.0000	0.0000	2.6667	0.1600
6.0000	2.0000	0.0000	0.0000	8.0000	0.4800
3.0000	0.0000	0.0 00	0.0000	3.0000	0.1800
3.0000	0.0000	0.0000	0.0000	3.0000	0.1800
			∑(i)	16.666	1.0000

Table 5-38: Prioritization for "Prostration..."

Prostration in children					
				i	**i/∑(i)**
0.0000	0.0000	0.0000	0.000	0.0000	0.0000
0.0000	2.0000	4.00 0	0.0000	6.0000	0.6316
0.0000	1.0000	2.0000	0.0000	3.0000	0.3158
0.0000	0.5000	0. 000	0.0000	0.5000	0.0526
			∑(i)	9.5000	1.0000

Just as the prioritization index has been obtained from the pairwise matrix of output options on Table 5-34, to assess the relevance of each symptom in relation to output options, the fractions are converted to decimal numbers and, by squaring the matrix and normalizing column sums, prioritization vectors for each criterion / symptoms presented by the patient are obtained.

Table 5-39: Prioritization for "Diarrhea..."

Acute diarrhea with signs of dehydration					
				i	**i/∑(i)**
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	2.0000	0.6667	0.0000	2.6667	0.1951
0.0000	6.0000	2.0000	0.0000	8.0000	0.5854
0.0000	3.0000	0.0000	0.0000	3.0000	0.2195
			∑(i)	13.6667	1.0000

Table 5-40: Prioritization for "Inadequate Breathing"

Inadequate Breathing					
				i	**i/∑(i)**
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	1.0000	1.0000	1.0000
			∑(i)	1.0000	1.0000

Using the values of the prioritization vectors, multiplying matrices by the ranking, we obtain the cumulative ranking of output options. Table 5-41 shows the results of such operations:

Table 5-41: Cumulative ranking of output options

Criteria/Symptoms							
		Probl./Compl.	**Prostration...**	**Diarrhea...**	**Inadeq. Breath.**	**Ranking (Rf=Pc*i)**	
	i	**0.0793**	**0.1579**	**0.2543**	**0.5085**		**%**
Outputs	Blue	0.1600	0.0000	0.0000	0.0000	0.0127	0%
	Green	0.4800	0.6316	0.1951	0.0000	0.1874	15%
	Yellow	0.1800	0.3158	0.5854	0.0000	0.2130	20%
	Red	0.1800	0.0526	0.2195	1.0000	0.5869	57%
					∑(Rf)	**1,0000**	

The cumulative prioritization described in Table 5-41 demonstrates that according to the combination of criteria/symptoms, the patient has 57% chance of “being” Red, 20% chance of Yellow and a 15% chance of having Green risk. These results are illustrated graphically in Figure 5-32.

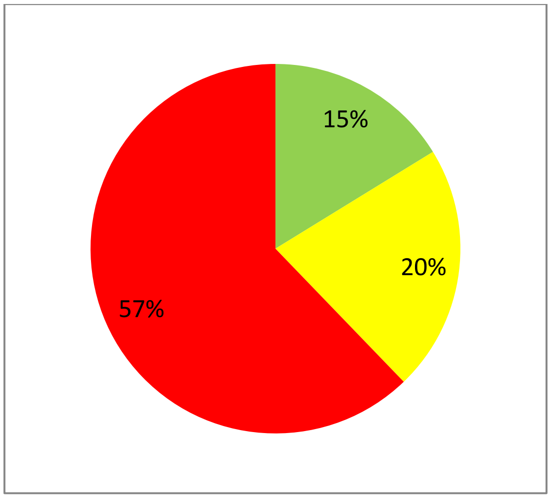

Figure 5-32: Suggested allocation of the patient's degree of Risk

The suggested approach shows the use of an inference mechanism that may be implemented in information technologies, and fit as an additional input for decision-making in the complex healthcare system.

5.4.5 Conclusions and Further Work

Health care facilities are characterized by a paradox: just as work features a lot of repetition, there is enormous variability, as the occurrences always have different characteristics. The sort of problem to be handled every day is unpredictable.

These factors point out the great cognitive effort made by health care workers while carrying out their activities, increased by the importance of the decisions made in health care environments.

Thus, this paper presents an approach to provide extra inputs to support decision-making in a major process on Brazilian Family Healthcare Strategy – the Risk Assessment process. We took advantage of concepts of the Fuzzy Sets Theory to establish the membership of criteria/symptoms on each degree of a risk scale, and AHP to prioritize the options according to the symptoms seen in patients. With such extra inputs, the risk assessment on Family Healthcare Strategy might be improved and standardized, as well as be supported by information.

Furthermore, it is important to highlight that the approach presented in this article was not used to define the order of patient entering a health care facility, which might be an interesting future work. Also, the development of a computerized system to assist risk assessment using the inference mechanism shown in this paper - and its proper trial - is also an good suggestion for further research.

Thus, healthcare professionals involved in this kind of work can carry out their activities more comfortable and confident, and get closer to the essentials of health care: to provide health care services that meet the needs of people.

6 Discussion

In this chapter, we present a discussion on the findings of this thesis, as a summary of the discussions presented in the results chapter. Table 6-1 shows a summary of the research effort in order to address the research questions presented in this thesis.

Table 6-1: Summary of the research effort

Research question	**Research effort**
Literature review	80h
1	38h
2	142h
3	30h
Total	**290h**

Furthermore, we enlist the core findings of this thesis:

- Ergonomics provides important features to good design for complex systems like health care. The employment of EWA in patient triage in primary health care shows useful in indicating points of tension and opportunities for intervention;
- Ergonomics and human factors concepts are able to enhance requirements specifications for information technology in complex systems like health care. Traditional software engineering approaches are poor for complex systems, and ergonomics and human factors is useful to add important information for software design;
- Fuzzy Hierarchical models are useful to support health care workers in making decisions about patients' risks, although algorithms must be used as a way of enhancing patient information and provide the means for better human decision making in patient triage.

First, we tried to demonstrate the contributions of an ergonomics approach to design for complex sociotechnical systems. Complex systems like health care are tensioned by high information requirements, therefore, context information effects decision-making significantly, which makes it difficult to design. Thus, we used EWA as an approach to design for patient triage in a health care facility, and EWA has shown promising in highlighting contextual and environmental aspects in people's work.

Our study has shown that the EWA was an effective method to identify redesign elements, elements in work situations that cause harm or discomfort for workers, and delimiting the boundaries of the intervention, i.e., parts of the work that need transformation or support. The results of the EWA provided descriptions of interactions between the elements of the system as a whole, improving comprehension of the domain and the gathering of knowledge from domain experts.

We also present in this thesis points for discussion on the influence of information technology support in complex systems like health care. Notably, design flaws in health information technology increase cognitive work, impact workflows, and patient harm. We believe that ergonomics can improve the design of technological support for complex systems by enhancing the description of software requirements.

Our study shows that, as complexity hampers the description of sociotechnical systems, comprehension of people's activities is usually poor – not only by systems designers, but by workers themselves. Thus, we believe that the indication of high-demanding work situations should be the first step to be taken in order to highlight the right candidates to technological support. Then, with the right candidates pointed out, ergonomics and human factors concepts and tools apply, to enhance the descriptions of software specifications.

However, our study has shown that classical workflow management systems work better for structured processes rather than complex, dynamic, and unpredictable systems like health care, although they have been useful to describe the boundaries of the process, enabling deeper analysis. One of the limitations of our study is that the results of the proposed method were not compared with the results of regular software engineering techniques.

Finally, we present discussions on the employment of fuzzy hierarchical models to support decision making on patient triage. Since patient risk assessment in the health care facilities that participated our study take into account social and biological aspects, two studies have been carried out to approach triage features.

Our studies demonstrate that the models suggested present results that are similar to expert opinions in most cases, although some interviewees have stated that the presented scenarios lacked information for a more accurately risk assessment and, thus, more accurate expert opinion for comparison. Moreover, information such as previous knowledge about the patient influences the risk, and it was not possible to reproduce this feature in the scenarios. Anyway, discrepancies between the assessments suggested by our approach and expert opinions are taken into account in our analysis.

The core finding of these studies is that fuzzy models do apply for triage support in primary health care. However, according to the results of our studies, the triage process is “too human” to be completely taken by any kind of computer algorithm, therefore, computer support in such decision processes must be restricted to providing enhanced information to human workers that can, thus, decide for themselves.

We conclude in this thesis that understanding – as largely as possible – is mandatory for an adequate design for any kind of systems, from the simpler to the more complex ones. Lack of knowledge about the system and how its components relate inevitably entails failures in the design, no matter if one is designing support tools, improved work processes, technological devices, etc.

Many factors – such as variability, unpredictability, emergence, and large sets of interconnected variables - challenge the gathering of information and building descriptions of complex systems. In these cases, good design is fostered not simply by understanding how workers behave, but by understanding what people think while performing their activities.

7 Conclusions and Further Work

In this chapter, we present some conclusions, in addition to the conclusions presented by each paper in the results chapter. We also recommend future work that might be useful to enforce the hypotheses that emerge from the research problem we present in this thesis.

First of all, we highlight the contributions of this thesis for Systems Design Engineering (Production Engineering in some countries) and Science. The elaboration of this study pointed out the ways cognitive engineering might entail the development of technology to support work in health care, improving work situations in patient triage.

We performed a detailed study of work performance, using ergonomics concepts and tools, and suggest the use of additional concepts such as CWA, requirements engineering, and fuzzy logic to design and build technological support to patient triage and risk assessment. Results were obtained and analysed, and they can foster future research in this field.

Innovation in this thesis relies on the combination of different approaches for work analysis, as well presenting a brand new fuzzy model for the assessment of patients' conditions and prioritization, enabling the construction of computerized devices to support decision-making in health care environments.

Since this thesis develops in the context of the Brazilian health care system, one of the major expectations is that its results might be employed in benefit of practical problems faced by the SUS and, especially, the Brazilian Family Healthcare Strategy. Social construction built to develop this thesis is large, and involves players in both the Group of Ergonomics and New Technologies (GENTE) at the Federal University of Rio de Janeiro and in the Coordination of the Family Health Care Strategy in the Municipality of Rio de Janeiro.

This engagement has worked not only in order to enable the development of this thesis, but continues working for the transferring of knowledge between parts and making the findings of this work useful to the work at the SUS. While we complete this thesis, results of its development is under experimentation at a family health care facility, and the results obtained will be useful to improve the patient triage and risk assessment process in such work environments.

Moreover, from an academic point of view, during its development, this thesis produced an amount of five scientific papers, all of them either published or submitted. Thus, we believe that the research effort employed to write this thesis produces results for both academia and industry.

Anyway, this work is limited by the reach of the fieldwork and by time constraints. To which relates to the reach of fieldwork, Brazilian family health care involves work in clinics and patients residences. Due to social constraints like urban violence, lack of authorization by authorities, among other aspects, we could not visit all the communities assisted by the health care facilities that participated this thesis.

The major limitation caused by time constraints relates to the lack of results of experimentation when trying to approach what might be an interesting related research question for future work, i.e. “How do software interfaces influence work in patient triage?”. This question is being explored as this thesis is completed, and we are performing an experiment to assess the implications of CWA and EID to approach it.

We also recommend future work to compare the approach we suggest for software requirements specifications to some traditional software engineering approaches. Presenting the results to software engineers - and collect their opinions - might be useful future work, since this could entail more comparisons and find specific gaps in software analysis that could be fulfilled by ergonomics and human factors. Our results point out that the requirements engineering process could benefit from the concepts, tools, and techniques suggested in this thesis, helping information systems to not only meet their technical requirements, but also to deliver anticipated support for real work in complex organizations.

To which relates to the application of EWA to highlight a set of problems in the risk assessment process, we recommend further work with more specific cognitive engineering techniques, employed to deepen the analysis and produce more detailed work descriptions, as decision making in such settings is difficult. One of our underway studies somehow, accomplishes this - when we employed CWA and EID in the patient triage process. However, in this study, our focus was on assessing the impacts how patient information displays on work performance, rather than finding problems.

Moreover, while proposing fuzzy models to support patient triage, we recommend as future work the deepening of the analysis to enable the inclusion of extra inputs and different combinations of criteria for the evaluation of patient conditions, as workers use criteria differently according to some sort of combinations.

The fuzzy model we propose in our study makes the assessment of all criteria mandatory, which represents a limitation, as in some cases workers do not take into account all the criteria to define the patient’s risk. Therefore, we recommend the exclusion of criterion according to the patient whose risk under assessment, as further work.

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