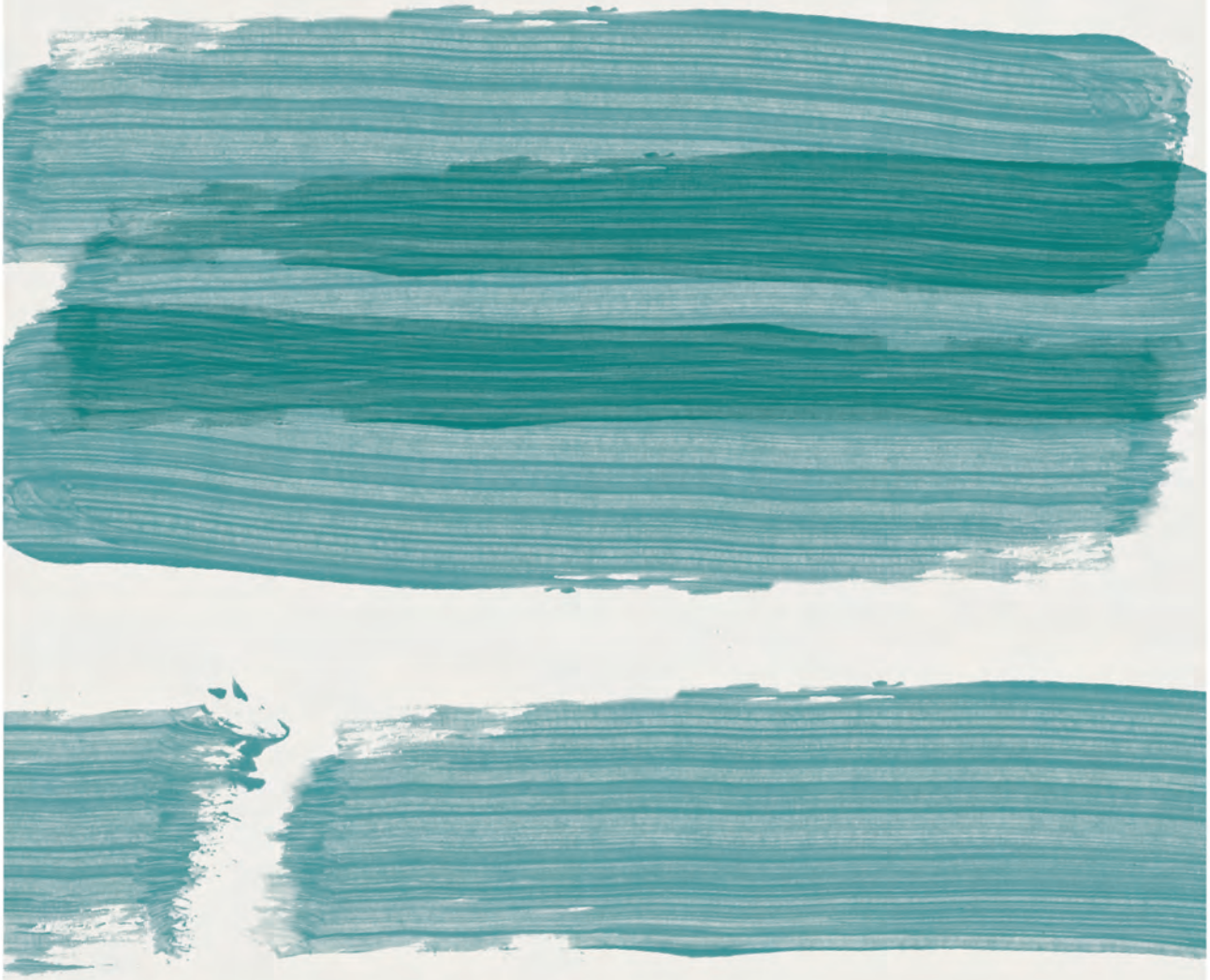

MIND THE GAP DESIGNING SUSTAINABLE HEALTHCARE FOR HUMANITARIAN AID

ANA LAURA R. SANTOS

Mind the gap
Designing Sustainable Healthcare In Humanitarian Aid

Proefschrift

ter verkrijging van de graad van doctor
aan de Technische Universiteit van Delft,
op gezag van de Rector Magnificus Prof. Ir. K.C.A.M. Luyben,
voorzitter van het College voor Promoties,
in het openbaar te verdedigen op 10 juli 2015 om 10:00 uur
door

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Mind The Gap: Designing Sustainable Healthcare In Humanitarian Aid
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Thesis, Delft University of Technology, Delft, The Netherlands
ISBN 97890-6562-3775
This research was funded by the POPH/FSE program through a PhD grant of Fundação para a Ciência e Tecnologia (FCT), Portugal
Grant nr. SFRH/BD/68445/2010

Cover design by Paula Rodrigues
Printed and distributed by Delft Academic Press

Mind the Gap
Designing Sustainable Healthcare in Humanitarian Aid

Ana Laura R. Santos

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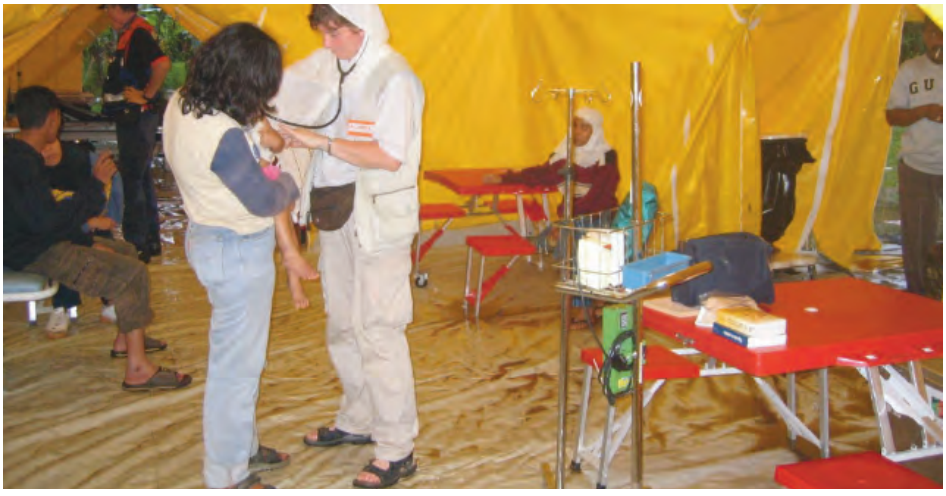

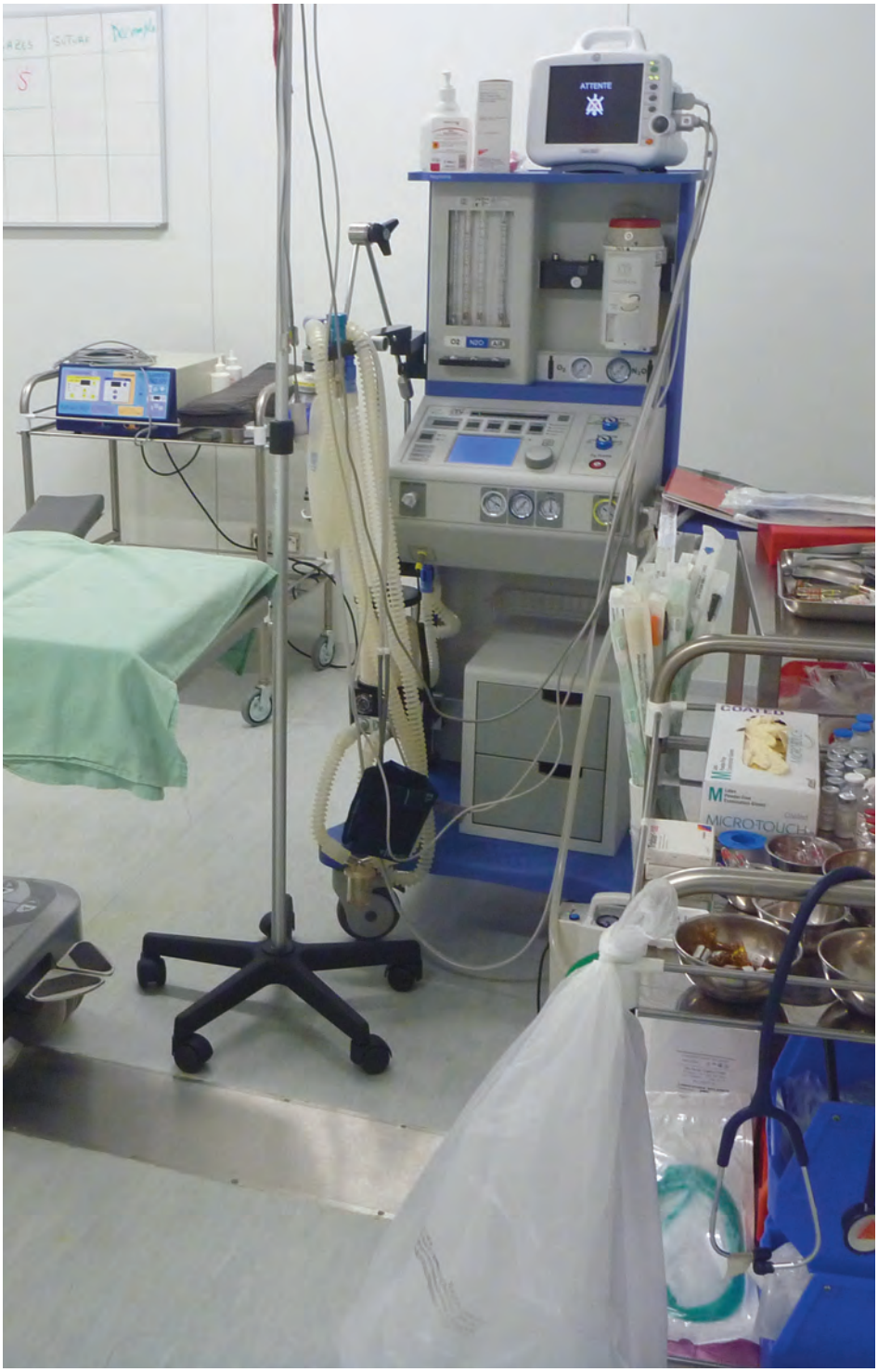
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MICRO-TOUCH

INTRODUCTION AND RESEARCH FOCUS

The argument has been made that it would be unethical not to do research to improve the delivery of health care to those caught up in complex emergencies—the most vulnerable and the most compromised populations in the world (…). It is simply not enough for the relief community to do the right thing—it must also do it right (Waldman, 2001, p. 1429).

1 General introduction

Haiti, Pakistan and Philippines are amongst the countries known for the devastating impact of natural disasters. Likewise, Syria and South Sudan are known for the thousands of refugees and internally displaced people fleeing from long-term conflict situations. These are high-profile humanitarian emergencies (or disasters), well covered by the news, but emergencies happen every day and everyone is to a certain extent subjected to them. Humanitarian emergencies include natural or industrial disasters and conflict situations that require immediate intervention and assistance to thousands of people. Often an emergency situation can result in an extended or chronic condition due to e.g. an epidemic or political instability, leading to the need to extend the settlement of camps.

Some regions of the globe are more vulnerable to the impact of a disaster (World Risk Index, 2011), mostly due to a combination of geophysical and socio-economic characteristics. One billion people are said to be living in disaster-prone regions under substandard life quality (Ryan, 2005). Political instability, over-population and poverty are reasons that make low and middle-income countries have a rate of about 97% of all deaths related to natural disasters (CRED, 2009).

The response to humanitarian emergencies, or humanitarian aid, involves the mobilization of a global network and complex system of actors (i.e. governments, private donors, aid agencies, non-governmental organizations, logistic providers and military). Humanitarian emergencies that involve international assistance usually generate large budgets and large response operations. The work of international agencies (e.g. International Federation of the Red Cross or United Nations) offering assistance in the field is characterized by its unpredictability and short timeframe for action. Furthermore, given the large number of competing operational organizations, there are several collaborative challenges during a response intervention, such as strict mandates and non-standard regulations.

Healthcare is one of the services generally provided in humanitarian emergency response, alongside with shelter, sanitation and food. International humanitarian organizations (e.g. Médecins Sans Frontières, International Relief, Save the Children) transfer, i.e. organize and transport, a variety of medical equipment and staff to an affected area with the purpose of reinforcing or even replacing disrupted healthcare activities. The replacement system they deploy is usually of a high quality standard, often superior to the one existing prior to the emergency (Rice, Gwertzman, Finley, & Morey, 2010; Sharp, Burkle, Vaughn, Chotani, & Brennan, 2002). In comparison to providing food or shelter assistance, providing safe healthcare in such situations is particularly challenging due to the level of medical and technical expertise required. Furthermore, the large numbers of patients, the austere work conditions (e.g. contamination risk, work around the clock) and limited infrastructure of an emergency can hinder the provision of healthcare.

A particularly challenging phase of humanitarian emergency response, not exclusively but especially relevant to healthcare, is the last phase of the transfer, in which international humanitarian organizations, after transporting medical equipment and expert staff to use and service it, must handover these services to local entities (e.g. local Ministry of Health). This phase, the humanitarian transition, is named with different terminologies (e.g. relief to development gap, early recovery), and generally described as a process involving blurry timeframe and responsibility boundaries for which there is usually no appointed budget. Common challenges in the transition of medical services, where medical equipment is often donated, include assuring the capacity to independently maintain the implemented quality of care and that medical equipment will continue to function.

Further information about global health and aid can be found in chapter 2.1, p. 15 of this thesis.

The unsustainability of the transfer process of medical equipment in humanitarian emergencies is the motivation behind the research in this thesis. Most of the medical equipment used by international humanitarian organizations, in particular for the provision of surgical care, is designed to operate in controlled environments and therefore not suitable to be transported, used, maintained and disposed in austere and low-resource settings. Ultimately, characteristics of medical equipment, such as fragility and dependency on supplies to function will lead to a mismatch between the medical equipment and the settings present throughout the whole transfer process in humanitarian emergencies. This mismatch means that, besides transferring potentially unusable medical equipment, events, such as the production of insect-attractive electromagnetic fields, use of compressed oxygen as targets during conflict or malfunctioning due to the lack of battery inventorization, imply threats to safety of healthcare provision during emergency response and also in the humanitarian transition, i.e. after medical equipment is donated.

This mismatch problem is twofold. Firstly, medical equipment has a limited capacity to function in the variety of context settings implicit throughout the transfer process (i.e. different countries or regions represent different challenges). Secondly, in order to temporarily reinforce disrupted healthcare systems, a support "ecosystem" needs to be in place for the equipment to function. This medical equipment ecosystem includes for instance a large diversity of complementary devices that are required for a single medical procedure, the occasional need for dedicated infrastructure, such as lead shielding or exhaust, the need for compatible energy sources and also the reliance on supplies and handling procedures, throughout the lifetime of medical equipment.

Further information about the healthcare context in humanitarian emergencies can be found in chapter 2.2, p. 21 of this thesis.

The research in this thesis explored the potential role of the design discipline to address the contextual mismatch of medical equipment in humanitarian emergencies. The World Health Organization (WHO) argues that there are three possible approaches to address the problem of transferring medical equipment to low-income countries: 1) to either design new appropriate medical equipment, 2) to reduce barriers of local research and development or 3) to reduce barriers of adoption (Petkova, 2010). Although these approaches are not specifically related to the context of humanitarian emergencies, they address a relevant problem, shared by international humanitarian organizations in emergencies.

The approaches proposed by WHO are not entirely divisible from each other. In this thesis, focus was given to relevant aspects related to both the design and the barriers of technology adoption, in particular during the transfer of medical equipment in humanitarian emergencies. This research assumed that, to address the above mentioned problems, the design of a support ecosystem for medical equipment is needed, in combination with the fragmented proposals suggested by the WHO. The proposed assumption is based on the fact that, despite increasing efforts, there are few success cases of large multinational companies that design both high-end and appropriate medical devices (Arasaratnam & Humphreys, 2013). Designing devices with different standards might not only affect the reputation of a company, but also the business models with wealthier clients. In fact, it is easier to donate equipment. In addition, and regarding the approach of reducing barriers to research and development, there are successful initiatives that emerged within countries where healthcare quality is substandard (Dewo, Magetsari, Busscher, van Horn, & Verkerke, 2008; Jarosławski & Saberwal, 2013). However, they mostly do not have enough manufacturing or organizational capacity to address the requirements of humanitarian emergency response. Overcoming the barriers for scalability of research and development in this context implies more than allocation of resources.

Medical device developers are not formally equipped to design a support ecosystem for medical equipment due to the lack of existing knowledge and a specific design process capable of dealing with the influences from 1) the variety of contexts and 2) the medical equipment ecosystem. The consideration for an emerging "humanitarian market" in low-income countries is rather new. While literature about the humanitarian context has been increasing substantially in the past four years, it mainly focuses on aspects related to supply and logistics (Mays, Racadio, & Gugerty, 2012; Oloruntoba & Gray, 2009; White & Lang, 2012). The problem studied in this thesis is that medical equipment is supplied and (mis) used in different contexts. Furthermore, and specifically regarding medical device design, most innovation is focused on incremental improvements of medical equipment through the design of their physical attributes rather than the "softer side of technology" or the related business models.

To conclude, there are different trends in the field of humanitarian aid that support exploring the contribution of design in improving the safety of healthcare provision at a global scale. These trends include an increase of partnerships between several international humanitarian organizations and the corporate sector and a more participative engagement from the recipient communities of aid. The exploration of the design contribution to humanitarian aid should, therefore, be framed within these trends.

Further information about the concept of humanitarian innovation can be found in chapter 2.3, p. 27 of this thesis.

In summary, the research presented in this thesis is based on four main assumptions (table 1.1).

First, the overlap of emergency response phases and priorities leads to a problematic transfer of medical equipment, from a sustainability point of view. Second, complex medical equipment is poorly suitable to use in humanitarian emergency response and therefore its transfer is particularly affecting the safety of healthcare provision. Third, medical equipment can be improved if designed in combination with consideration for its ecosystem and based on knowledge about the context of medical equipment use in humanitarian emergencies. Fourth, there are relevant trends that motivate change-making in humanitarian aid.

Table 1.1 Positioning assumptions

Positioning assumptions	Further information
Assumption 1 The overlap of phases and priorities in humanitarian emergency response leads to an unsustainable transfer of medical equipment	Chapter 1.1
Assumption 2 Complex medical equipment is poorly suitable to use in humanitarian emergencies and therefore affects the safety of healthcare provision in low-resource settings	Chapter 1.2
Assumption 3 Medical equipment can be improved if designed in combination with consideration for its ecosystem and based on knowledge about the context of medical equipment use in humanitarian emergencies	Chapter 1.3
Assumption 4 There are relevant trends that motivate change-making in humanitarian aid	Chapter 1.3

As illustrated in the outline of table 1.2, this thesis is divided in two sections. The first section includes the general introduction, where the research assumptions were laid out (chapter 1). The literature support for these assumptions is presented in the following chapter 2. In chapter 3, a sociotechnical perspective is introduced, as it is applied to the transfer of medical equipment in humanitarian emergencies. After this, in chapter 4, the goal of this thesis and the research questions are formulated. This section also includes a summary of the main findings in chapter 5, and a general discussion about the implications of the research in this thesis to design practice and education in chapter 6. Finally, methodological considerations and recommendations for future research are described in chapters 7 and 8, respectively. The second section of this thesis should be read as complementary literature to the first section. It includes published and submitted work that resulted from the studies that were carried out to address the research questions in this thesis. Publications 1-6 are cross-referenced in the first section to indicate their contribution to the main findings and general discussion.

Table 1.2 Thesis outline

Section I. Main thesis	**Section II. Publications**
1. General introduction	
2. In-depth support of research	
3. The sociotechnical perspective	
4 Goal of this thesis and research questions	
5. Main findings	9 Systemic barriers and enablers of medical technology transfer [publication 1] 10 Systems design perspective of healthcare provision in humanitarian aid [publication 2] 11 Medical emergency dynamics in disaster-prone regions [publication 3] 12 Safety challenges of medical equipment in nurse anaesthetist training in Haiti [publication 4] 13 Key challenges of product development for the humanitarian market [publication 5] 14 The value of collaborative design to address the challenges of the humanitarian sector [publication 6]
6. A holistic view of humanitarian innovation	
7. Methodological considerations	
8. Future recommendations	

2 In-depth support of research assumptions

This chapter provides the reasoning for the main assumptions explored in this thesis (table 1.1) and described in the general introduction. As such, it should be consulted as complementary to the general introduction.

> Health is a resource for everyday life, not the objective of living (World Health Organization [2015, para. 1]).

2.1 Global healthcare and aid

Health is a given right to any individual. A healthy individual or community, as opposed to one that is not, is more likely to live longer, be productive, cognitively skilled, and even actively participate in a common pursue of global sustainability (Ooms, 2013). However, worldwide there are several disparities regarding health delivery systems and their access conditions. Jeffrey Koplan and colleagues define global health as "an area for study, research, and practice that places a priority on improving health and achieving equity in health for all people worldwide" (Koplan et al., 2009).

Global health is based on the idea that health-related issues, such as communicable diseases or political unrest resulting from inequity, are not limited by boundaries of geography, time and culture, but serve the "shared" interest in varying degrees and ways, of the whole world (World Health Organization, 2015). Global health is not the same as "international health" which defines instead the international assistance, through cooperation and co-financing, from wealthy countries aimed to enable poorer countries to improve their public health (Ooms, Hammonds, Decoster, & van Damme, 2011). Despite debates about the effectiveness and nature of interventions in global health (van den Noort, 2011), the fact is that a great share of health-related issues, such as HIV/AIDS or the recent example of Ebola virus, conflict and natural disaster-related injuries, are a global-wide concern.

The Millennium Development Goals (MDG) (box 2.1) are central to the determination of activities and strategies of aid organizations. At least three of the goals are related to health and health provision: To reduce child mortality, to improve maternal health, and to combat HIV/AIDS, malaria, and other diseases. Since 2000, much progress was made towards the goals, with both healthcare disparities and preventable death reduced. However, it is also clear that these improvements are dependent on data surveillance and collection which is often lacking, inaccessible or unreliable (United Nations, 2014).

Box 2.1 Millennium Development goals (2000-2015) and beyond

The eight Millennium Development Goals were established after a UN Millennium Summit that gathered 189 member states and numerous international organizations to commit to the following objectives (which further include 18 targets and 48 indicators):

- Eradicate extreme poverty and hunger
- Achieve universal primary education
- Promote gender equality and empower women
- Reduce child mortality
- Improve maternal health
- Combat HIV/AIDS, malaria, and other diseases
- Ensure environmental sustainability
- Develop a global partnership for development

Criticism to the MDG include, amongst others, oversimplification of problems, questionable comprehensiveness regarding "local defined and owned definitions of progress", treating development as a one sided program, missing to address inequalities within nations and quality aspects in how goals are achieved (Ramalingam, 2013).
http://www.un.org/millenniumgoals/

New Health-related Developments Goals
Go4Health is a project funded by European Union Seventh Framework Programme aiming to "contribute to the implementation of the Framework programme and the preparation of future European Union innovation, research and technological development policy." New core elements for post-2015 are suggested, namely a universal health coverage, healthy environment, global governance and framework for accountability. Community participation is regarded as a transversal requisite for the achievement of these goals. The project has produced several publications related to policy and practice that serve to motivate an improved, more open system for global health innovation. This contribution might come to shape the future of how aid is performed and modernised.
http://www.go4health.eu

Overlap of aid activities

A distinction is usually made between two kinds of aid. Sustainable development aid, aimed at addressing structural health barriers, such as poverty, on the long-term, and Humanitarian aid, aimed at intervening, independently and on a short-term, to alleviate suffering and saving lives in humanitarian emergencies (or disasters) (table 2.1). In practice, these two, and other activities, such as military assistance, often overlap. The overlap of activities between development and humanitarian aid is related to shared responsibilities and needs. The different phases of humanitarian emergency response – emergency relief, humanitarian transition and reconstruction - are bridged to development aid in two ways.

On one hand, structural development limitations and lack of prevention, increase the risk vulnerability of populations to the impact of humanitarian emergencies. On the other hand, after the main relief efforts, there is the need to transition for prolonged assistance and reconstruction (Department for International Development, 2004; Pelling, Maskrey, Ruiz, & Hall, 2004).

Table 2.1 Types and examples of humanitarian emergencies (adapted from van Wassenhove [2006] and based on data base from the Centre for Research on the Epidemiology of Disasters)

	Natural [a] (geophysical or climate-related)	**Technological or man-made**	**Complex[b]**
Sudden-onset	Tropical storm/tornado Earthquake/Tsunami Landslide Volcano	Industrial accident Road/Air-traffic accident	Terrorist attack Conflict Epidemics
Slow-onset	Drought Famine	Air and water pollution	Political or refugee unrest Conflict Poverty

[a] The World Risk Index rates countries according to the impact risk from an extreme natural phenomena (slow or fast onset). The index is based on each country's vulnerability, exposure, coping and adapting capacities (Institute for Environment and Human Securiy 2014). Other indication risk, specific of geophysical hazards are the delineations of disaster-prone areas, such as the Ring of Fire and the Alpide belt. This index emphasizes the "unnatural" social, economic and political causes behind the denominated "natural disasters" above the extreme natural phenomena.

[b] The term "complex emergencies" is usually classified under Technological/man-made. It was purposely separated here to highlight that complex emergencies are caused by interrelated natural and technological/man-made emergencies.

Figure 2.1 illustrates the linear continuum of phases that are usually considered in aid planning and funding (Buchanan-Smith & Fabbri, 2005), despite this overlap. As illustrated, the humanitarian transition refers to the period between the immediate short-term intervention and the improvement of life standards by development. This implies a shift of focus and priorities (United Nations, 2006). Several publications indicate the existence of a "gap", between short-term humanitarian relief, and long-term development, pointing to the lack of sustainability in funding, management and delivery (Audet, 2015; Lloyd-Jones, 2006). Disaster Risk Reduction is related to reduction of vulnerability (and increase of resilience) to humanitarian emergencies through sustainable socio-economic development. Poverty and poor education (two targets of the MDG), poor health infrastructure and political instability are some of the reasons that make populations vulnerable to humanitarian emergencies (Institute for Environment and Human Securiy, 2014).

This thesis focuses on the humanitarian transition, characterized by the ambiguous overlap of activities in humanitarian aid and sustainable development. This focus in motivated by the predicted need of response to the increasing frequency and intensity of humanitarian emergencies, in particular related to future urbanization and political instability (World Economic Forum, 2015).

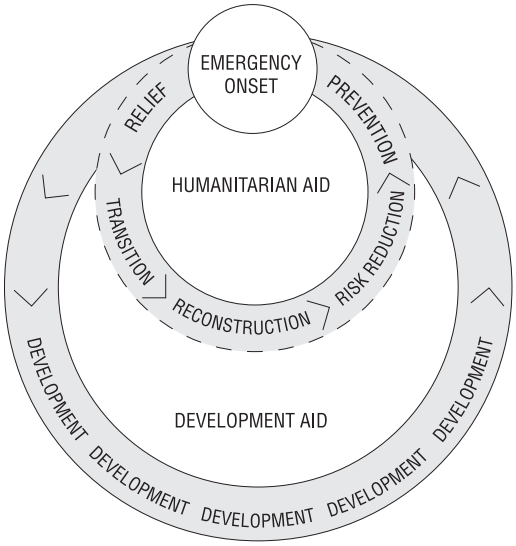


Figure 2.1 Interrelation between Humanitarian and Development Aid (adapted from Safran [2003] and Food and Agriculture Organizations of the United Nations [2001])

In addition, the overlap of aid activities, despite the formalization of the humanitarian sector (box 2.2), raises relevant concerns about the sustainability of humanitarian aid. Namely in regard to how integrated or self-reliant it is, and how it contributes to sustainable development, rather than seeding aid dependency.

Relevant stakeholders in humanitarian emergency response

The activities carried out in humanitarian emergency response, rely on a complex network of international and national stakeholders organized in theme clusters (ox 2.2). Humanitarian aid has grown significantly in the past century in terms of complexity of response networks and number of registered organizations. It is important to clarify the terminology used to distinguish the different organizations. An important aspect to distinguish organizations is the way they are financed, whether private or governmental (i.e. member countries from the Organization for Economic Cooperation and Development (OECD) integrating, or not the Development Assistance Committee (DAC)). In particular regarding the health cluster there are:

— Multilateral organizations, or agencies, such as the United Nations agencies or the World Bank, that obtain their funding from multiple donor governments and spend it on projects in various countries. The WHO is responsible for the most commonly used technical guidance on a wide range of health issues and is the lead agency for healthcare providers in humanitarian emergencies, which involves a major coordination role as lead of the "cluster".

— Bilateral organizations, or agencies, such as the Centre for Disease Control and Prevention, the European Centre for Disease Prevention and Control, United States Agency for International Development (USAID) or other national agencies for development, receive funding from the government in their home countries, and use the funding to aid developing countries.
— International humanitarian non-government organizations (some of them community-based or faith-based), such as Médecins Sans Frontières, International Federation of the Red Cross, Oxfam and Save the Children operate with private funding (e.g. foundations, companies and individuals) that they fundraise.
— Humanitarian non-government organizations and governmental agencies, at national level, such as the Sarvodaya Shramadana Movement in Sri Lanka, receive funding from their own government and private funds.
— Military (foreign) aid interventions are advised as a last resort by the United Nations Office for the Coordination of Humanitarian Affairs (Oslo Guidelines). Despite the military capacity to independently provide medical assistance, specialized equipment and logistical support, the military involvement in humanitarian emergencies, where a civilian nature must be kept, is rather controversial due to the different nature of their mandates and their specific security and political agenda.

Burden of humanitarian emergencies

Over the decade 2003–2012, a yearly average of 388 natural disasters occurred, affecting approximately 216 million people and causing over 100.000 deaths. These particularly high numbers are attributed to large impact emergencies, such as Indian Ocean (2004), Sichuan (2008) and Haiti (2010). About 50% of the countries with the highest disaster mortality are in low or lower-middle income countries and account for about 90% of total mortality (Guha-Sapir, Hoyois, & Below, 2013). By the end of 2012, an estimated (and increasing) number of 28.8 million people were internally displaced, about twice as much as displaced refugees (Albuja et al., 2013).
In 2013 an unprecedented number of 148.2 million people were affected by natural disasters (65.5%) or displaced by conflict (34.5%) (OCHA, 2014; UNHCR, 2015). There were 353 natural disasters registered in 109 countries and 2 conflict-related humanitarian emergencies of highest grade. In the same year, the international humanitarian funding was approximately 20 billion euro (an average of 136€/affected person) and approximately 793 million euro was used by the health sector (Swithern, 2014). In September 2014, the WHO highlights a number of 5 humanitarian emergencies of highest grade (box 2.2), namely West Africa Ebola outbreak, Iraq, Syria, South Sudan, Central African Republic. Four of these emergencies are related to complex conflict and clearly require differing levels of healthcare assistance (World Health Organization, 2014). In this year, people live in displacement for an average of 17 years.

Box 2.2 Classification and Cluster System to respond to humanitarian emergencies

The WHO classifies humanitarian emergencies in the three grades of urgency and required amount of technical, financial and human resources (World Health Organization, 2013). These grades define the allocation of funds and interventions taking place worldwide.

Cluster system to respond to humanitarian
In 2005 the Humanitarian Reform Agenda (IASC) has introduced the Cluster system as a strategy to improve the international response to humanitarian emergencies. The clusters organize humanitarian organizations in priority sectors (e.g. health, shelter, water) that can be overviewed by a related United Nations agency. Critics claim that this is an UN-centric, "one-size-fits-all" model that prioritizes external judgement of aid performance and leaves affected populations out of the action and evaluation plans.

Relevant online sources for updates regarding humanitarian emergencies
-Web Relief (Global Emergency Overview)
-Humanitarian Response (.info)
-World Health Organization (Crises)
-Centre for Research on the Epidemiology of Disasters (CRED) and EmDat (International Disaster Database)
-United Nations High Commissioner Refugees (UNHCR)
-Office Coordination of Humanitarian Affairs (OCHA)
-Global Humanitarian Assistance
-Imap-migration: Information on international migration

Figure 2.2 United Nations cluster system. Source: Humanitarian Response (2015)

2.2 Healthcare in humanitarian emergencies

Healthcare in itself is a complex system. Healthcare services are usually divided in three levels of care distinguished by their focus and growing specialization. The primary, focused on general promotion of healthy life choices and prevention of risk factors, the secondary, focused on treatment and illness management and the tertiary, focused on specialized treatment and death avoidance (Katz & Ather, 2009). Due to the complexity of needs occurring suddenly in a humanitarian emergency, many organizations offer care across these three levels. That means that, while primary care mostly focuses on prevention and basic resources, the other two require considerable more resources to transfer and implement.

Surgical (and anaesthetic) care is part of the services included in secondary (minor interventions) and tertiary levels of care and is an essential treatment for many different conditions. Globally surgical care was estimated to account for 11% of the global burden of disease (Debas, Gosselin, Mccord, & Thind, 2006; K. a K. McQueen et al., 2009). In humanitarian emergencies, surgery is an important part of the services offered in addition to other medical specializations, such as general medicine, psychology and nursing. Table 2.2 gives an overview of the diversity of surgical specializations included in humanitarian emergencies. In emergency settings there is a high incidence of injuries, but also a high number of unmet surgical needs common in low- and middle-income countries, such as urgent and non-urgent disease outbreaks, pregnancy complications or hernia repairs (Chu, Ford, & Trelles, 2010; Chu, Trelles, & Ford, 2011).

There is a strong promotion amongst the medical community about the need to professionalize surgery as an essential need in humanitarian and development aid (K. McQueen et al., 2010; Ozgediz, Jamison, Cherian, & McQueen, 2008; Ozgediz, Galukande, et al., 2008). Because of the low prioritization of surgical care in low-income countries, often seen as a luxury, and the poor documentation of humanitarian surgical care (Burkle et al., 2012; Nickerson, Chackungal, Knowlton, McQueen, & Burkle, 2012), the continuation of medical support to patients treated during humanitarian emergency is particularly challenging. The needed technical and human resources cannot be guaranteed, neither immediately nor independently from international humanitarian organizations. For this reason, the transfer of technology in emergency situations, despite its efficiency, is often not sustainable.

Table 2.2 Surgical burden of disease in humanitarian emergencies (based on Chu et al.[2010]; Gautschi, Cadosch, Rajan, & Zellweger [2008]; Kaneda [1994]; Ryan [2005])

Surgical specialization	**General procedures** Non-urgent and Urgent	**Geophysical emergencies** Caused by e.g. blood lost infrastructure destruction or prolonged entrapment	**Climate-related** Caused by e.g. drowning, water and sewage pollution	**Man-made** Caused by e.g. equipment misuse, hazardous chemicals, explosion, gunshot, violence
Orthopaedic Torso Plastic, Ophthalmologic Vascular paediatrics Obstetrics	Obstetric complications Congenital abnormalities Joint dislocation Fractures Neglected and infected wounds Abscesses needing drainage	Burns Limb fractures Crush and compartment syndrome Abdominal, thoracic or craneo-trauma Spinal cord damage Renal failure	Soft tissue injury Penetrating injury Contaminated wounds Skin infection Unstable infrastructure Electric shocks Traumatic injuries	Cuts Burns Fractures Skin contamination Complex injuries Fistula

Table 2.3 Timeframes of surgical care in humanitarian emergencies (Chackungal et al.[2012]; World Health Organization[2003])

Diagnostic 1st phase 0-48h	**Therapeutic** 2nd phase until 10th day after onset	**Assistive** 3rd phase follow-up
Triage	Lifesaving surgery	Rehabilitation/Physiotherapy
Immobilization of limbs	Fracture management	Reconstruction of limbs
Wound bleeding delay	Amputations	Close wounds, manage infections
Airway and hemodynamic stabilization	Wound management	Modify amputation to prosthesis
Radiology and imaging	Fasciotomy	Remote specialization
Blood collection and analysis	Laparotomy	

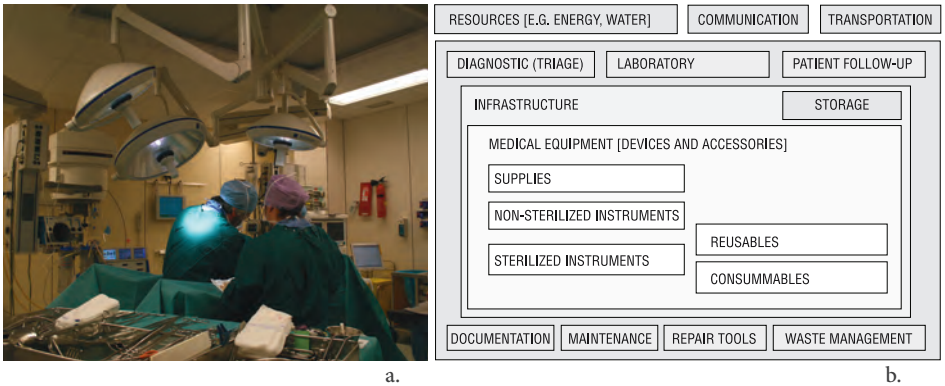
The complexity of providing safe surgery lies in the fact that a high level and diversification of expertise is required, as well as a chain of complementary needs, such as anaesthesia provision, intensive care provision and physiotherapy (table 2.3).

Part of the effort of professionalizing the sector is the registry of Foreign Medical Teams that guides and certifies the required competences of medical personnel (e.g. surgeons, anaesthesiologists, nurses and paramedics), and the medical equipment used in humanitarian emergency response (Norton, Schreeb, Aitken, Herard, & Lajolo, 2013; Redmond, O'Dempsey, & Taithe, 2011). This registry is a solution for shared accountability

(local and international) because it offers affected governments and aid agencies the access and choice of adequate professional teams and reduces the strain on capacity of institutions that send volunteers. The Foreign Medical Teams registry contributes to a sustained humanitarian emergency response by promoting specific training, oriented at humanitarian medical assistance, ensuring universal medical standards, ethics and documentation practices, and by including short- to long-term assistance planning.

Infrastructure and medical equipment

Most surgery, except minor procedures, needs to be performed in a specialized infrastructure and, because of its strong impact on human lives, safety is a very important aspect. An operating theatre, composed of operating rooms, is built under many safety regulations with consideration for air and people flow (figure 2.3a). There is usually output of air, oxygen and vacuum from the walls, storage space and complex medical equipment. The safe functioning of each medical equipment relies on a large number of other interdependent technologies that include direct and indirect relations, such as energy or supplies, sterilization and waste management equipment. These group of interdependent technologies form the medical equipment ecosystem (figure 2.3b). In a hospital setting, both the technologies and the required human expertise of this system are usually in place. The term complex medical equipment employed throughout this thesis refers to the combination of general surgical devices that are, according to Medical Device Directive classification, active, multi-purpose and mostly invasive (European Commission, 2010), and their ecosystem (i.e. the interdependent infrastructure, complementary accessories and supplies, such as suction device, electrocautery, anaesthesia machine and autoclave).



a. b.

Figure 2.3 a. General view of operating room in the Netherlands (Catharina Ziekenhuis, 2010)
b. Medical equipment ecosystem (publication 1)

In order to assure the provision of minimum essential surgical services in humanitarian emergencies the WHO has published lists of essential procedures, medicines and equipment that should be guaranteed in emergencies (WHO, 2006). Research has revealed that, although essential, equipment such as a pulse oximeter is often not available in many low-resource settings (Hodges et al., 2007; Myles & Haller, 2010).

Medical equipment mismatch

The Priority Medical Devices (World Health Organization, 2010b) was the first project dedicated to create awareness and evidence related to worldwide unmet needs for medical technology. From this project is became clear that "the context in which a (medical) device is used is of key importance for correctly using that device" (Beenkens & Stolk, 2010). As such, much of the medical technology developed in and for high-resource settings is not adequate for a large part of the world. The main report and background papers provide a comprehensive overview of the barriers to choose, use and design medical technology and propose research and action to address these barriers (World Health Organization, 2010b). Barriers in the report include inappropriate design of medical equipment, dependency on unavailable resources (such as stable electricity, trained personnel or repair tools), lack of information about lifecycle costs and effectiveness, lack of post-market surveillance, and excessive investments in high-end technologies with little impact on high-burden diseases. The project report states that these barriers often result in large numbers of obsolete and unused medical equipment in low-resource settings (figure 2.4 a-d). In this project, three possible approaches were proposed to address medical equipment inadequacy: 1) to either design new appropriate medical devices, 2) to reduce barriers of local research and development or 3) to reduce barriers of adoption (Petkova 2010). The Global Initiative on Health Technologies has also produced several publications regarding policies for medical technology management. An overview of the publications can be found in World Health Organization (2011).

In response, the Global Medical Technology Alliance has reacted with comments that show a contrasting perspective of the mismatch. The published commentary includes a set of relevant characteristics from the medical technology industry and criticisms of the negative standpoint in the project report regarding high-end technology.

> The Mismatch report seems to focus on requiring medical devices to conform to the overall healthcare setting, instead of promoting a more integrated approach appropriate to the needs of each country (General comments Global Medical Technology Alliance, 2011, para. 4).

a. b. c. d.

Figure 2.4 a. Locked urology medical equipment, used once/year by visiting professionals; b. Donated mobile fluoroscopy devices (C-arm), unused ;c. Broken vacuum devices; d. Broken medical ultrasound device

On one hand, resources should not be allocated in medical technology without first guaranteeing access to water and electricity. This suggests that the three approaches proposed by WHO are fragmented and overemphasize equipment adequacy rather than promoting an integrated approach. On the other hand, the cellular telephone is given as an example that even high-end technologies that are developed with uncertain benefits and high financial costs, might in time, become commonly available and important. Numerous examples are presented of partnerships between non-governmental organizations and the private sector and reference is made to companies within countries with emerging economies that create technologies dedicated to address own problems of the country. The comments end with a proposal for more collaborative efforts between the WHO, governments in low-income countries and the medical technology industry.

Emergency contexts

International humanitarian organizations take up different roles and operate in different ways according to the humanitarian emergency in question. Factors that vary include, the type of humanitarian emergency (table 2.1), the degree of collaboration with local communities or other organizations, the location of a refugee or displacement camp, its administration (national or international) and the design of that camp (i.e. open or closed). This has impact in the way healthcare is provided. There are two exemplary realities in humanitarian emergencies, important to consider, in regard to the important role of locally available healthcare infrastructure.

One is the reality of a fast-onset natural disaster. Natural disasters are only to a certain extent predictable. Some countries or regions, such as Pakistan, face floods almost yearly, whereas e.g. the tsunami in Indonesia (2004) was rather unexpected. This form of aid requires large amounts of healthcare infrastructure to be immediately mobilized to respond to the numerous victims with diverse possible diagnosis. Usually international humanitarian organizations coordinate with national authorities to define strategies whether to work in tents, located in specific destinations, or to work in close collaboration with local facilities. With the progression of such an emergency, organizations might resume their efforts, built new support infrastructures and continue to develop aid programs to support recovery, or phase out supporting fewer activities and donating resources to the local Ministry of Health (Owens, Forgione, & Briggs, 2005; Sharp et al., 2002). Since a natural disaster is usually circumscribed in a determined location (not necessarily affecting an entire country) people are temporarily displaced, but are resettled back to their communities.

The other reality is of a conflict in which large amounts of people are displaced outside borders and settle either in host communities or in refugee camps. In contrast with natural disaster response, this implies a different kind of healthcare support, a more long-term and diversified one, mostly to assure access to care for wounded and basic healthcare needs. The coordination of healthcare services in these settings is very political (sometimes occurring in a "political vacuum") (Hehenkamp, 2013). In conflicts in the Middle-East (e.g. Syria, Ukraine), as opposed to (e.g. Sierra Leone, Sudan) there are advanced expertise and facilities. International humanitarian organizations might work with national healthcare systems in hosting countries or, in case of displacement camps, in the midst of a conflict setting. Despite their location, healthcare facilities are often a target of theft or violence. International humanitarian organizations make medical services available and provide supplies on a weekly, monthly or yearly basis. When organizations resume their intervention, internally displaced or refugees still need to be assisted on the way back and efforts are needed to rebuild healthcare facilities and services (at country level) that were disrupted during conflict. Refugee and internally displaced environments disrupt much of the social cohesion, existing prior to conflict. Many people die or flee, and the sense of self-sufficiency, trust, safety, and familiar and community balance are affected.

In both these realities, as new employment and health problems arise from disrupted social structures, the transition from well supplied and western-centred health services to existing, governmental owned services, often centred in traditional medicine, is very difficult at any level (i.e. community, NGO or government level). A description of the humanitarian transition in Northern Uganda can be found in appendix 2, p.86.

2.3 Innovation in the context of humanitarian aid

Innovation is extensively described in literature in different ways, some associated with its application domain, its impact, or its organizational context (Berkhout, Hartmann, van der Duin, & Ortt, 2006). International humanitarian organizations, governments, donors and more recently the private sector, are increasingly aware of the importance of innovation in the humanitarian field (Ramalingam, Scriven, & Foley, 2009). Innovation, in practice is not uncommon within the humanitarian sector (Curtis, 2012). However, the concept of "Humanitarian Innovation", as formal activity, has only recently been consolidated by the Active Learning Network for Accountability and Performance in Humanitarian Action (ALNAP) and a Department for International Development (DFID) investment in a fund project for humanitarian innovation (Betts & Bloom, 2014). Further, organizations themselves have launched specifically purposed projects such as Médecins Sans Frontières Innovation Unit in Sweden or the Global Partnership for Humanitarian Impact and Innovation in Switzerland. Humanitarian Innovation defines the change in aid delivery processes and adaption of technologies aiming to improve the way how the needs of affected people in humanitarian emergencies are addressed (Bessant et al., 2014).

> Innovation is already and irreversibly part of the humanitarian system, driven by a demand for new models, growing private sector engagement, and rapid technological change (Betts & Bloom, 2014, p. 22).

The formalization of Humanitarian Innovation reflects a concern with the growing need for accountability and transparency in the use of available budgets. Moreover, and as in other societal sectors, the demand for sustainable practices is present. International humanitarian organizations are driven to be more competitive and learn from their failures. The private sector as well, is actively contributing to change the nature of aid towards an aid system that is competitive and demand-driven, that separates donors from service providers and integrates different stakeholders in operations (Sanders & Stokkom, 2009; Tomasini & Van Wassenhove, 2009). Advocating participatory approaches, centred to the end-users is an increasing trend, but it is subjected to legal, financial, infrastructural and social constrains (Betts & Bloom, 2013). Worldwide, several initiatives involving the manufacturing industry and international humanitarian organizations were initiated that focus on the development of new products, destined for use in aid: for example the Shelterbox, the Shelter Centre, the Humanitarian Innovation Fund and the INSEAD Humanitarian Research Group. In the area of products for healthcare, efforts have focused on the development of medical infrastructures, such as ready-to-deploy hospital containers and low-cost medical devices,

including the SpeedKits initiative, Hospitainer, Lifebox pulse oximeters and Glostavent anaesthesia machine. However, there is still no consensus regarding the goal or a formal framework for innovation. In addition, the approaches used to identify innovation opportunities or to design strategic plans for implementation are mostly unsystematic or not reported.

Potential role of design

> When applied to healthcare, effective design thinking can deliver products, services, processes and environments that are intuitive, simple to understand, simple to use, convenient, comfortable and consequently less likely to lead to accidental misuse, error and accidents (Clarkson et al., 2003, p. 9).

The design of medical equipment goes back centuries, and was influenced by different breakthroughs in the history of physics and medicine (e.g. invention of thermometer, X-rays, anaesthesia, sterilization). Since its beginning, the development of medical devices was closely associated with science and technology, contributing to innovate and develop medical practices of diagnostics and treatment. After the Second World War the relationship between technology and humans, bridged by multiple cognition and capabilities, gained increasing awareness. This awareness gave way to the formalization of the field of human factors and ergonomics (HFE). Since then, medical equipment is increasingly designed taking into account its complementary infrastructure, working patterns of professional users and patient lifecycle (Xue, Yen, & Boucharenc, 2008).

The field of HFE is until today a key relevance for the fields of medical design and innovation. The most important association of HFE and design is possibly the ISO/IEC 62366:2007: Application of Usability Engineering to Medical Devices. This norm regulates the process of manufacturers to include usability concerns, namely effectiveness, efficiency and satisfaction. There are several published examples of both methodology and successful cases relating the fields of HFE and design (Buckle, Clarkson, Coleman, Ward, & Anderson, 2006; Clarkson et al., 2003; Griss, Cote, Gerner, Hermjakob, & Vizcaino, 2003; Sharples et al., 2012). Success factors include: 1) the fact that design is a creativity-based field and that, associated with safety, is key for differentiation and competitiveness (Edwards & Intelliject, 2000; J. Martin, Murphy, Crowe, & Norris, 2006), and 2) the consideration for, and participation of, different users (from patients to management to maintenance technicians) in the design process increases the chance of success and avoids additional costs of changing the design a posteriori. User participation extends beyond surveying professionals, to shadowing and simulating their activities with the benefit of considering behaviour patterns and un-anticipated events. Despite the mentioned successes, some

authors claim that HFE is under-used or does not have sufficient expression in industry and healthcare organizations (J Dul & Neumann, 2009; Hal W. Hendrick, 2008; J. L. Martin, Norris, Murphy, & Crowe, 2008).

The design discipline and its application to the healthcare field has yet to be clarified. Design can be divided in different sub-domains, each with their potential contribution to the healthcare field: from a more generalist arts-based discipline to a more specialized and technology-based one (Bates and Pedgley, 1998). Medical devices are still mostly designed by (design) engineers, rather than (industrial) designers and so they are designed for clinical effectiveness in a technology-centred manner. Martin's (2008) review of methods to collect user requirements states that there is the need for more practical examples in order to motivate industry to adopt HFE and design, disclosing the benefits in terms of its strategic value. Second, authors claim that the system as a whole, including its multiple users, procurement and implementation processes must be considered and designed for and/or by healthcare organizations (Jan Dul et al., 2012; Karsh, 2004; J. L. Martin et al., 2008; K. J. Vicente, 2007). In particular regarding the subject of this thesis, although different types of products and environments (from hospital equipment to home use devices) are targeted, few research is available about usability and design of medical devices in medical emergency situations (Croskerry, Cosby, Schenkel, & Wears, 2009; Kristensen, Kyng, & Palen, 2006).

Xue (2008) reviewed the evolution through time of influencing aspects on the design of medical devices and demonstrated clearly a shift of focus and scale in design practice (and theory) similar to the design of industrial and consumer products (table 2.4). Important contributions to this shift were global movements, such as the Club of Rome and the Brundtland Commission that led to an increase of social awareness and of approaches to address societal problems, such as poverty, lack of industrialization and resource exploitation (Donella H. Meadows, Meadows, Randers, & BehrensIII, 1972; World Commission on Environment and Development, 1987). Industrial design was, already then, included as a potential approach to contribute to development. Throughout the years the contribution of designers has extended from an industrial to a social domain and from a focus on physical attributes to behaviour change and participation (Brown, 2013; Maldonado, 1991; Margolin, 2006).

The Ahmedabad Declaration in India (1979) defined for the first time the role of designers in development. It proposed that design should work on a more strategic, planning level, not solely restricted to the creation of physical products. Although movements that gained recognition in this period, such as Design for Development and Appropriate Technology, had a more narrow product focus (Papanek, 1985) (Schumacher, 1973), other influential movements have kept closer to the initial declaration.

Table 2.4 Evolution of influences in medical device design (adapted from Du Bois [2013])

Trends in Design based on Van Patter & Pastor (2011)	**Phases of influence in medical design** based on Xue et al. (2008)	**Examples of approaches**
Design 1.0 Traditional Design	Functionalism	Handcraft, prior to industrialization
Design 2.0 Product/Service Design	Technology appearance and aesthetics Universal design	Human-centred design Inclusive design Dynamic usability Design for development Appropriate technology Co-design
Design 3.0 Organizational Transformation Design	User experience and emotional design	Human-centred design Contextual design Taskonomy Product-service systems (PSS) Public sector innovation Vision in product design (ViP)
Design 4.0 Social Transformation Design	---	Complex systems Systemic design (Design for care) Sustainable system innovation Systems-oriented design

An example are the design interventions of Bonsiepe, for whom design is a key lead to the industrialisation process, by means of a staged practice development, knowledge exchange and thereby participation towards an design self-sufficiency (Bonsiepe, 1973, 1990, 1992).

Although there is scarce literature about both medical device design for low-resource settings, some authors suggest that important product requirements include both physical aspects, such as durability with regard to accuracy and reliability, portability, use of local materials and alternative energy sources, and organizational aspects, such as culture-sensitive communication and training (Lister, 2004; Mainsah, 2008; Nimunkar, Baran, Van Sickle, Pagidimarry, & Webster, 2009). Recommendations are made by the same authors regarding the design process. These include urging regulatory institutions to negotiate affordable pricing with suppliers, consider integration of traditional practice and western medicine, involving users, local producers, donors and the public sector throughout all design process, and ensure commitment from donors of follow-up consultation on the long-term. Although these requirements and recommendations were mostly targeted to Design 2.0 (table 2.4), they reflect the need for more integrative and systemic design approaches. The same is suggested by Mittermeyer, Njuguna, & Alcock (2010).

3 The sociotechnical perspective

This chapter introduces a sociotechnical perspective as it is applied to medical equipment transfer in humanitarian emergencies. The research presented in this thesis is based on the idea that technology is intrinsically related to social needs. Technology is embedded in systems that are composed of physical artefacts, natural resources and social organizations. These systems are called sociotechnical systems and depend on action, knowledge, values and policies to accomplish a determined social function (Geels, 2004; T. P. Hughes, 2004). The sociotechnical system concept is particularly useful when considering large scale technologies or complex heterogeneous systems, such as healthcare and humanitarian aid in which technologies are developed, produced, implemented, used and continuously improved (P. Carayon, 2006).

> [Sociotechnical] systems consist, on one hand, of complex technical/physical structures which are designed to produce or to transform certain things and, on the other, of social institutions and organizations designed to structure and regulate the activities (Burns & Flam, 1987, p. 298).

As mentioned in the general introduction of this thesis, the role of international humanitarian organizations is to provide relief to vulnerable populations affected by humanitarian emergencies, such as conflict instability, natural catastrophe or disease outbreaks. In these relief interventions, human resources, specific supply chains, technology and guidelines are set-up (organized, transported and used) in different contexts. Often healthcare services are disrupted, and therefore the work of international humanitarian organizations means the reinforcement or even replacement, of local services with professional healthcare staff and technology.

From a sociotechnical perspective, when international humanitarian organizations transfer medical equipment during a humanitarian emergency they create a parallel system to the institutional one (i.e. of established political, commercial and public channels) (Oloruntoba & Gray, 2009). Rather than a hospital procurement office procuring and purchasing medical equipment from a determined producer company for use by the hospital staff, in this case, organizations replace a great part of the roles of the consumer and the producer company, by means of their own procurement and logistic systems or by means of in-kind donations. This means that there is a different producer-consumer relationship because, instead of the consumer (i.e. the hospital or the aid organization) buying the goods or services, these are financed by private or public sectors (quasi-market) (Binder & Witte, 2007). Companies often have less responsibilities regarding servicing and training staff, since this must be done in contexts organizations have strict access to. Moreover, the consumer, as in other professional sectors, represents, but is not the end-user. The end-users of medical equipment are, on one hand, healthcare practitioners temporarily in the field, and on the

other hand, the ones under a Ministry of Health or a privately administered institution in low and middle-income countries. In an international context like the humanitarian context, these asymmetric relationships that characterize the "humanitarian market" have many implications for the design of policies, processes and of course, technologies.

In conclusion, through the sociotechnical perspective it is possible to connect the production of medical equipment and respective resources (i.e. scientific and design knowledge, facilities and tools, education, capital and human resources) and the use of medical equipment and respective resources (i.e. complementary artefacts, cultural meaning and maintenance/repair facilities) (Geels, 2004). Production and use of medical equipment are connected through distribution systems (i.e. markets and infrastructure) and trust-giving regulations (i.e. norms, standards, laws). These are called sociotechnical innovation systems.

> Sociotechnical systems may become sociotechnical innovation systems, if members of the social sub-system are allowed to actively contribute to the emergence of new tools as part of their daily work (Lindgren, 2013, p. 40).

Figure 3.1 illustrates the specific application of the sociotechnical perspective to the transfer of medical equipment in humanitarian emergencies. In the figure, the production or donation of medical equipment (and its inherent ecosystem) is connected, through the transfer process, to the use, or reuse of medical equipment by a variety of users and settings. The transfer process is carried out by a distribution network of international humanitarian organizations, a quasi-market, and is mediated by international and national regulation.

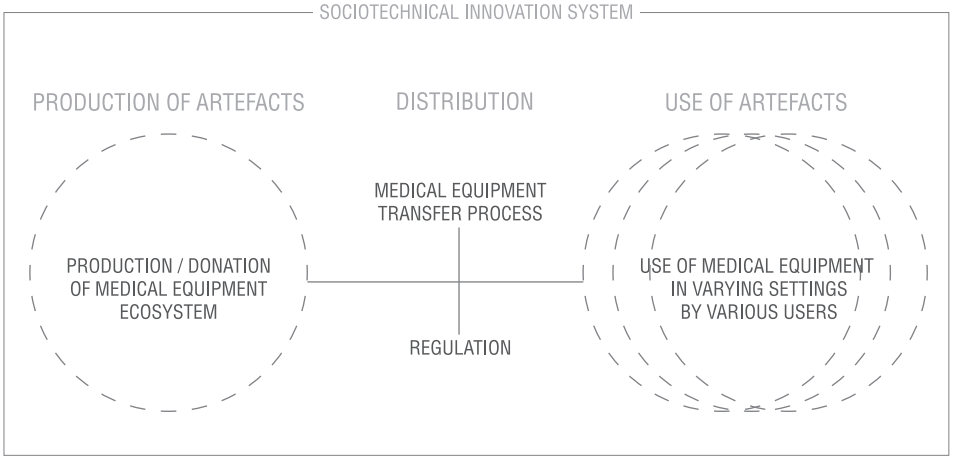


Figure 3.1 Basic elements of sociotechnical systems specific to medical equipment transfer in humanitarian emergencies (adapted from Geels [2004])

This perspective offers a broader unit of analysis of innovation systems by including both production and use domains of medical equipment innovation. It extends the focus of analysis from the group of companies producing certain technology to the relational structures needed for the development, distribution and use of innovations. This implies an active contribution from users in the innovation processes and relational structures (e.g. schools, skilled labour, societal interest groups, and media) that contribute to shape innovative technologies. Based on this perspective it is possible to investigate how systems design theory and practice can contribute to a more sustainable transfer of medical equipment in humanitarian emergencies. A "sustainable transfer of medical equipment" means that the medical equipment transferred in humanitarian emergencies can be safely used during humanitarian emergencies and integrated in the activities that follow.

4 Goal of this thesis and research questions

The goal of this thesis is to investigate the previously mentioned research assumptions in order to understand the implications of using systems design theory and practice to impact the transfer of medical equipment in humanitarian emergencies. Therefore, the main research question addressed in this thesis is:

How can a systems design approach contribute to a more sustainable transfer of medical equipment in humanitarian emergencies?

This thesis focuses on the use experience of complex medical equipment by international humanitarian organizations. In order to design a more sustainable transfer of medical equipment in humanitarian emergencies, more knowledge is needed about the context in which complex medical technology is transferred in humanitarian aid, and about the barriers that international humanitarian organizations face and how they cope with them. "Context" is defined as the conditions in which the transfer process is carried out, and include technical, organizational and political aspects.

The research was divided in three themes, related to the previously described assumptions, each with a respective research question(s).

The first theme is related to the first assumption that the process of medical equipment transfer is unsustainable due to the ambiguous overlap of aid activities. The respective research questions are:

a. What context characteristics influence international humanitarian organizations when transferring medical equipment during humanitarian emergencies?

b. How can systems design theory contribute to the study of complex medical equipment transfer in humanitarian emergencies?

The second theme is related to the second assumption that the medical equipment used is not suitable to the work of international humanitarian organizations performed in (different) low-resource settings. The respective research question is:

c. What are the safety-related challenges of using medical equipment in low-resource settings?

The third theme is focused on the third and fourth assumptions that medical equipment can be improved through systems design and leveraged by current trends in humanitarian aid. The respective research questions investigate the preconditions for design-based innovation from the perspective of manufacturers and an academic initiative dedicated to systems design.

d. How does the medical device industry currently deal with the humanitarian market, from a design perspective?

e. How can the practice of systems design support innovation within the humanitarian market?

Research approach

Throughout the research in this thesis, a research in design approach (Horvath, 2008) was followed in order to explore, with a design lenses the contextual relationships between medical equipment and their transfer process, carried out by international humanitarian organizations in humanitarian emergencies. Research in design is defined as a domain-independent and context-specific research approach that uses determined background disciplines and their respective methods to explore and understand design-related phenomena. Research in design is common in industrial design engineering research practice to generate knowledge about the relationships between people, artefacts and their surroundings.

The main research design consisted of qualitative methods which are described in detail in each publication (table 4.1 and chapters 9-14). The research questions a and b, related to the influence of context characteristics in the transfer process of medical equipment, were researched using available reports and publications from international humanitarian organizations and complemented with interviews with experts in medical equipment transfer from humanitarian emergencies. Research question c, related to the safety of use of medical equipment in low-resource settings, was researched by means of observations in two different real-life settings, Indonesia and Haiti, and combined with semi-structured interviews with the healthcare practitioners. Research questions d and e, related to the perspective of designers and their relationship with the humanitarian market, were first addressed using interviews with the industrial sector and followed by organizing three design workshops, dedicated to the design of technologies for the humanitarian market.

Table 4.1 Outline of section II including the research questions relative to each study and the respective methodology used

The transfer of medical equipment in humanitarian emergencies	
a. What context characteristics influence international humanitarian organizations when transferring medical equipment during humanitarian emergencies?	
b. How can systems design theory contribute to the study of complex medical equipment transfer in humanitarian emergencies?	
Publication 1 and 2	Literature study and interviews
Safety of medical equipment use in low-resource settings	
c. What are the safety-related challenges of using medical equipment in low-resource settings?	
Publication 3 and 4	Case study: Interviews and observations in real-life settings
Medical equipment improvement through systems design	
d. How does the medical device industry currently deal with the humanitarian market, from a design perspective?	
e. How can the practice of systems design support innovation within the humanitarian market?	
Publication 5	Literature study and interviews
Publication 6	Design workshops

MAIN FINDINGS

The successful transfer of technology is not a matter of transporting a piece of hardware from one geographic location to another. It often involves much more subtle issues of selection and discrimination, and a capacity to adapt and modify before the technology can function effectively in the new socio-economic environment (Rosenberg, 1982, pp. 247–8).

5 Main findings and answer to research questions

This chapter summarizes the most important findings of this thesis, based on the overall experience gained by carrying out the studies in publications (1-6). These findings are integrated to answer the research questions and complement the specific findings of each study presented in section II of this thesis. This thesis built upon a sociotechnical perspective and delivered insights to the study and practice of systems design in humanitarian emergencies.

— First, by investigating the context of medical equipment transfer in humanitarian emergencies and describing the systemic nature of barriers to that process, from the perspective of experts from international humanitarian organizations.
— Second, by generating empirical understanding of the safety of medical equipment use in low-resource settings, and discussing the practical and methodological challenges of researching in this field.
— And third, by reporting on the challenges of innovating within the academic and medical industry contexts.

Figure 5.1 illustrates the main findings and their positioning according to the sociotechnical perspective of the transfer of medical equipment in humanitarian emergencies. Each main finding will be described according to the three explored themes: Transfer of medical equipment in humanitarian emergencies (5.1), safety of medical equipment in low-resource settings (5.2) and medical equipment improvement through systems design (5.3).

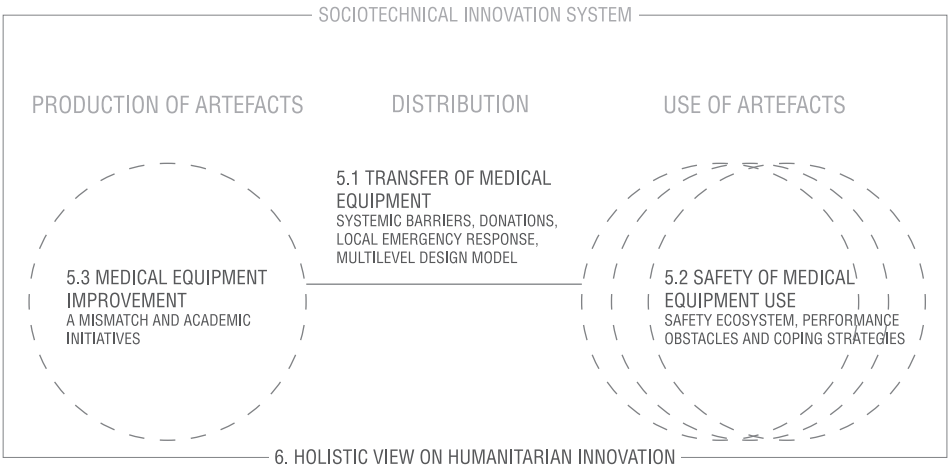


Figure 5.1 Main findings according to basic elements of sociotechnical systems specific to medical equipment transfer in humanitarian emergencies

5.1 Transfer of medical equipment in humanitarian emergencies

> Once a technology is implemented, several changes can subsequently occur in the technology itself and/or in the tasks and processes associated with the technology. Therefore, the implementation of a technology in healthcare can have characteristics of both episodic change and continuous change (P. Carayon, 2012, p. 11).

Publications 1 and 2 focused on the context characteristics that influence the transfer of medical equipment in humanitarian emergencies and the applicability of a systems design thinking in this context. The following main findings are complementary in answering the research question:

a. What context characteristics influence international humanitarian organizations when transferring medical equipment during humanitarian emergencies?

The barriers of transferring, and sustaining the use of medical equipment in humanitarian emergencies are systemic. However, they are not addressed as such

In publication 1, barriers and enablers of transferring medical equipment in humanitarian emergencies were identified. For this, the transfer process was divided into five phases of its lifecycle (supply, procurement, deployment, use/servicing and handover) to guide interviews with six experts from two international humanitarian organizations. The described experience showed that providing healthcare in humanitarian and low-resource settings is highly complex and irregular. In addition, the transfer is influenced, and has influence on local practices, infrastructures and (lack of) policies. The most frequently mentioned barriers included difficult equipment implementation, uncertainty regarding differing local settings, absence or difficult compliance with standards, and lack of continuous or appropriate supply and servicing. The enabling mechanisms through which organizations deal with barriers, were also identified. Amongst the most frequently mentioned enablers were, the choice of adequate equipment in terms of purpose and characteristics to perform in austere settings, elaboration of standards and of kits for harmonization of practices, and effective agreements with suppliers or manufacturers to ensure servicing and follow-up. The lifecycle approach to the transfer process allowed to explore issues beyond only the transport or the use medical equipment. It allowed understanding how logistics, as a whole, often replace commercial, social and technical functions due to the lack of additional supporting mechanisms.

In order to translate and generalize the specific barriers and enablers into context influences, the findings were analysed according to the three principles openness, interconnectedness and non-linearity of systems thinking. This allows describing the systemic and complex

nature of the transfer of medical equipment:

— First, barriers and enablers are caused by varying external factors, namely different types of regional contexts and type of disaster, different disaster relief phases and different types of organizations.
— Second, the identified barriers have a multiplicity of dimensions. This is evident from the relation between the identified barriers and enablers. Although mechanisms are in place, and being developed to address different barriers, barriers are still present.
— Third, given the diversity and constant change of contexts, the relationships between different, and often uncertain, stakeholders also change. This leads to an incremental build-up of latent barriers and loss of control, evident in other barriers identified in the study.

Donations of medical equipment motivate end-of-life considerations in medical equipment design

Donations are part of the technical and organizational complexity of the humanitarian emergencies context. International humanitarian organizations are faced with trade-offs when choosing medical equipment. Such decisions include amongst others, choosing for low-cost or for equipment accuracy, dispose or reuse, reuse or donate and transport or buy locally. Well-grounded decisions are usually hindered by sudden-onset emergencies which often call for medical equipment, personal protective equipment and supplies donations. Worldwide, governments, companies and hospitals organize donations, most often based on WHO requests but sometimes also based on uninformed judgements or convenience of donors. Donations include new and used medical equipment. The medical equipment used during an emergency by international humanitarian organizations is usually not reused by international humanitarian organizations but donated because of import/export regulations related to Value-Added Tax and export licenses (publication 1). Donations, made during an emergency or afterwards, can be beneficial to increase the capabilities of a country, and to motivate local and international healthcare practitioners to work and help. However, "it is generally accepted that the characteristics of a technology are mostly mined by the prevailing conditions of the technology-producer country" (Shahnavaz 2002 p.312). Therefore medical equipment faces barriers because it is usually designed under certain policies and for a certain infrastructure, different or unavailable in the multiple ones existing in humanitarian emergency settings (principles of openness and interconnectedness, publication 1). This results in a misalignment of medical equipment donations with the national healthcare priorities or the activities carried out by the international humanitarian organizations. Especially if donor entities limit donations to a specific origin or brand. Donations can also result in high variety of equipment within a hospital, which is unpractical from a maintenance and usability point of view. Besides that,

and in particular in emergencies, not all medical equipment is suitable or necessary, some creates un-addressable needs and can be, besides ineffective, harmful (publication 1, 3, 4).

Local emergency medical services are an essential basis of humanitarian emergency response, in any country, with more or less expression

The barriers and enablers identified in publication 1 do not only result from inadequate medical equipment donations or a complex context nature. They also result from a short-term oriented practice and business models (principle of non-linearity from publication 1). International humanitarian organizations are known, amongst the aid sector, for their short-term planning. They collect specific and narrow-focused funding, and are specialized in saving lives in worldwide large-scale emergencies. As with other medical emergencies (e.g. large-scale traffic accidents with multiple patients), the main objective of relief if to stabilize health conditions and limit mortality, especially in the initial period, when most lives can be saved. Critics of short-term aid claim that humanitarian aid does superficial aid, not addressing root problems that caused the emergency and offering a type of aid that feeds the dependency on an unsustainable healthcare quality (Audet, 2015).

However, the borders distinguishing the phases of emergency, reconstruction and development are not so clear due to the complexity of healthcare itself (needs and processes) and unpredictability of disasters. This means that international humanitarian organizations, besides addressing the immediate medical needs of a humanitarian emergency, also offer support to address the posterior and side-effect medical needs of a population. This necessary transition of medical services requires specific competences of coordination, task-shifting and use of less advanced technology, in order to align efforts between emergency and local services. In order for organizations to really function only in emergency, their services and equipment would need to be as self-contained as an ambulance is. For example, although rather robust medical equipment is already developed for the military, and some organizations are more self-contained than others (e.g. United States Naval Ship Mercy, MSF), that would require a strict coordination with often inexistent local emergency medical services, Ministry of Health and other NGOs. The extent to which policy and infrastructure of national medical emergency services are available depends on their prioritization by governments and professional associations (Beresford & Pettit, 2012). Worldwide there is a large diversity of healthcare settings associated with political and socio-economic factors, that is more complex than the difference between high and low-resource settings.

A multilevel design model contributes to the understanding of the nature of medical equipment transfer in humanitarian emergencies and of the role of design in it

The multilevel design model (MDM) (Peter Joore & Brezet, 2014) was used in publication 2 to complement the previous analysis of three systems thinking principles openness, interconnectedness and non-linearity and answer the research question:

b. How can systems design theory contribute to the study of complex medical equipment transfer in humanitarian emergencies?

The MDM is based on sociotechnical theory and is originally used to describe a change process implicit in systems design and involving different system elements. Because of its descriptive nature it can be used to analyse the systemic nature of the transfer process (similarly to a design-implementation process) and to explain the mismatch of technologies and context of use (figure 5.2). When analysing the suitability of medical equipment and its use context from a sociotechnical systems perspective, it is clear that the transferred technology must be considered together with the systems levels of a determined context because it depends on them to function. In the MDM, system levels are defined by relationships between human and technical factors that have hierarchical degrees of influence, scale, time, and tangibility. For a determined medical equipment, the range of system levels of a determined context, illustrated in figure 5.2, includes relationships between human and technical factors associated with manufacturing, servicing, using, managing and regulating that medical equipment.

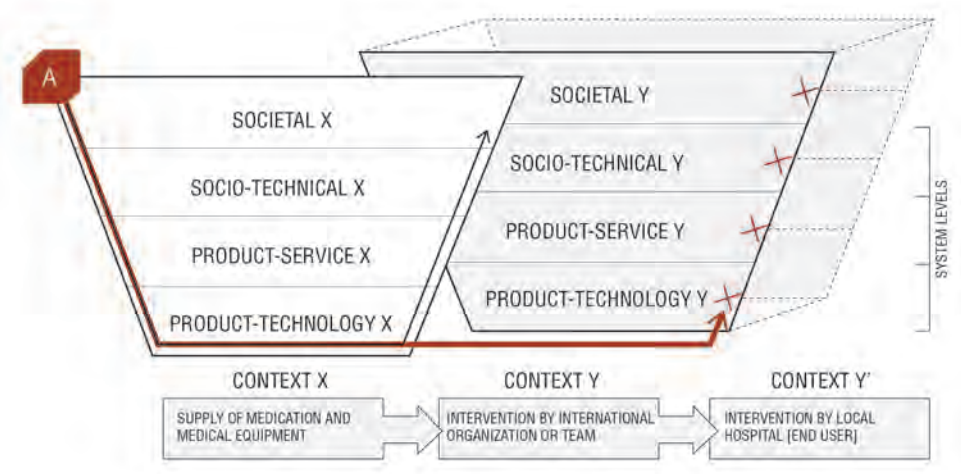


Figure 5.2 Multilevel Design Model applied to describe mismatch of medical equipment and humanitarian aid context (adapted from P. Joore & Brezet [2014])

The particular challenge posed by the response to humanitarian emergencies, illustrated in figure 5.2, is that it implies a temporary transfer of technology between two inherently different contexts (x and y) with long-term effects (y'), rendering the available medical equipment inadequate to function. The transfer of medical equipment is therefore a "systemic transfer" where the medical equipment works as a carrier of those system levels, from one to another context. This mismatch (crosses in figure 5.2) is the result of differing system levels within contexts that act as barriers for healthcare safety (e.g. different services, regulations and cultural values). In addition, the same transferred medical equipment and services are used by different stakeholders in different phases of aid.

An additional implication of the MDM is that, in order to address the systemic nature of the transfer process, international humanitarian organizations would benefit from a collaborative, multidimensional approach to their activities: an approach that promotes an adaptable, more inclusive action, and a balance between short- and long-term priorities. The MDM can help to guide such an approach, where the design of products, services or organizational interventions is integrated, by helping to position different design methods and tools. In order to operationalize the MDM, the combination of the two concepts: product-service systems (PSS) and human factors and ergonomics (HFE) was proposed, because they are complementary in the way they enhance the role of organizations as change actors. Both concepts contribute to explore ways to redesign the elements of the transfer process, optimize the use of resources and become more competitive and transparent in the way medical equipment is used. PSS offers a design framework to designers to shift from product-oriented focus to a focus on integrated technical and social interventions, where different ownership structures and use scenarios are considered, as a way to be more competitive. HFE offers an important framework for evidence-based human/activity-centred design of medical equipment and healthcare environments. The combination of the two concepts resulted in a list outlining characteristics for a sociotechnical systems design orientation to humanitarian innovation (chapter 6, p.52).

5.2 Safety of medical equipment use in low-resource settings

> A system involves an interconnected complex of functionally related components. Failing to consider the systemic properties as derived from the interaction of the parts leads to sub-optimization of the performance of the whole (Pourdehnad, Wexler, & Wilson, 2011, p. 2).

Publications 3 and 4 focused on the safety context of medical equipment use in low-resource settings. The motivation for these studies was the assumption that the complex medical equipment transferred in humanitarian emergencies is not adequate, and therefore affects

the safety of healthcare provision in low-resource settings. The following main findings are complementary in answering the research question:

c. What are the safety-related challenges of using medical equipment in low-resource settings?

Safety of medical equipment use involves more than user-equipment interaction

Safety is a property of a system and, as such depends on the functioning of all the human and technical factors within a system and their interconnectedness (Dankelman & Grimbergen, 2005; Dekker, Cilliers, & Hofmeyr, 2011). Publications 3 and 4 describe the field studies that were carried out in two distinct low-resource settings in disaster-prone regions, Indonesia and Haiti, in order to investigate safety-related challenges of using medical equipment. Both studies focused on surgical and anaesthetic practice. The settings of the two field studies are representative of the diversity between low-resource settings, and they underline the importance of considering different local healthcare settings and emergency response capacities. A macroergonomics framework (figure 5.3) from human factors and ergonomics literature was used, because it provides structure to study safety from a systems functioning perspective, focusing on aspects that extend beyond the physical aspects of medical equipment, to aspects, such as access and management that are important for the systems design approach proposed above.

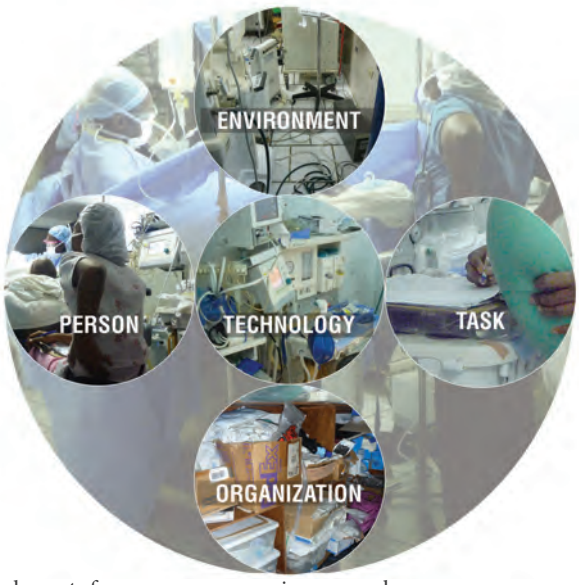


Figure 5.3 System elements from macroergonomics approach

Publications 3 and 4 showed that, just as the availability of medical equipment is important, so are its affordability and maintainability on the long-run. With regard to medical equipment, safety challenges were found in the relation of technology with its entire ecosystem and related processes. For example, the safe use of an autoclave cannot be guaranteed without the availability of simple sealing strips for sterile packaging. Similarly, safety of medical equipment involves the ease and speed of sterilization, the ease to dispose, and the coherence of available functionalities. Without consideration for these human and technical dimensions, medical equipment is prone to lead to unsafe healthcare provision. Two important indicators of safety challenges were identified: performance obstacles and coping strategies.

Performance obstacles, as medical error are an important indicator of safety

Performance obstacles are defined in this thesis as factors related to the work structure of healthcare practitioners that disturb the execution of particular activities or tasks, affecting to a certain degree their time, comfort or result. Performance obstacles were used as indicator of safety, rather than the more common analysis of medical errors. The identification of performance obstacles is an important contribution to safety and error research in a way that it helps to identify system problems while they are building up. In addition, the study of medical equipment use is not only relevant when a determined task is being carried out but throughout the whole procedure, given that different occurrences might disturb the attention of practitioners (e.g. unexpected emergency and interaction with other experts).

A tool called observable performance obstacles (OPO) was iteratively designed and used for data collection and analysis in both studies. The OPO tool is an adaptation of the macroergonomics model of safety from Carayon (2014) and focuses specifically on medical equipment by capturing performance obstacles in the relation between medical equipment and other system elements (publication 4, figure 11.2a, p. 180). In both studies, performance obstacles were more frequent due to environment-related factors (i.e. positioning, avoidance and infrastructure). Medical equipment can cause more disturbance because of its misplacement when it is not being used, than while in use. Further reasons include infrastructure limitations in terms of energy stability and space for use and storage, deteriorated condition, or lack of medical equipment, and incompatibility with varying activities. A parallel analysis from publication 4, suggests that there are four different ways performance obstacles contribute to near misses and can ultimately lead to patient harm (box 5.1).

Box 5.1 Four ways in which performance obstacles threaten safety (Santos et al., 2014)

Delay of procedure
The implementation of medical devices implies the management of standardized processes that guarantee their proper functioning. Processes, such as blood labelling and preparation for transfusion, storage and replacement of cylinders, and inventorization of batteries and supplies, require planning of location, responsible staff and tools, and when not properly supported might lead to potentially hazardous delays.

Attention diversion
Two aspects had a clear influence in the occurrence of near misses by diverting the attention of practitioners. First the lack of operation space leads to recurrent entanglements and falls of equipment. Secondly, the deterioration or advanced age of equipment or components (e.g. cylinders, batteries, air-conditioning unit) which malfunction leads to an unanticipated need to initiate new tasks. Despite the sophisticated technology being available, novice nurse anaesthetists are strongly encouraged to be proficient in using basic anaesthesia techniques, for in case technology might fail.

Introduce errors
Several OPOs indicated that due to the unavailability of equipment, users create mechanisms to work around the absence like sharing or adopting alternative products for a certain purpose (e.g. use of microwaves and generic maintenance tools). Though these improvisations have a direct positive impact, they may also lead to introducing wrong variables in a procedure. For example, use of a microwaves to warm up intravenous fluids or – transfusion blood (acceptable for warming other intravenous fluids but inappropriate and contraindicated for blood) without a temperature indicator and the use of improper maintenance tools will lead to or accelerate the occurrence of potentially life threatening situations. Another case of error introduction was caused by repeated administration of spinal anaesthesia and therefore losing track of administered dosage.

Worsening work conditions
Environment-related OPOs included reoccurring blackouts, limited or inappropriate infrastructure (i.e. no room temperature regulation) and logistics including improper storage in the operating room (i.e. gas cylinders and idle equipment), disordered floor use (e.g. cables crossing room, stacked equipment). These aspects strongly contribute to reduced comfort and space in the workplace as well as increased confusion and tension between practitioners. Additional origins of tension were the need to readjust the position of trocars during the spinal anaesthesia and to position the pulse oximetry on the floor due to lack of space.

Transfer of medical technology relies on coping strategies

This thesis showed evidence of the different ways users adopt technologies and practices to overcome performance obstacles and be able to proceed providing care. In literature, these coping strategies, violations or work-arounds, mean that a health practitioner took an action to overcome a problem that deviates from standard practices.

In many cases these strategies allow healthcare practitioners to carry on their work, but in most of these cases this also means there is a degree of safety compromise because of the deviation of standards (Reason, 1997). Several examples were mentioned in this thesis, from the use of a carpenters drill instead of a surgical drill (publication 3) to the use of a microwaves to heat up blood and intravenous solutions (publication 4), the development of a "bricolage" scavenger system and a mechanical autoclave handle that reduces human variability of valve management (publication 1).

It is important to acknowledge that performance obstacles and coping strategies are not specific of low-resource settings. Surgical and anaesthetic care involve much uncertainty and professionals working in these fields are known to have problem-solving abilities. However, these indicators are particularly relevant in low-resource settings, because they focus on healthcare practitioners working in extreme circumstances to guarantee safe healthcare provision, and to whom the definitions of "safety", "emergency" and "obstacle" might differ. And so, even if obstacles seem to coincide in different settings, they are more prone to represent serious safety threats in low-resource settings.

5.3 Medical equipment improvement through systems design

Publications 5 and 6 focused on the challenges of designing products and services to the "humanitarian market" from the perspective of academia and the medical device industry, in order to understand the preconditions for design-based innovation. The following main findings are complementary in answering the research questions:

d. How does the medical device industry currently deal with the humanitarian market, from a design perspective?

e. How can the practice of systems design support innovation within the humanitarian market?

The mismatch between the private and the humanitarian sectors hinders the practice of design

Publication 5 uncovered the priorities and the practical challenges of developing products and services for the humanitarian context. The study included eleven interviews with product development companies from relevant sectors, involved in product development for the humanitarian market.

The findings showed that companies prioritize self-explanatory and controllable requirements, like safety and robustness whereas there is discrepancy regarding the relevance of e.g. adjacent services and cultural aspects. The approaches used by the interviewed companies lacked specific indicators and strategies to address the humanitarian market, mostly due to a mismatch between the humanitarian and the private sectors.

As shown in publication 5, business effectiveness not only depends on addressing logistics from the "ground up", but also aspects such as policy, coordination and information. Four challenges of concern from companies were identified, in regard to the mismatch between the two sectors: time and context, finance, stakeholder network, supply chain and information flow. The identified challenges showed that product development could benefit from a shared agenda with international humanitarian organizations. Both sectors can learn from each other and develop shared practices, aligned with contextual and timeframe limitations but also with long-term common goals. This can be done by initiating and supporting pilot projects that extend beyond the traditional timeframe. Academics can play a key role in bridging knowledge and practice in these projects through an interdisciplinary effort to systematically design, implement and evaluate these projects.

> I have never seen a large funded tender for equipment for Africa that even considers life-costs of the product or even the consumables. Ever... that is quite frankly disgracious (R. Neighbour, Managing Director of Diamedica UK Ltd at Appropriate Healthcare Technologies for Low-Resource Settings conference, 2014).

Academia plays a key role in collaborative design initiatives involving multiple stakeholders

Publication 6 introduces an approach to humanitarian innovation used in an academic initiative called Rethink Relief (RR) which was carried out in three locations between 2011 and 2014 (see table 5.1). This publication positioned design practice in the humanitarian transition and presented the results of a system design approach. The results were analysed and discussed together with the methodological challenges of such an approach.

Table 5.1 Rethink Relief locations 2011-2015

Delft, Netherlands (1 week)	**Boston, USA (1 week)**	**Pader, Uganda (1,5 weeks)**
22 participants	20 participants	37 participants
1 partner	1 partner	2 partners

The proposition of RR is that "*collaborative design* can offer the humanitarian sector a neutral, yet differentiating space for discussion about humanitarian innovation and also contribute to establish a *lasting commitment* for an effective co-development of suitable product and services" (emphasis added). RR started with the purpose of transforming a lengthy policy-level discussion about the humanitarian transition into a discussion with concrete and tangible solutions, where stakeholders with different perspectives of aid create consensus through the decision-making processes of design. This collaboration has resulted in integral concepts for immediate relief that empower affected communities by using the relief supply chain to distribute adaptable and scalable solutions (in contrast to disposable solutions). Examples include "do-it-yourself" solar and garden systems, health information safekeeping with promotional positive living and emergency-specific medical furniture. Some of these products are materialized as guidelines of open designs (instead of physical products) that can be locally built, adapted and shared with input from beneficiaries themselves. The following findings were derived from the built experience in RR regarding: 1) the involvement of multiple stakeholders in a design activity and 2) establishment of a lasting commitment.

First, when involving multiple stakeholders, including aid beneficiaries, it is important to define in-depth what their intended role is, given that several factors might affect that interpretation. These factors include power hierarchies within a healthcare system and programmatic priorities of organizations (often prioritizing social group instead of individual capabilities). The "inclusion" and "well-being" lenses (e.g. genre, age, security, and comfort) help to understand the diversity of perceptions (within governments, organizations, communities and families) about who should access aid and who actually accesses aid. Furthermore, at the basis of collaboration is a shared language and understanding of needs. There are several challenges about co-design regarding individual and social differences that affect the design process and its potential results. These include differences in geographic/cultural and professional background, expertize and attitude towards change and health, and are in line with the confirmed expectancies from (Diehl, 2010). These challenges are intensified by varying characteristics throughout the design process (i.e. from idea generation to consensus making). The role of a facilitator requires a professionalization of skills and adequacy to socio-cultural setting (e.g. power difference dynamics). This professionalization should include language, interpretation, design, ethnography, and a versatile intervention toolbox that allows choosing appropriate methods with which participants are comfortable with. A multidisciplinary and multicultural collaboration is not an end per se, but a means for problem-solving.

Therefore, the participation of different stakeholders must be sufficiently planned for and justified with a specific contribution to problem-solving.

> The conflict destroyed the cultural heritage of the people, most especially in weakening the bounds that held society together, the roles played by elders in society and the male-dominated role of provider or bread-winner. Where other communities unaffected by conflict can rely on social safety nets girded by cultural norms and traditions, in the conflict-affected areas such safeguards were eroded by the IDP camp experience ("The Return, Resettlement and Reintegration of IDPs in Northern Uganda: Challenges Faced by Local Governments" presentation, Michael Oloya Aliker Tebere).

Second, in regard to the "lasting commitment" of RR, there are three necessary conditions to consider: allocated responsibilities and roles (for the participants and future students), funding and alignment of goals with participant companies or organizations. The academic environment is appropriate to host design initiatives like RR, because of the educational benefits of such an experience. However, in order to have real impact, the initiative should include a handover of results before a next initiative is planned. A possible solution is to link the results to specific research that facilitates overcoming curriculum limitations and lack of knowledge management, but also enables ownership and overview of project continuity. Furthermore, the (re)design, test and implementation of each resulting project requires varying expertise and funding throughout the progress phases, that is not always foreseeable or obtainable within the institution. Building and managing a diverse network is therefore important. Building a network requires time and allocated resources, and involves significant costs if partners are distant from each other. A possible solution is to engage with existing networks or require that engagement from participants. Finally, the alignment of the initiative's goals with the ones from international humanitarian organizations is key for their commitment and time/effort investment. This means that, the initiatives should offer space for specific problem-solving and concept experimentation, and effective knowledge exchange.

GENERAL DISCUSSION AND CONCLUSIONS

What are the priorities in complex emergencies that are characterized by low mortality, where psychosocial and reproductive health concerns outweigh those posed by the incidence, if not the threat, of acute communicable diseases, and where chronic diseases, currently ignored by the relief community, are of greater importance even in the emergency setting? Even if we can identify those priorities, do we know how to intervene safely and effectively? The only way to answer these questions is to carry out carefully targeted, appropriately designed, applied research in complex emergencies (Waldman, 2001).

Inequality of healthcare systems is inherent to our society and it is a reason that drives the will of people to be better, more efficient and competitive and deal with existing political, financial and performance constrains. Inequity (unfair inequality) however, turns this driving will into a necessity.

6 A holistic view of humanitarian innovation

This chapter includes a discussion about the practical and didactic implications of the main findings in this thesis for design and innovation. As a result, a systemic approach to humanitarian innovation, focused on the transfer of medical equipment, is proposed and reflected upon. This discussion answers the main research question driving the research in this thesis:

How can a systems design approach contribute to a more sustainable transfer of medical equipment in humanitarian emergencies?

This thesis addressed the context nature of the medical equipment transfer in humanitarian emergencies, the safety-related challenges of medical equipment use in low-resource settings and finally, the barriers to innovation from the perspective of manufacturers and academics. The main findings (chapter 5) contributed to promote a decentralized and long-term approach to the planning of humanitarian operations and the inclusion of multidisciplinary design and research in ongoing practices involved in all phases of technology transfer.

Decentralized and long-term approach

The complex variety identified in the studies about the context of medical equipment transfer suggests that a unidimensional approach to the planning of humanitarian operations is not adequate (publications 1 and 2). This is in line with the research from Swanson et al. (2012) and Plsek (2003) on rethinking healthcare systems. No robust self-contained medical equipment will solve the problems of technology transfer, if the medical equipment is not aligned with local needs and health priorities. The interwoven services and roles of international and local staff, and government priorities that are organized around differing medical procedures, justify organizational change and a decentralization in planning and innovation interventions. But to what extent do international humanitarian organizations and the medical device industry mind about a more sustainable transfer of medical equipment? How realistic is it that international humanitarian organizations will adopt a long-term and decentralized planning? This thesis supports the idea that this is a strong possibility.

First, international humanitarian organizations are increasingly required to be efficient, and therefore competitive, due to the escalating number of NGOs and required budgets, which on the long-run are unsustainable (United Nations Department of Economic and Social Affairs, 2011). One way of being efficient might be to optimize resources and therefore increase efforts in terms of prevention. This means working closer to national

governments, to strengthen their capacity to align the efforts of response and take over products and services. Second, countries that traditionally received aid are developing and becoming active participants in response and funding. Their engagement in defining priorities is very important to actually stay competitive. And third, the increasing presence of the private sector, to whom e.g. safety is a key requirement, means that new issues will be addressed (e.g. usability, user-producer relationship, lifecycle issues). In addition, a better understanding of the context of local healthcare, beyond evidence of infrastructure unavailability (which focuses on donation-driven solutions), is needed (box 6.1). For the medical equipment industry, understanding the local constrains (e.g. variable layout of facilities or lack of basic supplies of which equipment depends to perform in safety) can determine how improved products and services could fit humanitarian emergencies (publication 5). This is in line with Bar-Yam, founding president of the New England Complex Systems Institute when referring to aid in Haiti, "duplication and competition among NGOs is not a bad thing, so long as organizations are rewarded with donor money for delivering effective solutions. And those solutions can only be determined by Haitians themselves (…)". And that "this implies that we need to be seeing a lot more creativity and innovation in coordination efforts, in ways that are appropriate and tailored to different emergency contexts" (O'Connor, 2011).

Multidisciplinary design and research

The idea of a long-term and decentralized planning is not exclusively based on the findings related to context characteristics of the transfer of medical equipment in humanitarian emergencies. The findings described earlier regarding safety of medical equipment

Box 6.1 Relevant differences in healthcare systems from Indonesia and Haiti (publications 3 and 4)

In Indonesia for example, urban centres have autonomous health facilities with formalized services like ambulance and emergency department. In the occurrence of a humanitarian emergency, efforts can be mobilized to support relief to e.g. a rural community. However, in low-income countries such as Haiti, most healthcare provision is assured by international efforts focused on specific parts of the country. The work of international humanitarian organizations is based on a constant replacement of visiting doctors and there is a less defined boundary between services and priorities.

The transfer of a CT scanner (device used mostly to diagnose cancers) is adequate in projects that are assigned to treat cancer patients but not in projects dealing with more primary health problems, such as HIV or diabetes. Performing (emergency) surgery in rural Haiti can be extremely challenging due to the lack of e.g. adequate sterilization or waste management facilities. Poor-resourced emergency services are often dependent of the cooperation of survivors in responding to the emergency by e.g. bringing wounded people to the hospitals or supporting them in psychological shock.

use also motivate the need for continuous research and design in low-resource medical environments oriented towards management of risks, and applied in daily practice and training, technology use and management.

A first step is to ensure the (multidisciplinary) commitment from all persons in a system, to be aware and prioritize safety. In this way, safety is seen as a global goal, central to the activities of the system. The "need-for-change" (necessary to drive innovation) in the medical setting is a mind-set, a culture, in which coping strategies are valued and problems are acted upon by all persons. The continuous improvement of healthcare systems through such multidisciplinary collaborations (e.g. healthcare practitioners, managers and engineers), focused on human factors and ergonomics, can contribute to an accessible and equitably safe healthcare for people living in countries where access to healthcare is inequitable (Rahardjo, 2003). According to Shahnavaz (2002) the research and development of technology in high-income countries has contributed to the awareness and recognition of the importance of human factors and ergonomics. And it can also do so in low-income countries. It can make a healthcare system more emphatic, creative, flexible but also more resilient to deal with problems. Performing research in emergency medical settings implies several practical and ethical considerations that must be overcome with practicing experience (e.g. patient consent and security of the researcher).

A multidisciplinary collaboration can benefit from the intersection of engineering and the medical application domain in order to create opportunities for designers, engineers and healthcare practitioners to work closer together in leveraging solutions at any level of the system. The involvement of healthcare practitioners in the design engineering work requires particular "lenses" to allow different mental models to be expressed. Experience and observations of "the real" environment of technology can change the way an engineer looks at technology and thinks of usability, in the same way it can to an healthcare practitioner (Jalote-Parmar & Badke-Schaub, 2008; Rasoulifar, Dankelman, Thomann, & Villeneuve, n.d.). This proposed interaction between different professional fields and levels of expertise is hindered by different conceptual barriers (or intangible barriers) that are related to the constructed mental representations and experiences that define how different professionals understand, perceive and prioritize events in the world (e.g. exposure to technology, language). As Meadows claims, "everything we think we know about the world is a model" (D. H. Meadows, 2008, p. 87). In the context of humanitarian healthcare, conceptual barriers will affect the way professionals communicate and, ultimately determine the reliability of the information they exchange. Because of the ability to think abstract, the understanding of "safety", as a concept is often not the same. The development of tools, such as the OPO tool, is key for the communication between e.g. engineers/designers and doctors. Although the OPO tool is specific to the surgical context, it is an important contribution to the designer's toolbox, because it helps the designer/

engineer to visualize and co-design with healthcare professionals the implicit goals of the design process, and thereby build a shared understanding of e.g. what safety is.

In particular in low-resource settings, healthcare practitioners work under stringent financial and organizational constrains and must therefore adapt to be able to perform as good as possible. Rasmussen's model describing the migration of work practices toward safety boundaries (Rasmussen, 1997) shows how these influences will "push" the healthcare practitioners to limits of safety and work closer to a boundary where accidents occur more easily. This "push" also means that the limitations faced by healthcare practitioners drive them to sometimes design their own activities. The ability to creatively cope with problems is dependent on a person's cognitive behaviour level. Rasmussen's model distinguished between knowledge-base, rule-based and skill-based behaviours. This distinction allows us to understand why experts are more likely to find solutions to performance obstacles than trainees because they have built a larger range of known and experienced situations, as opposed to trainees who need to follow rules and practice guidelines. Furthermore, this distinction is helpful to recognize that grass-root innovations (e.g. using mosquito nets as surgical dressings) do not only rely on experience of context limitations but also of built knowledge and experience. In Haiti, for example, there are no anaesthesiologists working in the rural areas, so anaesthesia-related grass-root innovations are not likely to exist. Likewise, as mentioned in publication 1 and 4 testing or studying medical equipment in low-resource settings does not guarantee reliable or comprehensive evaluation of medical equipment, because local healthcare providers lack exposure to reference standards and quality. Healthcare practitioners and technicians working in low-resource settings have a different mental model of technology than people exposed to ubiquitous technology.

6.1 How systems design for medical equipment transfer in humanitarian emergencies could look like

The systemic perspective of the multilevel design model (Peter Joore & Brezet, 2014) used earlier to illustrate the mismatch of technologies and propose a systems design approach, is shared by e.g. Rasmussen (1997) in the field of safety and Brezet (2001) in the field of environmental sustainability. All argue that, the more system elements (network of stakeholders, their goals and dependencies) are considered in a design process, the better a system can accomplish its function. This means, the target of design is not a product or a service but a whole-system ecology that allows a system to function. The MDM supports a continuous improvement and redesign rather than a punctual involvement of stakeholders. In this perspective, incremental improvements are important but have less impact than service or organizational improvements, in the accomplishment of system change. Importing models of sustainable transition or system innovation from the context of e.g.

alternative green energies and smart cities to the reality of basic needs in refugee camps or natural disaster response is not linear because problems in humanitarian aid are deeply rooted in societal level and happening in a political climate of instability. Nonetheless, the recent adoption of the "humanitarian innovation" concept, defined by words like "sustainable", "beneficiaries", and "long-term" brings an encouraging view ahead (Buyle, 2015). Perhaps this is the beginning of a transformation of the aid sector motivated by the need to be competitive and more integral when giving people (rather than beneficiaries) the capabilities to self-develop and to actively participate in the aid process (Bessant et al., 2014; Betts & Bloom, 2014).

The literature revision from Bessant et al. (2014) clarifies the need for humanitarian innovation to define itself in face of earlier existing concepts and practices, such as open innovation, entrepreneurship, public sector, inclusive and social innovation. To also still define is the "route" towards sociotechnical, sustainable change: whether humanitarian innovation will be used in the instability of a disaster as an opportunity to introduce radical changes in the performance of international humanitarian organizations, or will introduce incremental steps that gradually lead the way into new models of aid. A possible development in the transformation of the aid sector is the change from service providers to facilitators of operations that are carried out by local organizations and governments and the private sector. Figure 6.1 illustrates how a system design approach to medical equipment transfer in humanitarian emergencies could look like in order to contribute to a more sustainable transfer.

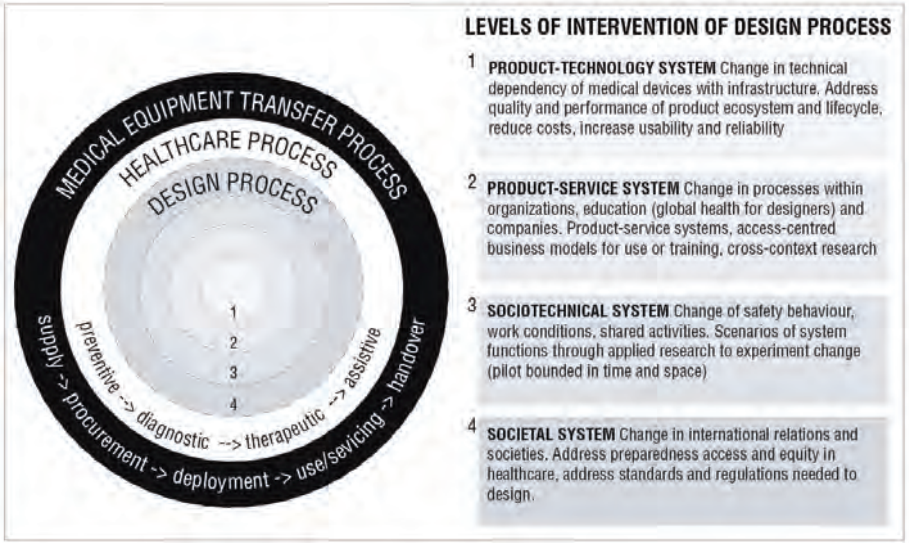


Figure 6.1 System design approach to medical equipment transfer in humanitarian emergencies

Figure 6.1 integrates the most important concepts mentioned in this thesis:

— There are three interconnected processes that make it possible to have a decentralized, long-term and multidisciplinary approach. The processes are: 1) the medical equipment transfer process as carried out by international organizations (from supply to handover), 2) healthcare process (from preventive to assistive healthcare) as it is carried out by national authorities and finally, 3) a design process (including design, implementation and research). While this approach places the process of medical equipment transfer as the main object of design, the consideration for the lifecycle of the local healthcare process, centered in a continuum of patients' needs, ensures that the processes are bridged. Design and research should be an embedded process that ensures the continuous joint development of products, services and practices. It is the thoughtful lifecycle perspective of the three processes that contributes to a more sustainable transfer.
— The design process can be positioned in four levels of intervention from the MDM (from product-technology to societal level). In the figure, examples are given of an intervention toolbox, composed of interrelated design and research activities across all four levels.
— Transversely applicable to all four levels of the design process, are the principles of socio-technical design proposed in publication 2, and built from the combination of relevant design tools. The principles should be seen as the "glue" that holds MDM together

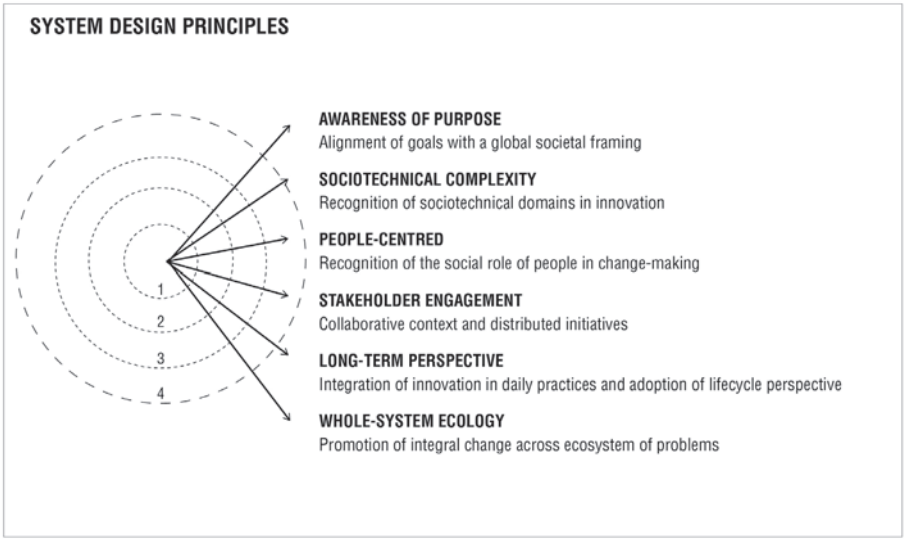


Figure 6.1 [cont.] System design approach to medical equipment transfer in humanitarian emergencies

Box 6.2 Example of the systems design approach application

> Just as toothbrushes should be based on an understanding of the size and shape of our hands, mouths and teeth, legislation has to be predicated on an understanding of the socio-political forces that motivate people in the area of question. And in both cases, the overarching objective is to satisfy a human or societal need. [Despite the obvious differences between a concrete physical object and an abstract policy decision] [...] both are system design levers, in the sense that they are tools that shape human behaviour in ways that affect the success of a system, albeit not on the same scale (K. Vicente, 2006, p. 246).

The proposed systems design approach suggests using the system design principles as ingredients to map two processes: the transfer of medical equipment and the patient-centred healthcare. And in addition, the four system design levels should be used to define a strategy for the improvement of technology transfer (incl. design of medical equipment and/or parts of its ecosystem). It is assumed that this approach is used by (system) designers and humanitarian organizations aiming at reformulating problem statements and analyse them beyond the best available solution. Above all, it aims at figuring out how to support organizations to leave an affected region without disrupting local services that were reinforced. Whether organizations involve designers in their activities or train staff to identify opportunities, depends on the specific emergency (i.e. safety, accessibility).

For example, orthopaedic/trauma care is an important component of medical assistance in humanitarian emergencies. It is so valuable that orthopaedic/trauma surgeons are often part of the first assessment teams. Providing this type of care involves several interrelated processes and implies the transfer of specific equipment (i.e. immobilization collars, surgical drills, saws, pins, etc.) but also of appropriate sterilization equipment and supplies. Furthermore, patients that receive this type of care need to be adequately informed of their condition and supported with a wound management, prosthesis and physiotherapy plan.

Say after the first response phase to the earthquake in Haiti (2010) an organization sets itself to "Improve orthopaedic support in humanitarian emergencies". Based on the experience of international and local staff of a humanitarian organization, it is possible to map the transfer process and the patient-centred healthcare, creating an overview of relations between healthcare practitioners, technologies, activities and spaces (figure 6.2). The use of an integral enquiry approach is very important because the perspectives of e.g. logistic management, surgeons and cleaning staff do certainly differ and are required for a complete overview of involved processes. In this way, activities that are not often seen as related, can now be included into consideration, such as portable equipment for triage teams to prevent crush syndrome (increases chance of renal failure and amputations), hygiene of wounds or orthopaedic fixators for infection control and post-operative care, and waste management.

After the identification and choice of an opportunity, the improvement strategy is chosen by distributing challenges across the MDM system design levels. This will help to

determine the different, but complementary activities and stakeholders involved in a project. If for example, amongst all activities, the project focuses on local sterilization of equipment, there are challenges in the autoclave redesign, the Product-technology system (e.g. ergonomics of loading, of operation, safe transport, and adequacy to large orthopaedic equipment). Similarly with the product-service system (e.g. the autoclave integration in the pre-cleaning process, the available supplies, infrastructure, maintenance tools required to function), the Sociotechnical system (e.g. modular service solutions to adapt to other disasters, countries and organizations, usually implying long-term research) and the societal system (e.g. existing sterilization regulations and their compliance, implicit sense of status and values associated with hygiene, national objectives and support of governments and NGOs).

Improvement decisions made with this approach converge in pilot projects focused on the implementation of a concrete simulation (sociotechnical experiment), circumscribed in time, space and budget, carried out in "real" settings with a sample of "real" participants. Here, assumptions are tested or promoted and feedback is collected for follow-up. The use of pilot projects is further elaborated in the recommendations chapter of this thesis.

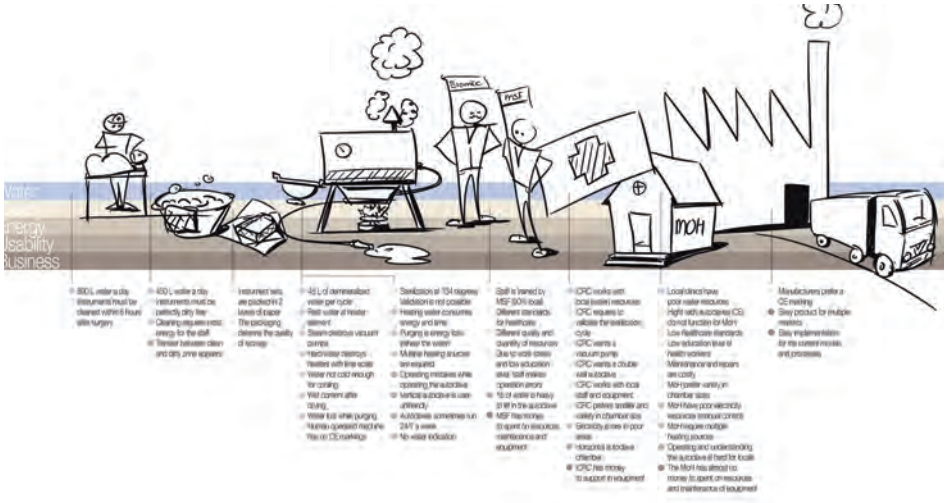


Figure 6.2 Example of illustration of system map describing critical points in user-centred sterilization process (Frenk Stokman)

This holistic view of innovation, when applied to healthcare humanitarian aid has implications for practice of international humanitarian organizations, companies and governments as agents for innovation. First, international humanitarian organizations do not have expertise or resources to develop products and do not have knowledge in the broad innovation field (Bessant et al., 2014). The required intersection of the humanitarian (public) and the private sectors in a quasi-market, is equivocal because of their differing social functions, responsibilities and capabilities. These two are also ruled by different mechanisms: whereas the governments (and donors alike) are ruled by public judgment, companies are ruled by market competition. The role of organizations, and the way they profit from the involvement in innovation must be defined. Options include finance projects, facilitate access to the "field" for research and experimentation, share knowledge about operational contexts or become early adopters of new medical equipment and services. For international humanitarian organizations, a benefit of the systems design approach is that it empowers them to assume the existing interdependency within their system. Thereby becoming a centralized knowledge base, but also a flexible organization.

> Humanitarian actors are not yet taking full advantage of opportunities to benefit from the expertise, capacity, resources and influence of the private sector (…) they are often unclear about what specific "asks" they could address to the private sector and are potentially naïve about the interests, priorities and approaches of private sector actors (Inter Agency Standing Committee, 2014).

Second, companies lack the motivation to engage in a long process of new product development without market knowledge and feedback, without a shared cost overview, and with an unpredictable and complex environment to settle partnerships. Furthermore, medical equipment-related standards are often not applicable to the nature of humanitarian work since not all regulatory and managerial policies can be guaranteed for the safe performance of medical equipment as it was designed to operate (e.g. Medical Device Directives compliance is required for the CE certification). Companies might be discouraged to produce equipment e.g. less dependent on reliable energy sources, because of requisites to acquire a standard. For organizations and countries, the CE marking and FDA approval are also relevant quality references, even for countries less represented in the membership of regulators. Similarly to the efforts of establishing an international regulatory framework for the global reduction of carbon dioxide emissions (i.e. Kyoto Protocol), regulating donations or medical equipment development is difficult, because of the essential volunteering nature of the participation and establishment of goals from different countries and industries. Nonetheless, efforts like promoting a democratic participation of all countries in e.g. International Standards Organization and highlighting the global and transversal aspects of global access to healthcare are important drivers for companies. The participation of companies in the proposed systems design approach is important

because companies help to identify inadequacies of standardization that ultimately hinder the embodiment of projects. Furthermore, companies can establish relations with potential customers in low-resource settings, while benefiting from resources required to implement medical equipment that are provided by international humanitarian organizations. For this, companies are required to reduce the strictness of budget allocation and look beyond medical equipment to the opportunities of a medical equipment ecosystem.

> The plain design and implementation of new medical devices, as the WHO proposes, is challenging. First, a new device implies the replacement of existing devices to which users are accustomed (multipurpose devices often offer functions for which devices are already available meaning they will be not used or render other devices waste). Second, technology implementation conveys additional systemic problems. Finally, there is the need for training, space, and management practices (e.g. maintenance and disposal) which are aspects not usually considered in product development planning (Santos, Wauben, L.S.G.L. Guilavogui, & Rosseel, 2014).

And finally, the development of capacities at Ministry of Health level, needed for the functioning of a medical industry, namely regarding procurement, expertise, legislation and on the side of industry, R&D, certification, and infrastructure, is a lengthy process. Especially after the impact of a humanitarian emergency. The heterogeneous infrastructure (existing infrastructure and familiar brands) and its handicaps in low-resource settings can be negative for the introduction of technologies. The continuous nature of the systems design approach means that projects should be carried out in parallel with ongoing healthcare processes, and make use of the existing interdependency between international organizations and local health ministries. This interdependency allows local research and development capabilities to be developed while informing the systems design process.

6.2 The humanitarian designer

> Designing, if it is to survive as an activity through which we transform our lives, on earth, and beyond, has itself to be redesigned, continually (Jones, 1991).

The field of design has shifted its target and aim since the Second World War, from an industrial design focus on functionality and aesthetics, to service design and experience. This shift had also impact on the design of medical equipment (Xue et al., 2008). The systems design approach and the sociotechnical design principles illustrated in figure 6.1 are included in an overarching approach called the Systems-Oriented Design (Sevaldson, 2009, 2010). Such approach requires rethinking the role of designers within circles of different stakeholders.

The designer, alone, is rather powerless in the complexity of the humanitarian sociotechnical system. And despite the integrative capabilities, creativity and inquisitiveness of the design field, as Jasper van Kuijk states, many designers in large-scale product development industries, hardly ever work in integrated teams. Within the systemic design movement, Jones (Design for Care 2014) identifies four design domains, defining action boundaries for the designer. For each domain, a different (and not necessarily transferrable) set of skills and a different arrangement of stakeholders are needed. This means that the design practice is broadened to a range of possibilities and engagement levels in society. In the case of healthcare and humanitarian aid, four different types of designers can be distinguished that have potential different contributions to humanitarian innovation:

— Designers focused on communication tools and languages between healthcare providers themselves, them and patients or communities, at a personal or team level. Engagements with this focus include communities of patients or social groups, healthcare practitioners and professional associations, social scientists, amongst others.
— Designers involved in the development of complex healthcare technologies, bounded by evidence-based and international standards. Engagements with this focus include different engineering specialists, safety and human factors specialists, healthcare technology users, technicians and managers.
— Designers that envision new business and social interactions and experiences at an institutional level. Engagements with this focus include economists, healthcare institution managers, practitioners, safety and human factors specialists and communities of patients or social groups.
— Designers championing and facilitating innovation initiatives that look at health more holistically to address basic problems of health inequity (e.g. cultural exclusion of basic services). Engagement with this focus requires the mobilization of a large number of participants, within international and national organizations and healthcare, research and education institutions. Ambitious goals tend to lose focus and momentum due to a high level of participations. Intermediate objectives are an important tool for the designer to keep all stakeholders involved.

The diversity of skills proposed by Jones (Design for Care 2014) does not set aside the fact that all of these activities should have a systemic orientation. This has several implications for the field of design education. The conclusions from this thesis, with regard to the implications of this shift, are in line with the following statement (also discussed in publication 2):

> DesignX requires skills, knowledge, and a vocabulary that enable it to engage effectively with stakeholders and professionals of many kinds. (…) Today, universities are focused upon discipline-based education that no longer suffices to deal with large, complex

> problems that involve multiple disciplines, technology, art, the social sciences, politics, and business. We need robust, new models for education, some based upon disciplinary skills, others based upon problems rather than disciplines, where experts and students from many backgrounds work together on a specific issue. This requires adding problem-based education to the existing emphasis upon disciplines (DesignX: A Future Path for Design joint statement by "The DesignX Collaborative").

First, a problem-based education must include problem-management rather than problem-solving. This idea is based on the principles of societal complex problems, or wicked problems for which there is not one specific solution (Ackoff, 1974; Senge, 1990). The complexity of today's societal problems requires a continuous and joint effort in its understanding and management. Second, a systems language must be integrated into the curriculum and skills toolbox (Dubberly, 2014). Systems theory and thinking are analytical lenses that acknowledge the dynamic nature of human activities and therefore, the best way to learn them, is through their application in practical experience (Collopy, 2009; Godfrey, Deakin Crick, & Huang, 2014). Sustainability (social, economic and environmental) is an integral part of systems thinking and should be introduced as such. Third, designers that work for professional sectors can benefit from specific education, oriented towards the "specific" languages of practice, business and regulation in order to reduce the designer-user knowledge gap. As mentioned earlier, the "field" experience is beneficial for both students and healthcare practitioners as it allows them to share mental models, important references for problem-management. Fourth (as mentioned in publication 2), in order to motivate and design organizational change, design education must include "diplomatic/relational skills" that facilitate the creation of shared visions of the desired change, but also enable exchange of knowledge in a democratic way.

This change does not go without overcoming certain barriers. First, academic curriculums should encourage problem- or project-based assignments and deliverables. By this, not limiting a project to the timeframe of individual assignments or disciplines but tying assignments and disciplines together to meet the goals of a larger project. Second, "field experiences" can be unsafe or not accessible (e.g. emergency situations). Third, sustainability research still needs to be recognized as a priority in both medical and humanitarian sectors (Nielsen & Santos, 2013a, 2013b). And finally, although it is important that this education leads to advances in design practice and theory, it is even more important that it also creates jobs.

The potential of design (theory and practice) to promote innovation, to contribute to bridge science, business and practice communities, to be applied in different fields and in systemic levels, must be explored and promoted in education as a competitive asset for social and economic development (Heitor & Bravo, 2010). The (design) academic environment is prone to host the engagement of universities, government and non-governmental

organizations, research centres and companies, at both national and international level. Innovation-oriented and practice-based collaborative initiatives (e.g. Rethink Relief, Access to Innovation or D-lab) provide a physical space where the "field" is present and also enable a context of creativity, knowledge exchange and diffusion to develop, try and promote new ideas. Above all it is through them, and their resulting research, that the systemic design approach can be advocated for, experimented and exemplified.

Box 6.3 Why were only principles (rather than a method) prescribed in this thesis?

Carrying on innovation initiatives requires many resources to be available. In the context of humanitarian aid, resources might be limited due to e.g. diverging and strict timelines, conditioned budget and existing competences. And methods take time to learn and apply. The author encourages the application of different design methods available, at choice, according to the specific context.

Examples of design and evaluation methods

- Design for usability (Babbar, Behara, & White, 2002; Maguire, 2001)
- Activity-centred design or "Taskonomy" (Norman, 2005)
- Product-service systems (Baines et al., 2007; Vasantha, Rajkumar, Lelah, & Brissaud, 2012)
- Design for sustainability (Crul, Diehl, & Lindqvist, 2009)
- Eco-cost/value ratio (Hendriks, Vogtländer, & Janssen, 2006)
- Systemic context variation (Kersten, Crul, Diehl, & van Engelen, 2014)
- Systems-oriented design (Sevaldson, 2010)

7 Methodological considerations

The main research question in this thesis was addressed with qualitative methods of data collection and analysis due to its explorative nature. Despite the existing debate on how to assess quality of research, based on different worldviews, there is a common agreement that criteria to assess research is necessary, and that there are ways to enhance the research towards that criteria (Patton, 1999). In contrast to a view that social reality can be captured, which is closer to the principles of quantitative research, some authors suggest that concepts and theories are representations of social reality (Bryman, 2001). Within this debate, there is a gradient of possibilities. Patton (1999) also states that it is increasingly important to argue for the appropriateness of methods to a specific research purpose and question. The qualitative researcher must use strategies, be prepared, and argue for the appropriateness and impact of own approaches when faced by the worldview debate.

Guba and Lincoln (1994) propose an alternative to the terms and methods of validity and reliability assessment with two main criteria in which most defining terms keep a parallel to quantitative research (Bryman, 2001):

— Trustworthiness, made up of credibility, transferability, dependability and confirmability;
— Authenticity, considered in the different forms of fairness, ontological, educative, catalytic and tactical.

In this thesis, the criteria proposed by Guba & Lincoln (1994) and Bryman (2001) are used to describe and assess the choices made throughout the research. Authenticity is described, in a general manner, as the societal value of the research.

7.1 Assessment of trustworthiness in qualitative research

In the following paragraphs, an introduction to each trustworthiness criterion is made, followed by a description of how it was addressed throughout this thesis.

Credibility refers to the congruency between what is "observed" and the developed theoretical concepts. It can be enhanced by means of using multiple ways of collecting and analyzing data, also called triangulation. Triangulation increases the evidence of a determined finding because each method, researcher, source of information or theory reveals different aspects of reality, increasing also a match between reality and theoretical concepts. Other strategy to enhance the credibility of the research, is to clarify different perspectives or inconsistencies, and search for data to support alternative explanations or classification of themes. The choice of research methods for this thesis was limited (as

well as the sampling of case studies described below, in Dependability), given the work characteristics and reservations of humanitarian aid organizations. Nonetheless, the variety of methods applied in each part of the thesis was aimed at deriving consistent, and sometimes richer findings. Observations and document analysis were complemented with interviews and the data analysis was carried out by two researchers. Improvements were suggested in publications 3 and 4, such as additional means of data recording (e.g. sound or video) that, could improve the credibility of data, but are limited by bureaucratic and ethical factors. Finally, the research was peer-reviewed in the process of publication in academic journals and relevant conferences.

Transferability, in parallel to external validity, refers to the extent to which results are applicable in other contexts or, in time in the same context. Results from qualitative research are usually highly context and case dependent, often based on small samples, which means they are bounded to be unique. Nonetheless, to overcome this, information should be provided at many levels of depth so it is available for others to judge. It is important to highlight that the goal of the case studies was not to generalize, but to accentuate the differences in each case. This research focused on the emergency surgical environment. The research is expected to be transferrable to similar settings within healthcare, such as Intensive Care Unit or Ambulatory care, or other industries that are technology-intensive. The application of the OPO tool in Indonesia and in Haiti differed. Transferability is affected by whether the research is carried out in an academic environment or not, by the extent to which professionals are aware of safety and by socio-cultural variables existing between and within countries. In addition, it is important to refer that the two case studies were carried out with a European design research perspective. As such, transferability is affected by an attitude towards the research subject and a tendency to prioritize "reality" aspects that relate to design practice and theory.

Dependability, in parallel to reliability, refers to the degree of replicability of a study when the same setup is used, by either a researcher within a team or external researchers. The detailed reporting of data collection and analysis can ensure another researcher is able to repeat the study. Nonetheless, this assessment is difficult since the specific contextual conditions of qualitative studies are very bounded in time and circumstance. In this thesis, and particularly the studies conducted in a surgical care setting are characterized by differing experience of healthcare practitioners, differing operating rooms layouts, unplanned black-outs, and differing patients. The case studies (i.e. Indonesia and Haiti) were selected for practical reasons and not by theoretical sampling. The access of an independent researcher to emergency medical settings is not possible to guarantee for reasons including safety, ethics and funding. The case studies were sampled by 1) established contact with authors of relevant journal publications and 2) their accessibility, interest and availability. Both case studies were realized in a real-life setting, in surgical environments and in disaster-prone

regions. Further, a measure to ensure dependability includes adopting a similar social role as original researcher when replicating a study. However, this can be hindered because the research also depends on who and how the researcher is introduced in the research environment (i.e. the operating room). In the studies presented in publications 1-6, all methods are described in detail, and the researcher distinguishes between contextual characteristics confined in time and space from general context characteristics.

Confirmability refers to the degree of objectivity. This can be enhanced by making the research as independent as possible from the personal experiences, relationships, mental/physical characteristics, and values of the researcher. According to Patton (1999), "qualitative analysis is a creative process, depending on the insights and conceptual capabilities of the analyst"(Patton, 1999, p. 1190). For this reason, the qualitative researcher should be methodical and detailed in reporting and describing possible sources of bias, in the same way he/she is, with the process data collection and analysis. Furthermore, it is important to describe the preparation and training of the researcher as part of the methodology, and the possible effects of the researcher's presence during research. In all the studies presented in publications 1-6, measures were undertaken to reduce the potential bias. Nonetheless, some context characteristics are important to highlight. First, in such an unexplored field of research, personal relationships actually contribute to have granted access. Second, due to the work characteristics of international humanitarian organizations, often interviews are conducted via Skype, which weakens the communication between the interviewer and interviewee. Third, although the researcher had the required training in observations in surgical care settings, she was not prepared for the researched settings in terms of e.g. differing concepts of safety.

7.2 Societal value of research

The authenticity criteria is rather controversial and refers to the impact of a research in a wider political context (Bryman, 2001). The importance of science in society was recently described in the Rome Declaration for Responsible Research and Innovation (Italian Presidency of the European Union, 2014; Stilgoe, 2014). The document presents a strategy to connect science and society in a framework of six dimensions, namely engagement of societal actors, genre equality, improvement of science education, ethics as means and not constrains, open access and a policy-making umbrella. The research in this thesis relates to this framework dimensions in regard to the participation of actors from the humanitarian and the private sectors, ethics as a meeting point to find shared values and acknowledgment of education and policy implications.

This research addresses an unexplored side of an increasingly relevant societal concern: the transfer of medical equipment in humanitarian emergencies. The discipline of design research, which is concerned with both theory and practice aspects of design, from products to systems, was used to understand the role of design in such an unexplored context. This research started with a focus on product design and usability. Therefore, it was important to understand, step-by-step the process of transferring medical equipment in humanitarian emergencies. In the end, the research proposed a systemic approach to product design in this context which means focusing on designing a support ecosystem rather than making incremental changes in the physical attributes of medical devices.

A qualitative approach was more appropriate for several reasons including the exploratory nature of the research. The result was a descriptive overview of the dimension of current problems that is mainly meant to raise awareness and guide further research. It focused on the subjective experiences of experts from international humanitarian organizations, the initial absence of a network of international humanitarian organizations and the barriers of data monitoring and collection in the respective settings. In this thesis, objectives of further improvement that go beyond the analysis of usability during a medical procedure were identified. These include tasks involving multiple users, reasoning behind coping strategies, hygiene processes and sharing of medical supplies, and compliance to ergonomic guidelines in limited space. In the future, quantitative methods should be used to complement the applied research proposed in this thesis in a systematic manner. The study of performance obstacles can be used as measurement criteria for the impact of an intervention. It can be improved by focusing on specific procedures and tasks (including inside and outside the OR), specifying the definition and quantifying observed events and then, repeating and comparing results. As such, design interventions become more objective and focused on effective improvement.

Finally, the proximity of the researcher to the field of design helps to translate the findings to practical advice for international humanitarian organizations. Therefore, the knowledge generated through the research in this thesis contributes to the humanitarian innovation agenda. As science increasingly turns to creatively address complex societal problems (e.g. social inequity, climate related displacement, war), there is the need to expand the narrow concept of a science bounded by strict disciplinary boundaries. Science can embrace new multidisciplinary models in excellence references, so that these multi-nature problems are viewed by different perspectives, addressed with various responses, roles and responsibilities.

8 Recommendations for future development and research

Based on the explorative research presented in this thesis, different research areas related to the healthcare context of humanitarian aid and beyond, are recommended. The proposed recommendations are illustrative of the diversity of opportunities for further study, and contribute to direct application of knowledge within this field. They include practical suggestions, some more tangible than others and therefore, address different audiences: medical device industry managers, product developers, international organizations, design researchers and healthcare practitioners. Medical emergency settings offer a very rich space for further research and innovation, across high to low-resource settings, and within the humanitarian context. Medical emergencies are generally characterized by their complex, diverse and unpredictable nature and scale. They require applying different expertise, intertwined processes and resources. A very important characteristic of medical emergencies, humanitarian or not, is the practice of doing much lifesaving with less resources. The work in this thesis encourages future research and development in the field of design of medical equipment and infrastructure, process innovation and access-based businesses. Theories from HFE, from micro- to macro ergonomics, offer a strong scientific foundation to build from when linking design and engineering to healthcare practices.

A design research laboratory for creative networks and pilot projects (sociotechnical experiments)

The type of work done in medical emergencies is not easily accessible to researchers, especially the one of humanitarian emergencies. A possible format for knowledge generation and management is the one of an applied (design) research laboratory[1] (using the principles proposed in this thesis). Such a laboratory can be, locally, a physical space to meet, work and display evidence of design approaches, and it can also be a distributed space for research and experimentation. Key for its impact is the (lasting) engagement of partners with relevant practice and geographic experience in disaster response (e.g. academic hospitals, international and local NGOs and GOs from Netherlands, Turkey, Italy, Indonesia and Philippines). That means that a large part of the research is organized in a distributed manner and the laboratory is the entity responsible to organize and leverage the research. The knowledge generated and managed by such a laboratory should contribute to the design practice and education, but also to the enhancement of the change mind-set

[1] Examples of similar initiatives include: Humanitarian and development Labs at MIT, Research Centres at Utrecht Hoogeschool, Access 2 Innovation in Aalborg University, Centre for Innovation from Mayo Clinic, Centre for Affordable Healthcare Technologies from University of Oxford, the Helen Hamlyn Centre for Design from Royal College of Art and Pontes medical in Utrecht Medical Centre

in medical practice. Such a cross-boundary collaboration (geographic and professional) could contribute to harmonize the awareness in human factors in hospitals across the different countries by sharing practices, allowing interchange and sharing of experiences.

From a (design) academic perspective it is important to further investigate the application of available theories and methodologies of HFE to systems design (Design Council, 2014). Academic institutions offer an adequate environment to further study specific processes in healthcare and humanitarian aid, through project-based education and thematic curriculums (e.g. infection control in medical emergencies and post-emergency care of orthopaedic patients). Future research and development should start with 1) further embodiment of the systems design approach to medical technology transfer (based on the proposal in this thesis), that enables guiding a systematic approach for the laboratory and 2) the development of qualitative impact metrics to evaluate the interventions of the laboratory.

There are several examples of medical equipment and infrastructure developed in academia for low-resource settings that are interesting examples of the intersection of science, engineering and the "field" (The Institution of Engineering and Technology, 2014; World Health Organization, 2010a). However, the dependency of medical equipment on production, certification, marketing and supply facilities, often stops these concepts from scaling up and reaching their full potential because business and industry perspectives are lacking. Further research should focus on understanding business and regulatory barriers associated with the development of specific medical equipment for low-resource settings. This research should lead to the development of tools that help designers making sense of "field" information at a macro level when designing context/user-friendly medical devices.

The findings from this thesis suggest that the following topics should be investigated:

— Community-based emergency response systems and prevention: a community-centred approach to improvement of public health (operations and access), establishment of priorities focused on transitional systems in post-emergency;
— Cultures: Development of knowledge regarding the design "universality" of specialized medical equipment and worldwide standardized practices. How professional and geographic cultural differences impact and are impacted by standardized equipment and practices (e.g. teamwork, interconnection of medical specializations). Additional research should look into the genre and general social cohesion aspects in aid. Potential paths are practice-based approaches such as Norman's "taskonomy" concept and Bijl-Brouwen's "design strategies for dynamic usability";
— Coping strategies of users (doctors, nurses, technicians): The resulting "artisan inventions" created to overcome systemic gaps (e.g. poor infrastructure, unaffordability) are adopted through time and often become consolidated in daily practice. There are

opportunities of generating relevant knowledge about users coping strategies, beyond their impact in safety, to empower humanitarian/medical experts to enhance their coping strategies to innovation.

From an industry perspective, an applied design research laboratory could also facilitate access to the field, sharing information and introducing a network of potential clients. The findings in publications 1 and 5 suggest that there is a rather difficult environment for small companies (Jarosławski & Saberwal, 2013). Large medical companies can benefit from local insights[2] and for that sharing information with smaller companies. Companies that opt to design specifically for this market, in form of subsidiary, start-up or independent company, should be aware of the barriers to innovation from frugal businesses, such as processes and regulatory support needed to implement, develop, sell and assure the continuity of supply.

In regard to donations of medical equipment, the WHO and the Tropical Health Education Trust have devised specific guidelines to improve the donation processes (appendix 1, p.83). Donations require, amongst others, a proper communication between donor and recipient, follow-up consultation of performance, facilitation of supply of consumables and (outdates) parts and disposal assurance. A study presented at the conference Appropriate Healthcare Technologies for Low-Resource Settings shows that even when a donation process is followed according to guidelines, donations can still become cumbersome for some organizations (Adjabu, Bradley, Gentles, & Mirzazadeh, 2014). In order for donations to be effective they should be streamlined and planned for, according to how they were designed. Further research should focus on a "donation-ability" index to allow the integration of donated medical equipment in transfer processes and in system design purposes. This is relevant for different kinds of organizations because, even organizations that do not accept donations, must sometimes work with donated infrastructure.

The findings from this thesis suggest that the following topics should be investigated:

— Test, improve and harmonize product-service system approaches in healthcare considering waste management and access-based business models;
— Characterize international humanitarian organizations as market unit, and businesses contribution for a decentralized aid;
— Encourage standardization for access to generic devices tools and parts (similarly to the generalization of micro USB has benefits from user and environmental point of view);
— Encourage WHO to revisit standards of medical equipment by providing additional guidelines for certification of devices for rough environments (standards CE to harmonize risk exposure level).

[2] For example: General Electric's handheld ECG machine Mac400 and Laerdal Medical's birth simulator MamaNatalie

From the organizations perspective, such a laboratory can be an opportunity to engage in innovation. As international humanitarian organizations begin to develop innovation practices (and networks) it is important to really define what is meant with innovation in terms of processes and goals. Because system-wide changes require the involvement of an increasing number of capabilities along time (e.g. economics, medical specializations, graphic design to cost analysis, production advice) that might not be at hand within an organization. For organizations, who lack the resources and time to actually develop products/services, innovation means to actively participate in devising requirements and applying products/services/ideas in a way that improves their practice. In the future, organizations that promote innovation initiatives should focus on developing and formalizing knowledge learning (and sharing) mechanisms that empower them to better collaborate in products development. At the same time, such innovation initiatives can facilitate that the research capabilities of local academia and hospitals are leveraged.

A key factor for organizations to benefit from such a laboratory is the presence of a mediator (established during the period of this research by the author) to bridge the different interests and languages (i.e. medical, humanitarian and technical). The engagement in such process requires continuous overview and in-depth knowledge about how industry, academia and the "field" work. Each organization should acknowledge that innovation is dependent on a mind-set of willingness to integrate change in daily practices. Innovation can only be achieved, and sustained through time, with incremental steps that assure that people realize and value what is being done, and by leveraging the handful of motivated proactive experts who attempt to improve the system (Cairo, 2011).

Ethics

Ethics are an important, but difficult to manage, aspect of research and design, especially in humanitarian settings characterized by many converging emotions and values inherent to individuals and groups. During this research, relevant issues were brought up that must continue to be openly discussed by the research and design community in order to contribute to the creation of adequate codes of conduct. First, ethics related to the introduction of (new) standards of practice, enacted by who delivers aid, and usually regulated by local ethical committees. Second, ethics related to donations. Third, ethics related to collaborations that conflict with humanitarian principles, such as the involvement of companies or political groups. Fourth, ethics related to the priorities (e.g. saving lives or the environment) and the boundaries of aid, in terms of type and extend of care delivery. And finally, particularly regarding healthcare, ethics that might not be in place in low-resource settings, but should nevertheless be followed, such as the consent of patients or their families to perform research.

Innovative finance of aid initiatives

Governments, the general public and donor institutions also play an important role in humanitarian innovation, although they have generally less direct incentives, no allocated budget and more aversion for risk (Mulgan, 2014). There are reasons for both public and donor institutions to become permeable to innovation and embrace the need for change. In particular, the variation in the characteristics of low and middle-income countries, brings new challenges to development aid and, in addition, emerging economies play a growing role in the donor landscape (Lundsgaarde, 2012). The findings in this thesis suggest that further research should be made about innovative financing mechanisms to inform the donor community. A more flexible way of financing, focused on quantitative, but also qualitative results, would facilitate the creation of distributed networks and the integration of different stakeholders in different phases of a project.

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Appendix 1. Relevant guidance and standards

This appendix includes references to guidance documents and relevant institutions for the design of medical equipment and the understanding of humanitarian aid.

Regulation for medical equipment design

— Joint Commission (formerly the Joint Commission on Accreditation of Healthcare Organizations (JCAHO) evaluates health care organizations and supports them to excel in providing safe and effective care of the highest quality and value.
— The International Medical Device Regulators Forum (IMDRF), successor of the Global Harmonization Task Force (GHTF) is a voluntary forum for regulators around the world to discuss future directions in medical device regulatory harmonization. The IMDRF was born in October 2011, when representatives from the medical device regulatory authorities of Australia, Brazil, Canada, China, European Union, Japan and the United States, as well as the World Health Organization (WHO).
— ISO/IEC 62366 is a process-based standard that aims to help manufacturers of medical devices "design in" usability and "design out" usage errors. The standard also applies to documentation that may accompany a device, and to the training of intended users. ISO International Standards ensure that products and services are safe, reliable and of good quality. Our standards are developed by the people that need them, through a consensus process. Experts from all over the world develop the standards that are required by their sector. ISO has a membership of 163*national standards bodies from countries large and small, industrialized, developing and in transition, in all regions of the world.
— New references of harmonized standards for Medical Devices of the European Union http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ%3AC%3A2015%3A014%3ATOC
— The Medical Devices Directive is concerned with all medical devices, from sterile gloves to electronic monitoring equipment and complex MRI-scanners. Directive 93/42/EEC covers the placing on the market and putting into service of Medical Devices within the framework of CE marking.
http://cetest.nl/mdd.htm
— The website of the World Health Organization offers reliable information about medical devices innovation and regulation on manufacture, use and management.
http://www.who.int/topics/medical_devices/en/

Relevant documents consulted for the research in this thesis include: Generic Essential Emergency Equipment list; Surgical Safety Checklist; Guideline for Healthcare Equipment Donations; Field Manual for Capacity Assessment of Health Facilities in Responding to Emergencies

Regulation for humanitarian aid

— The steering committee for humanitarian response (SCHR): draws up from the Red Cross and NGO Code of Conduct for Disaster Response, together with InterAction, set the Sphere Project up in 1997 to develop minimum standards for humanitarian assistance in four major sectors, water and sanitation, food, shelter, and health, as well as framing a humanitarian charter for disaster response.

— The Sphere Project is a voluntary initiative that brings a wide range of humanitarian agencies together around a common aim: to improve the quality of humanitarian assistance and the accountability of humanitarian actors to their constituents, donors and affected populations. The Sphere Handbook, Humanitarian Charter and Minimum Standards in Humanitarian Response, is one of the most widely known and internationally recognized sets of common principles and universal minimum standards in life-saving areas of humanitarian response.
http://www.spherehandbook.org/en/how-to-use-this-chapter-4/

— In response to the perceived confusion, lack of awareness and inconsistent application of standards, three of the leading standards initiatives (Humanitarian Accountability Partnership (HAP), People In Aid and the Sphere Project) have launched a process to seek greater coherence for users of standards, in order to ultimately improve humanitarian action to people affected by disasters. This pioneering collaborative effort is called the Joint Standards Initiative (JSI) and has the potential to significantly improve quality and accountability across the sector.
http://www.jointstandards.org/about

— The Code of Conduct for The International Red Cross and Red Crescent Movement and NGOs in Disaster Relief, was developed and agreed upon by eight of the world's largest disaster response agencies in 1994.
— http://www.ifrc.org/en/publications-and-reports/code-of-conduct/
— Furthermore International Committee of the Red Cross (ICRC) publishes basic reference manuals (War Surgery Guidelines) for surgery in humanitarian/military aid. Giannou (2009) includes a short list of ICRC's criteria for introducing new technologies.
— The Humanitarian Action Summit 2011 (Harvard Humanitarian Initiative) resulted in the publication of a set of Best Practice Guidelines based on a literature review and a discussion held by the surgical working group during the summit. The document includes practice standards for humanitarian surgery, anesthesia and rehabilitation delivery that can be effectively implemented on the ground by any international humanitarian organization (Chackungal et al., 2012).
— The "Classification and Minimum Standards for Foreign Medical Teams in Sudden Onset Disasters" is a document published by the WHO and developed by the Foreign Medical Team Working Group under the Global Health Cluster. The document is an important reference of the professionalization of the humanitarian sector and defines disease management activities, human resources and skills, as well as medical equipment required by a foreign medical team to provide a particular service in an affected country.
http://www.who.int/hac/global_health_cluster/fmt_guidelines_september2013.pdf
— The tropical health education trust (THET) has published a handbook for guidance about donations of medical equipment to low-resource settings.

Appendix 2. "Relief, transition, development" panel, Rethink Relief 2011

Okello David, Program Manager, Caritas Gulu Archdiocese (Partial transcript)

"Thank you very much. I will share with you our experience as Caritas during operation in relief and then the transition from relief to development. As I said before, I come from Uganda with my colleague Jennifer and we both work for Caritas Archdiocese. Uganda is a very fast growing country at the moment. Population wise is about 33 million people. And 1/2 of that is below 18 years of age. And then there are very different ethnic groups within Uganda. We have about 53 different groups, they speak different languages. And then particularly where we work in north Uganda we have a tread called the Acholi speaking tribe and they constitute about 1,2 million population for the country. Caritas has been working in Uganda for the last 30 years and we have been particularly involved in the relief given the two decades of conflict and this conflict has been between the government of Uganda and the Lords Resistance Army, a rebel group that is led by Joseph Kony. The rebel leader and the five top commanders are currently in the list of the International Criminal Court (ICC), I think they are wanted here in Den Haag. And then hopefully they will be arrested and brought to the ICC.

Camp settings

So for the last two decades there has been a movement from the population from the village to internal displaced persons (IDP) camp so actually the whole population of the north moved away from their homes and they were in the camp setting and at the time of the war we had about 120 IDPs camp settlement and the biggest was in a radius of 1sq km with a population of about 65.000 people. So you can imagine such a kind settlement with so many heads compact together and then people become so prone to diseases outbreak and other health problems. But eventually as the conflict was getting down there was opportunity for the people to move away from the camps to their own villages. And that's when different agencies had a lot of challenges, in the transition period. Because during the emergency there were so many agencies that got involved in the conflict situation both the national and the international. We had the World Food and also MSF, also there, Save the Children and so many others. In the camp setting there were a lot of agencies intervening giving out relief in terms of water and sanitation, food item, non-food item. When the government declared the end of conflict in the north many of this agencies withdrew because most are emergency based agencies. But I think that was very premature because the situation hadn't changed so much. But also given the money they took the different agencies couldn't operate in the area any more.

Dependency syndrome

So the challenge now we have from the period of transition from relief emergency to development… I think during the process of emergencies the different agencies created a lot of dependency syndrome in the community. Because it was always give, give, give and give. So when they withdrew the community went back home and still they have that hangover of give and give and give. So, even now as we want to make development work they still want us to give give give. Other agencies commit themselves to be relevant they will give for communities to come for meetings or training otherwise people don't come. That also led to a money ties intervention. You see the big agencies with a lot of money because they want to maintain their presence so they will keep on paying community members when they come for meetings whereas other agencies that cannot afford to pay automatically people don't come for your meeting. That's quite a big challenge.

Agencies withdraw

And then I think also agencies withdrew so fast. Because that transfer period from relief to development is a process. So when they withdrew very fast there has been now a gap created. So the community still expects things to be given to them but they are not anymore. And then another big challenge we experience is coordination. If during the emergencies there were so many agencies and you don't know who is doing what and how. So they use different approaches and then each of them is creating a different structure in the community. Then, as you move back to development processes the structure in the villages, in the community doesn't exist. So you have to again now start putting up a new structure to deliver different services. From our experience also I think most of these agencies don't have an exit strategy. By the time you realize they are gone, they are gone. So that leaves the community still expecting still waiting for more to be given to them and then still as people start moving back home from the camp there was a lot of debate on whether the services should first be put at the camp site or the population should first move and then they follow with water roads and health. So as the different agencies were still debating what should come first the community started moving by themselves to their sites and they start putting up a whole health center, road, schools in those return sites. Which I think was quite a big challenge.

Infrastructures

And also with the life in the camp there were a lot of structures that were put up in the camp you find motorized water sources, ventilated improved pit latrines, you find schools and centers. Now when it came to the phase of transition, moving away from the camp to the villages where things were totally destroyed there was a big challenge. So people found it difficult to leave this facilities in the camp and go to the camp where almost nothing

exists. As a result other opted to stay around where they get these facilities while those who move back to their villages had to move quite a long distance again to fetch water, clean water to access medical services. And these agencies that put up this structures in the camp where no more there, there was no way they could move or transfer again these items to the return sites. As I said before during the camp setting the different agencies created their own structures and they should have used the existing local government structures to deliver their services so as they now move back home, the leadership created that was created by the different agencies still expect to maintain that position of leadership inside of the community. But then the government said no, no more. We should now begin to use the government structures to deliver the services. So that also causes a bit of friction between the agencies that are working there and the government.

Coordination

Then also I think the role of coordination is a big challenge in this time. In our case the coordination was now left to the government or also you find when it comes to coordination there should be facilitation of coordination meetings and other things. But the government didn't have the resources to do that. You can't utterly see the impact of the different agencies that are in the area and then from our experience also in the return process. There came up a very big issue of land conflict because the population was moved away from their homes to the camp for two decades and then, as we started going back home, some of the land boundaries were not identified and also the government showed some interest in getting a big share of land for investors in the north and that cause a high tension amongst the population. So as we talk now although the conflict in the north now is getting settled, I think the land issue is still coming very strongly. Is getting even more complicated with the discovery of oil in the north, the government has discovered a lot of oil and that is causing a lot of fear that the government wants to take a very big part of land in the north. But either youth who in these 2 decades of conflict missed a formal education also realize there is value in land and want to grab as much as possible to sell as a source of their livelihoods.

Culture

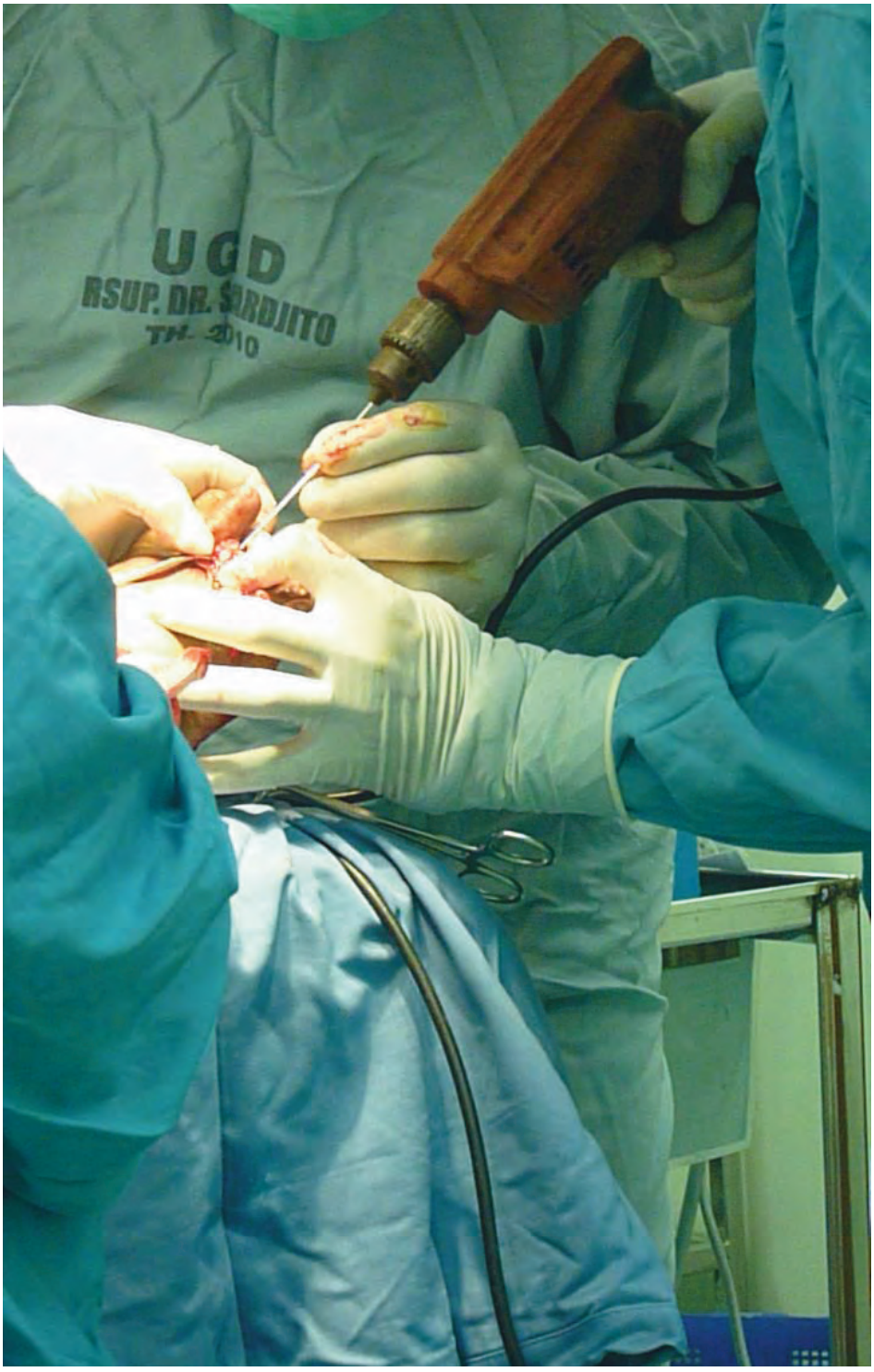
The return and settlement process was also a very big challenge for the populations. When the rebels forced the population to move away from their homes to the camp, there were a lot of killings of the civilians in the villages and they moved. Now as people start going back to their homes they would come, cross the remains of the human bodies that were killed. Traditionally we believe that if a dead person is not given a decent burial their spirit lives to haunt the living persons and this causes a lot of physiological problems. So to open up ways for the community to move and settle in their homes we consulted with the elders and they said in their culture there is a way which you can perform some traditional rituals, ceremonies to peacefully lay the souls of these diseased persons to rest. We facilitated that

where the elders would perform the traditional ritual and that opened up ways for the community to resettle.

I think briefly this is what I wanted to share with you, but also i generally i think we need to rethink how we deliver relief during emergencies. So that we avoid creating dependencies and also we try to put at the back of it the culture of the different communities. Like in our case, the women were taken as the lead persons in the household when it came to deliver food items. Now that has caused a lot of problems because in the African setting the man is the head of the family, the head of the household and when he speaks it's final. But now when the agencies came they wanted to work with women, of course because they were taken care of children and they had a lot of responsibilities to do. But now that made a very big divide between the women and the husbands. So when the women were taken up to be like the people receiving the food and non-food items, the men folded up their hands. And that resulted into drinking. Cause their sense of being the head of the family was kind of taken up, that role was taken up by the women. So it resulted in drinking and again that resulted in domestic violence. So we should also look at the culture of particular community when we are giving relief items.

Exit strategy

And also important to notice, I think for agencies working in emergencies only it's also good to kind of work out and exit strategy. So that by the time people start the transition period, the beneficiaries or the community are made aware of how you can close up your project and shift to another area. So briefly this is what I have and thank you."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THE TRANSFER OF MEDICAL EQUIPMENT IN HUMANITARIAN EMERGENCIES

9 Systemic barriers and enablers in humanitarian technology transfer [publication 1]

Santos, ALR., Wauben, L.S.G.L.,Goossens R., Brezet, H. (submitted journal paper)

Abstract

Purpose: This study has two purposes. First, to collect information about barriers and enablers experienced by international experts when transferring medical equipment to countries affected by humanitarian emergencies. Second, to discuss the suitability of the principles of "openness", "interconnections" and "non-linearity" of systems to understand the nature of the barriers and enablers as described by the international experts.

Design/methodology/approach: In this study, six semi-structured interviews were conducted with experts from humanitarian organizations. The interviews were based on a simplified model of the transfer of medical equipment adapted from supply chain literature. The model ensured that all the process steps undertaken by humanitarian organizations were considered. Afterwards, the interviews were transcribed and structurally analysed to derive barriers and enablers. Finally, the results were described in light of three theoretical principles of systems thinking.

Findings: 14 types of barriers and 12 types of enablers were uncovered that illustrate the complexity of transferring medical equipment in humanitarian emergencies. The paper concludes with a proposal for future research to investigate if, and how, an approach guided by systems thinking could help to create a designated space for the formulation of original, synergetic solutions that address the identified barriers.

Originality/value: This study is the first to explore the specific logistic challenges implicit in the transfer of medical equipment in humanitarian emergencies with a lifecycle perspective. Furthermore, the concept of systems thinking is rather novel in the field of transfer of medical technology.

9.1 Introduction

The provision of healthcare during humanitarian emergencies is complex. Humanitarian emergencies are events that disrupt the livelihood and ongoing services of a population and include conflicts or epidemic outbreaks, climate or geophysical related disasters (Leaning & Guha-Sapir, 2013). The international response to humanitarian emergencies

involves the (often sudden) mobilization of several stakeholders including donors, humanitarian organizations and service providers (figure 9.1). This mobilization involves multiple information, financial, human and material resources. Within all the actors, humanitarian organizations (such as Médecins Sans Frontières, Save the Children) are service providers with a robust logistic and cooperative capacity to enable the continuous flow of activities and resources for the provision of healthcare. This includes, assessing, procuring, categorizing and storing a variety of resources, such as medical equipment. There are formal mechanisms (i.e. principles, policies and standards) build from field and logistic experience to guide the activities of humanitarian organizations (World Health Organization, 2005; Giannou & Baldan, 2009; Norton et al., 2013). Nonetheless, there are differences in the way these organizations work in terms of their involvement with local affected populations and in terms of the quantity of items they deploy. Also, in some cases individuals travel on their own initiative and responsibility to provide healthcare to the affected population (Kri et al., 2010; Redmond et al., 2011).

Healthcare needs differ according to the type of emergency, its intensity and location (Gardemann, 2002). Natural disasters tend to result in more complex wounds (requiring a variety of specialists) and poorer populations tend to be vulnerable to epidemic outbreaks. So depending on whether it is an earthquake in Haiti, a drought in Sudan or conflict in

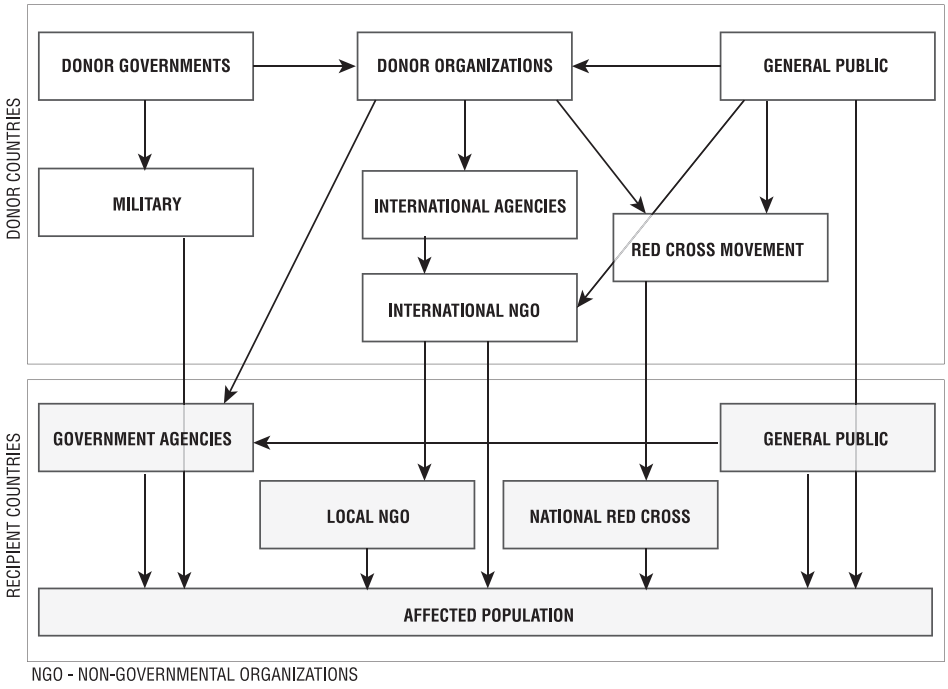

Figure 9.1 Mobilization of resources amongst stakeholders in humanitarian emergencies (adapted from Development Assistance Committee, 1999, p. 8)

Syria, humanitarian organizations face different barriers and need different logistic systems to be in place in order to provide lifesaving services to affected communities (Kovács & Spens, 2009). There is the need to deploy a whole logistic system including e.g. medical equipment, vehicles, energy generators, information and medical and logistic expertise, to work in multicultural teams and train local staff (Chu et al., 2011). Because of the need to set up this "replacement" healthcare system, humanitarian organizations offer a higher (and temporary) healthcare quality than the one previously existing in the disaster-affected area. After the immediate disaster phase, the follow-up of the humanitarian healthcare system is dependent on varying priorities and budget. The transition process to recovery is known to be a "gap" that can take weeks to several months (United Nations, 2006).

Medical device ecosystem

Medical devices, and complementary equipment, are an essential part of the necessary logistic system to provide healthcare. Their use is highly regulated because of its involvement with the management of human lives (European Commission, 2010b; Global Harmonization Task Force, 2005). Medical devices and complementary accessories are defined and regulated by different international relevant bodies (2010a Annex I - Directive 93/42/EEC; U.S. Food and Drugs Administration, 2014). According to the International Medical Device Regulators Forum, a "medical device" is defined as "any instrument, apparatus, implement, machine, appliance, implant, reagent for in vitro use, software, material or other similar or related article, […] used, alone or in combination […] for one or more of the specific medical purpose(s) […]". (Global Harmonization Task Force, 2012, p.6). In addition, medical devices are also classified according to their intended purpose and interaction with the human body (European Commission, 2010b).

These regulations allow manufacturers to collectively provide the same conditions of manufacturing and sales, continued use and disposal in order to ensure that the medical equipment is safe to use. Safety is an important aspect of a healthcare system and of medical equipment. The more complex medical procedures are, the more complex medical equipment is and the more chances there are for incidents to occur.

The performance of all medical equipment is dependent on the presence of an "ecosystem" (figure 9.2). It includes e.g. dependency/reliance on accessories and complementary equipment, dedicated infrastructure requirements (e.g. lead shielding, gas scavenging and heat exhaust), compatible energy sources and tools for handling procedures throughout lifespan (e.g. cleaning, disposal). Besides the technological and logistical components of this "ecosystem" there is the need for trained, knowledgeable experts to both use and maintain medical equipment (Cheng, 2007).

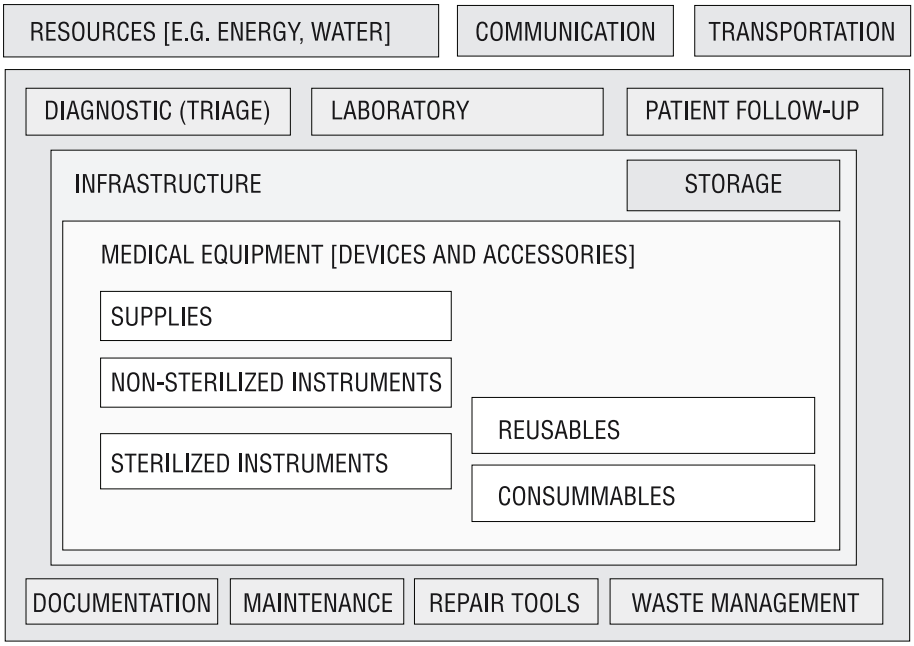

Figure 9.2 Medical equipment "ecosystem"

Technology transfer in humanitarian emergencies

The term "technology transfer" can be defined as the process of movement of physical assets, know-how, and/or technical knowledge from one entity to another (Souder et al., 1990; Bozeman, 2000). For technology transfer to be successful the receiving entity, the transferee, can effectively utilize the technology transferred and eventually assimilate it (Ramanathan, 2009).

In humanitarian emergencies, the transfer of medical equipment to a disaster-affected area has consequences for the servicing contracts and safety standards of healthcare provision, on both short- and long-term (World Health Organization, 2008) (Dzwonczyk & Riha 2012; Adjabu et al., 2014). Medical devices are supplied from a variety of sources (including direct purchase at manufacturers and suppliers and donation from different organizations) (Organization of Health Services Delivery, 2000) and humanitarian organizations are responsible to ensure their functioning through continuous support. The logistics involved in this process extent beyond immediate response logistics, and include choosing equipment and expertize according to logistic limitations, organizing, servicing and assuring the continuity of healthcare provision.

Although there is evidence of countless complex barriers that represent threats to the performance of the humanitarian aid system, the experience of humanitarian aid

organizations when transferring medical equipment in humanitarian emergencies, particularly to countries with low-resource settings, is unsystematically described (World Health Organization 2010; Tatham & Houghton, 2011).

9.2 Systems thinking

There is a growing interest from the international academic community and from humanitarian organizations on the challenges and accountability of humanitarian aid (Kovács & Spens, 2009). The variety of disciplines and research themes reflect the broad nature of the humanitarian field and includes amongst others logistics (Mays et al., 2012; Kovács & Spens, 2009) and supply chain management (Whybark et al., 2010; Oloruntoba & Gray, 2009; Richey, 2009). One of the current growing perspectives is the perspective of systems thinking. Systems thinking is overarching of theories that share its general principles, such as cybernetics (Ashby, 1957), complexity theory (Cilliers, 1998) and socio-technical systems (Trist, 1981), and has been used by fields as diverse as biology, engineering and organizational management (Peters, 2014).

In the field of organizational management, systems thinking aims to use systems theory to address complex problems typically found in "real world" settings, such as the ones found in the humanitarian aid sector (Jackson, 2007; Ackoff, 1974).

A system is defined by (Meadows, 2008) as a structure composed of a set of elements interconnected with the purpose of accomplishing a determined (system) function. System thinking, as an analysis tool, promotes the comprehensive understanding of a system as a whole, rather than through individual elements composing the system. The use of systems thinking implies a shift in mentality in humanitarian organizations, from a goal-centred orientation to a continuous adaption orientation, in which processes and activity outcomes (e.g. achievements, barriers) are seen as emerging and uncertain (Senge, 1990b; Stacey, 1995; Adam & Savigny, 2012).

It is important to define the meaning of complexity, as opposed to complicatedness, of the transfer of medical devices in humanitarian emergencies. Complexity is a defining property of a system. Whereas a complicated system (e.g. medical device, protocol of infection control) is possible to build and oversee, even when requiring very specialized knowledge, a complex system is not. Similarly to an example of a jet airliner from Dekker et al. (2011), when a medical device is introduced in a transfer process involving differing cultures, priorities and changing needs, the conditions for it to function become more difficult to define. The following three basic principles of systems thinking contribute to the understanding of the complexity of medical equipment and technology transfer within humanitarian emergencies:

Openness

Complex systems are open systems which co-evolve with their external environment, or external context (Katz & Kahn, 1967; Trist & Labour, 1981; Bertalanffy, 1950; Jeffrey & Salancik, 2003). The study of such systems describes organizations as activity systems that are influenced and influence their external environment. Events happening externally from the organization affect the ongoing activities within the organization.

Humanitarian aid and disaster relief is influenced by several external factors, such as the preparedness of local population, differences in disaster nature and magnitude, and long-term efforts to support local recovery (e.g. donor competition) (Kovács & Spens, 2009; Fawcett & Fawcett, 2013). These factors affect the effectiveness of humanitarian aid approaches rendering them successful (or not). Successful examples that point to the need of humanitarian organizations to be aware of these factors include adjusting humanitarian programs to local practices (i.e. cultural, technical) and allowing for planning flexibility (Ramalingam, 2013; Savigny et al., 2012).

Interconnectedness

The analysis of a determined organizational barrier in a complex system cannot be reduced to the analysis of its system elements (e.g. people, tasks, technology, organization) as individual units, because of the relevance of interrelationships and interdependencies that, together, contribute to a system behaviour and function realisation (Ackoff, 1974; Meadows, 2008; Flood & Jackson, 1991; Jackson, 2007). Furthermore, complex systems have different dimensions that characterize the function of a system, beyond and across its structuring elements (e.g. "safety" dimension must relate to all elements or functions of a system). This interdependence perspective challenges the traditional cause-effect reasoning and proposes instead, a reasoning of range of causes-range of effects. The result of such interdependencies is a complex system behaviour in which there is not a single matching cause or solution for a determined barrier. Instead, there are multiple. This means that a determined barrier can result from 1) different combinations of actions and 2) the degree of dependency amongst system elements (Waterson, 2009). Therefore, including different perspectives of a barrier is important to have a holistic perspective of the range of existing causes and solutions.

Many of the logistic problems dealt with by humanitarian aid organizations have a complex nature (Moshtari & Gonçalves ,2011; Tatham & Houghton, 2011). This nature is characterized by numerous (and often uncertain) individuals, institutions and countries and a variety of socio-economic dimensions. All of these stakeholders, their activities and decisions depend directly or indirectly on each other to deliver aid and address humanitarian problems. For example, the multiplicity of factors leading to HIV incidence in refugee camps might involve different dimensions, such as deprived access to immunization, family planning, rape,

illiteracy and social exclusion. A solution focused on a single dimension may never address the problem completely. Furthermore, the dependence degree of these dimensions and institutions can strengthen the polarity of solutions. For example, most aid service providers see donors, rather than beneficiaries, as their clients (Nielsen & Santos, 2013). This results in a tighter connection of aid services to policy goals than to goals of beneficiaries.

Non-linearity

Complex systems have a particularly dynamic/emergent and non-linear behaviour owing to the interconnectedness principle mentioned above. This means that the interconnected system elements and dimensions that make up an organization's behaviour, affect each other by means of feedback interactions which can either maintain, reinforce or weaken a certain behaviour. The fact that they may affect each other in different ways and different intensities results in a non-linear chain of influence between elements and dimensions. This means that different combinations of feedback interactions will emerge and, on the long-term, trigger different results (Senge, 1990a; Meadows, 1999).

In humanitarian aid, these feedback interactions lead to the transformation of small decisions of one organization into large consequences on the long-term, at the humanitarian system level. Disasters (and aid dependency) are caused by this kind of feedback and interrelationships (Ramalingam et al., 2008). The different perspectives of stakeholders are representative of trends that exert feedback on determined decisions. For example, where one sees cheaper equipment for more people, others see less safe healthcare patterns. Once again, a solution focused on a single dimension may not address a problem completely and may also lead or build-up to new/underlying problems in other dimensions and to other stakeholders. Addressing problems in humanitarian aid with a systems perspective means acting on all of their dimensions, with both short-term goals, and long-term guiding visions, as opposed to long-term assurances that are implicitly not possible to design due to the unpredictability of feedback interrelationships.

8.3 Focus and aim

This study focuses on the transfer of complex medical equipment within humanitarian emergencies, particularly those in countries with low-resource settings. The aim of this study is twofold. First, the study collects information about barriers and enablers experienced by international experts when transferring medical equipment to countries affected by humanitarian emergencies. Secondly, these findings are used to discuss the suitability of the principles of "openness", "interconnectedness" and "non-linearity" from systems thinking to understand the systemic nature of the barriers and enablers

as described by the international experts. This study contributes to uncover knowledge about the systemic implications of humanitarian logistics and is valuable to the redesign of organizational practices.

9.4 Methods

Semi-structured interviews with experts from international aid organizations with experience in coordinating or handling the transfer of medical equipment were conducted. The interviews were based on a simplified model of the transfer of medical equipment within humanitarian emergencies adapted from supply chain literature (Baldini et al., 2012). The use of this simplified model was aimed at assuring consideration for all the inter-departmental process steps undertaken by international aid organizations when transferring medical equipment in humanitarian emergencies. The transfer process composed of five phases occurring in different contexts:

Context x represents the place of origin of international aid organizations and includes the following phases:

— Supply, includes the medical equipment manufacturing and sales;
— Procurement and stock, includes the arrangement of medical equipment in kits and the purchasing process from non-governmental organizations (NGOs).

Context y represents the place of destination of international aid organizations and includes the following phases:

— Deployment and set up (context y), includes the transport and installation of medical equipment in order to be used by humanitarian experts;
— Use and servicing (context y), includes all activities performed by humanitarian experts.

Context y' represents the long-term perspective of context y, after international aid organizations have left.

— Handover (context y'), includes the disposal or further use of medical equipment in the settings of the affected country.

Despite the fact that the previously mentioned studies focus on specific disasters or locations, this study explores the logistic complexity that organizations face while working with a variety of disasters and locations. Interviewees were asked to recall and describe an experience when transferring medical equipment in a humanitarian emergency. During their description they were systematically asked to specify the activities performed per

phases of the simplified model and if a problem was mentioned, they were asked to elaborate how the problem was addressed. Afterwards a set of general questions was made related to the adequacy characteristics of medical equipment and the implications of working in different contexts and with different kinds of humanitarian aid projects.

Data analysis

The interviews were transcribed and iteratively analysed with a structural coding approach (Saldaña, 2013; Guest et al., 2011). This coding method is appropriate for interview transcripts where phrases from content represent a topic related to the research question used to frame the interview. The transcript codes were categorized and conceptualized based on the exploration of experienced barriers (i.e. physical, psychological or relational, safety or time obstacles to the course of activities) and enablers (i.e. personal or organizational mechanisms to address perceived barriers during the course of activities) throughout the process of transferring medical equipment in humanitarian emergencies. Later on the frequencies were derived on the basis of the number of individual participants who mentioned a particular topic.

9.5 Findings

The findings of this study contribute to the understanding of the work of humanitarian logistics by uncovering a variety of barriers and enablers from the perspective of humanitarian experts. In total six interviews were conducted with experts from two international organizations. The experts included two biomedical referents [I1, I3], one referent for anaesthesia [I2], one procurement officer [I4], one anaesthesiologist and consultant [I5] and one biomedical consultant [I6]. From the conducted interviews 14 types of barriers and 12 types of enablers were identified. These are illustrated in figure 9.3. In total 164 barrier quotes and 70 enabler quotes were categorized. 10 types of barriers and 7 types of enablers were commonly mentioned by three or more interviewees.

Barriers

There were three types of barriers commonly mentioned by all interviewees: “difficult equipment implementation” (n=27), “uncertainty regarding differing local settings” (n=24) and “absence or difficult compliance with standards, protocols and guidelines” (n=10). In addition to these three, “lack of continuous or appropriate supply and servicing” (n=29) has been the most frequently mentioned type of barrier.

Figure 9.3 Barriers and enablers within humanitarian emergencies according to the transfer process

These three barriers deserve to be further elaborated as they represent, due to the consensus and frequency they are mentioned with, the most evident barriers of transferring complex medical equipment in humanitarian emergencies. The complete list of barrier and enabler types, examples and the respective quantity of references can be found in appendix P1, p.114.

First, "difficult equipment implementation" is related to the difficulties of transporting, setting up and using medical equipment as a complete "ecosystem". Difficulties and delays are caused by misaligned timings of arrival of complementary equipment and experts, by the responsibility to establish a comprehensive system in place and on time, and by the continuous manifestation of unplanned needs. The interviewees specifically mentioned the dependency on complementary products (e.g. cables, software, spare parts and cleaning filters) and running processes (e.g. maintenance or hand hygiene) and the fact that medical equipment itself is not sufficient to carry out healthcare activities. Furthermore, absence of transport equipment and additional products to deal with substandard local resources and environment, such as water softeners and dehumidifiers, were also mentioned. This dependency leads to side problems that cannot be addressed. The expression of needs from international doctors is based on what they have seen in western hospitals. But often, the complexity of technologies in western hospitals needs to be balanced with the possible technique in the field. Also, technologies that offer functions to which there is no possible use, induce false needs.

Second, "uncertainty regarding differing local settings" is related to a diversity of variables across the world that affect procurement and healthcare decisions. Socio-economic and cultural variables were mentioned in relation to attitude towards learning and literacy levels. Infrastructure variables were also mentioned and included physical configuration and energy supply power of different hospital types, quality and number of available equipment and the respective perceived value by local medical staff. Interviewees also mentioned the relevance of climate seasons and the geographic location of equipment suppliers for planning and medical equipment choices. Differing customs bureaucracy and political instability were appointed reasons to delays and unsafe working conditions, respectively.

Third, the barrier "lack of continuous or appropriate supply and servicing" includes allusion to the uncertainty about production and supply continuity due to difficulties that companies face in the humanitarian market. Besides that, interviewees provided several examples of the lack of commitment or clarity of suppliers and manufacturers regarding the provision of services, such as maintenance or repair. In practice, agreements might not actually work given that available technicians are not adequately prepared. The reliance on local resources also extends to supply of substandard oxygen or medicines. This barrier also relates to the lack of experience and capacity from innovative, but small manufacturers to supply adequately and timely. Although most of these issues occur during procurement,

they extend to the handover phase, because humanitarian organizations leave. Here, the supply chain, logistic planning and relationship with original manufacturers is interrupted or even lost, leading to an unsustainable transfer of medical equipment.

Finally, "absence or difficult compliance with standards, protocols and guidelines" (n=9) was consensually mentioned as a logistic challenge. Standardization of medical equipment or procurement processes represent barriers due to a diversity of reasons. These reasons include the absence or the inadequacy of medical equipment standards, often leading to unsafe functioning or a negative perception from local doctors of the equipment used by humanitarian organizations. Alternatively, if standards do exist there is often a problem of compliance. They are either not applicable in emergency settings, due to either time or financial constraints. Or they are not followed due to limitations caused by the existing local infrastructure, because there is medical equipment already available or because of a preferred proximity of maintenance or supply services.

Enablers

The type of enablers that were most frequently mentioned were "adequate equipment requirements and choice" (n=16), "Use of standard equipment and kits" (n=12) and "effective agreements with suppliers or manufacturers" (n=9). "Adequate equipment requirements and choice" includes several "adequacy" characteristics, such as simplicity of equipment and language use, robustness, trustful calibration, versatility of energy sources and supply readiness. Adequacy also includes, according to the interviewed experts, being appropriate to the care provided. Organizations with ample capacity and experience can deduce the necessary equipment from the type of medical procedures being done in the different types of humanitarian emergency.

The "use of standard equipment and kits" is a way how humanitarian organizations deal with the uncertainty of procurement and logistics. First, this is a way to control quality and ensure the organization is familiar with the equipment and the suppliers. Standardized equipment ensures transparent criteria of choice and a uniform inventory of spare parts. Second, the elaboration of kits with the basic complementary equipment guarantees, at least in part and for the initial phase of an emergency, the completion and portability of the medical equipment "ecosystem" and also its readiness for international transport.

Finally, the enabler "effective agreements with suppliers or manufacturers" includes three purposes of engaging effectively with suppliers and manufacturers. There are agreements for servicing and follow-up during a period of time, in which suppliers often partner up with suppliers located closer to the affected country to perform maintenance or training and they take in equipment to repair. Deployment agreements consist of additional

tasks suppliers carry out to prepare medical equipment for a secure transport. The third purpose agreements include a long-term perspective in which the manufacturer and the organization are engaged in improving the medical equipment and the manufacturer uses that learning experience to successfully enter a future market.

9.6 Systemic nature of barriers and enablers

The barriers found in this study illustrate the logistic complexity of healthcare provision in humanitarian emergencies. There are numerous stakeholders and processes interrelated throughout the whole transfer process, which possibly contribute to hinder the transfer of medical equipment and ultimately the provision of healthcare. The following subchapters describe the barriers and enablers described by experts according to the three principles described above of openness, interconnectedness and non-linearity of systems thinking.

Openness

The logistics involved in humanitarian aid are affected by a great unpredictability in terms of three factors: different types of regional contexts and type of disaster, different disaster relief phases and different types of organizations (Kovács & Spens, 2009). Kovács reviews how challenges like security, usability of infrastructure, local presence and time of response and limitation in collaborations relate to these differences.

Throughout the whole process of transfer of medical equipment in humanitarian emergencies, these three varying external factors produce particular effects on healthcare. In the following paragraph, these effects are described and exemplified with numbered barriers and enablers (appendix P1, p.114).

Different locations and disaster types determine:
- The diversity of healthcare needs and the required medical equipment (E6);
- The different education level available to collaborate (B9);
- Customs efficiency in terms of time and implicit restrictions (B1);
- Availability of local supplies (B4) (e.g. water quality, oxygen cylinders) (B4);
- Medical equipment and medicines adequacy in terms of atmospheric and security conditions (B1).

Different phases of aid mean:
- Changing healthcare priorities in time (B14);
- Following protocols is not always possible (B2);
- Prioritization in healthcare needs which might not be adequate (certain general medical

needs such as pregnancy complications do not strictly occur during an emergency, but still represent a large part of the problems addressed) (B12).

Different organizations conducting overlapping programs results in:
— A diversity of equipment, supply parts and components (B1);
— Misalignment of practice standards (e.g. between large and small organizations) (E12).

Additionally, 10 of the 23 logistic barriers mentioned by (Kovács & Spens, 2009) were also identified in this study and are marked in figure 9.3 with the character "*".

Interconnectedness

The following examples of barriers to handling of medical equipment illustrate the interconnectedness in this system's structure (i.e. involving other physical elements and processes). This interconnectedness means that there is a network of dependent and complementary elements that function as a whole and are essential to guarantee the successful transfer of medical equipment in humanitarian emergencies (system's function).

The biomedical referents stated:

> We didn't only need the x-ray to be installed but the software had to work, electricity connections, shielding, transport from the harbour.
> During the sterilization procedure there are so many different things that could transfer infection and autoclaving is just a part of it.

The procurement officer mentioned:

> We know that if we need spare parts or if we need maintenance it is very important that they can be supplied on the spot, especially maintenance.

Medical equipment is an essential part, but as one biomedical referent said, "only a part" of extensive healthcare processes. More activities and equipment need to be in place for them to function and this means they are tightly coupled. To a lesser extent, other issues, or looser connections are also influencing the safe/successful use of medical equipment. For example, if medical equipment is perceived as not useful or offensive, or if it is donated, careless of whether it can function or not, because it is too expensive to import back and reuse. This can ultimately lead to useless or less safe transfer. The previous example shows that the problems faced by international experts have a multiplicity of dimensions. This is evident from the relation between the identified barriers and enablers. Although mechanisms are in place, and being developed, to address different barriers (e.g. the adoption of different supply mechanisms and improvisation are used to deal with uncertainty, use of own standard equipment to increase safety by reducing diversity, and training and supplies provision to

address the broken supply chain and lack of expertise in the handover phase), barriers are still present. Addressing the challenges from humanitarian organizations requires a holistic overview of elements, roles and relationships involved in producing barriers. This means that multiple approaches from different actors are needed (Ramalingam et al., 2008).

Non-linearity

From a logistic system point of view, and with a long-term perspective, there is evidence from the emergent (and unpredictable) behaviour of this system. The biomedical referents and consultant stated:

> You can have your planning (deployment phase), but then it still does not always succeed. We tried installing a softener (water purification device) but [...] they [local staff] wanted to use the softener for other purposes.
> The time to resolve all these things was just more than what it was planned for. (Normally) the machine works, you connect and it runs, but that was not the case in this situation, at all.

Given the diversity and constant change of contexts, the relationships between different, and often uncertain, stakeholders also change. This leads to an incremental build-up of latent barriers and loss of control, evident in barriers, such as "Protocols not always followed", "Process of transition is unclear", "Safety compromise due to equipment limitations" and "Uncertainty of production and supply continuity". These barriers require humanitarian organizations to be flexible to deal with uncertainty. This study identified some of the mechanisms humanitarian organizations use to cope with uncertainty, such as "Improvisations" and "Partnerships". First, when faced with organizational and logistic constrains it is often the staff in the field who takes the measures to assure the continuity of healthcare provision. The referent for anaesthesia mentioned:

> How the machines will be localized might not be the same in low-income countries. [...] In a lot of western hospitals [...] the corridors are going around [the operating rooms]. While in LIC [...] corridors go in the middle. This is very important because when you have a machine of anaesthesia that you need to connect a scavenger system [exhaust system to release anaesthetic gases from operating room] [...] in LIC [...] you have the machine very far from the windows. So you need to make a whole situation how to scavenge the gas to the other side.

Also, opportunities for partnerships with other organizations, local and international, allow barriers to be overcome, as mentioned by the biomedical referent and the biomedical consultant:

> In the end it was the army who brought it (x-ray device), they had access to the harbour (organization did not have equipment to take device out of truck).

> For me is crucial to listen to what the people say. […] I try not to assume there is anything, just observe and know what is really going on before acting and also before investing. [...] I try to collaborate and stimulate the people who are there to improve their own situation and assist in that.

The unanticipated activities that humanitarian organizations carry out to cope with uncertainty contribute to the non-linearity and unpredictability within the system. This is because new (feedback) interactions occur within and amongst the organizations. And because organizations might have differing perspectives, and thus differing lines of action. For example, complying with humanitarian principles (B13) is contradictory to collaborating with the military (E9). Emphasis on knowledge transfer through training (and experience) (E11) is threatened by the exodus of trained staff or by practice with inadequate skills (B9). And finally, deploying a whole system can be seen as inevitable (B5) or as an unsustainable replacement (rather than reinforcement) of ongoing healthcare services (B11). These differing perspectives can either support or be disincentive to the way activities are carried out. Because of the power of the diverging perspectives, feedback interactions trigger unforeseen lines of action and outcomes.

In summary, systems thinking allows us to understand the systemic characteristics of the experienced barriers by experts in humanitarian organizations. Medical equipment logistics and transfer, as part of a larger humanitarian aid effort, are susceptible to unpredictable external influences, involve numerous processes and people, often engaged in addressing problems, unexpectedly, on the short-term and finally, its success is ultimately perceived in different perspectives. From a systems perspective, this has implications in the planning from humanitarian organizations, in the way they define medical equipment requirements and servicing collaborations.

In order to address the complex barriers identified in this study, there is the need for a collaborative, multidimensional approach to promote an adaptable, more inclusive action, and a balance between short- and long-term priorities. An approach guided by systems thinking, could help to create a designated space for the formulation of original, synergetic solutions that embed a diversity of perspectives and values. In the adjacent field of design for sustainability, several models of systems design and change have been proposed that embrace, amongst others, openness, interconnectedness and non-linearity of complex systems and offer potential perspectives that could help to tackle the barriers faced by humanitarian organizations (Joore & Brezet, 2014; Jones, 2014; Davis et al., 2014; Dubberly, 2010; Elzen et al., 2004). Research about the suitability of such approaches is outside the scope of this article but should be further investigated.

9.7 Research limitations

The low number of interviews carried out limits this study. In the future, a similar research setup should be used with a larger number of international experts from different organizations. The research would benefit if access to and availability of experts is formally arranged. And although the study is limited to the experience of international aid providers, the experience of local experts should be researched. Second, a difference between interviewees was seen. Interviewee 1, as opposed to interviewee 5 for example, demonstrated a larger awareness about systems thinking whereas others, possibly due to personal characteristics, keep their descriptions to an operational level. A group interview/focus group/workshop is a potential technique to overcome these differences, because it creates a space for open discussion where participants stimulate each other to participate. Furthermore, an introductory presentation of systems thinking might reduce the dissimilarity in their awareness.

The barrier types "Lack of adequate field testing" and "Limiting humanitarian principles", and the enabler type "Reduced logistical workload by company clusters" were mentioned more than once by one interviewee. Although these results are based on the experience of a single interviewee, they are considered relevant given the diversity of examples provided.

The introduction of systems thinking in this paper was purposely simplified in three general concepts. Given that this is a relatively new perspective in humanitarian aid, it is the authors' conviction that in order to grasp the value of systems thinking, a simple starting point should be taken by looking at a small number of characteristics in order to make the learning more practical and tangible. This is in line with the criticism from (Collopy, 2009) about the over-difficulty of systems thinking application.

9.8 Conclusions

The findings of this study indicate that humanitarian logistics play a very relevant role in healthcare provision during humanitarian emergencies. This study revealed types of barriers and enablers experienced by experts from humanitarian organizations. The uncovered types of barriers are, each caused by a diversity of reasons and the types of enablers, although not strictly related, illustrate the kind of mechanisms humanitarian organizations use to deal with barriers. Afterwards, the principles of "openness", "interconnectedness" and "non-linearity" from systems thinking were used to discuss, and confirm, the systemic nature of the barriers and enablers as described by the experts.

The evidence of the systemic nature of barriers and enablers found in this study indicates

that humanitarian organizations would benefit from further research about how a systems thinking approach would improve the logistic experience on the short- and on the long-term of humanitarian emergencies. This study contributes to uncover knowledge about the systemic implications of humanitarian logistics and is valuable to the redesign of organizational practices. Because the logistics implicit in the transfer of medical equipment must often replace commercial, social and technical functions, collaborations and a long-term perspective are potential aspects to learn how to continuously support the provision of healthcare after humanitarian emergencies.

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Appendix P1. Table of barriers and enablers

B	Barriers	Examples	n=x	1	2	3	4	5	6
1	Uncertainty regarding differing local settings	*"(There are) lots of countries where it can take a long time to import something."[I3]* *"We left Somalia this year, because of the Al-Shabaab and all the abductions. We had to decide in no time to leave without the chance to let the staff know [...]. But we had a plan that we communicated via teleconferences and skype to the staff, we left much medicines so they could pursue for a couple of months. In a couple of days it was taken over by the rebels [...]."[I1]* *"Maybe this machine which has been procured is taking 64kW of power, if you know that the hospital only has a generator of 32 of power then you know it's not worth to send such machine, it's not going to be used."[I6]* *"We found some Glostavents (brand of anaesthesia machine) in our hospitals in Afghanistan because apparently the British army was giving Glostavents to all the hospitals there [...]. So we said we will continue with the Glostavent (…)".[I2]*	24	•	•	•	•	•	•
2	Absence or difficult compliance with standards, protocols and guidelines	*In an emergency you will not follow these normal procedures to every detail, you just need to find a solution quickly [I3]* *"All the guidelines and the protocols that we have there, they are never completely taken over, parts of it... The links disappear and so they disentangle.[...]Often there is just no more money."[I1]* *"Very often it (guarantee contract) doesn't work. It has been standing there for more than a year and the guarantee period is only a year so it's already gone."[I6]* *It can be that you find a product that is suitable for most places but in some places it will be still difficult to implement because the human resources that are present are not familiar with this kind of devices, that the infrastructure is not in place... For example in Sudan or Chad it's extremely hot. And then in other countries, like in Syria, they will just laugh when you come with it (TBM autoclave), it's too basic.[I3]*	10	•	•	•	•	•	•
3	Lack of appropriate field testing	*"The responsibility ends when they put a machine in place and nothing more, and they don't care how the user is using it. [...] If a TBM manufacturer goes to Ghana and sees an awful sterilization room he will end saying ah because all is awful the machine is not working correctly. [...] they will blame the set-up."[I2]* *"(Manufacturers) need to test (medical devices) in an organization where standards are high enough to be able to find all the problems [...] If you ask an anaesthetist in Ghana or Uganda [...] They don't have another thing they could compare with." [I2]*	2		•				

4	Lack of continuous or appropriate supply and servicing	*"In a normal situation [...] we use oxygen cylinders because we are in the capital. [...]When we are located in projects that are very far [...] we go for oxygen concentrators [...] You might not have a good supply chain [...] the transport, it is very difficult [...] In some cases it might take 6 months to arrive by river."[I2]* *"They (company) design autoclaves for NGOs, very specific, and they were actually almost bankrupt because it is such a horrible market."[I4]* *"Upon arrival that machine was a different model than we thought it was. [...] the manufacturer [...] had released a new version of that machine but they left it having exactly the same model number, but it proved to be a much more complex machine than the previous version."[I6]* *"The problem in Jordan is that we cannot, or almost, not import (medicines) [...] we ask our pharmacist to select local suppliers. So the whole supply system that we do here, we must also do there. [...] But after three months, you try to buy something again and they don't have it anymore."[I1]* *"Yes, you have guarantees but if in the meanwhile the device breaks down, try to find someone who goes to there (Haiti)... Often it's the middlemen who are the problem."[I1]* *"You need to have a stock of all spare parts, in many cases you also need special instruments for measuring and following up so it's a whole package. If you have to assure all this yourself, as customer or user it's starting to get quite complex."[I3]*	29	•	•	•	•		•
5	Difficult equipment implementation	*"During the sterilization procedure there are so many different things that could transfer infection and autoclaving is just a part of it. Before you have all the cleaning and pre-disinfection. And if this is not properly done, even with a good autoclave, the end result would not be good and also when you do the procedures you need to be sure the hygiene in the OT (operating theatre) is well kept. It's god to keep the big picture in mind also."[I3]* *"It would be very interesting to have an anaesthesia machine that does not have Nitrous Oxide flowmeter. [...] Because you have this and almost nobody has this Nitrous Oxide gas in the field [...] the manufacturer is creating a need."[I2]* *"In the end it was the army who brought it (x-ray device), they had access to the harbour (organization did not have equipment to take device out of truck)."[I1]* *"And other thing was to be an installation kit which would have components to connect the machine to water supply and electricity supply. That installation kit was supplied according to the delivery note, but it was not included in the shipment."[I6]* *"We know that our standard autoclave might arrive in one week and then it still needs to be installed [...] so we just had to find possibilities with the small autoclave [...] which is not really ideal for surgery."[I3]*	27	•	•	•	•	•	•

6	Inexistent or inadequate equipment and use	*"It is difficult for example to find an x-ray that fulfils the minimum standards and is robust and simple."[I1]* *"We tried installing a softener (water purification device) but [...] they wanted to use the softener for other purposes."[I3]* *"I have seen so much misuse of machines in hospitals around the world."[I2]*	23	•	•	•	•		•
7	Challenging transportation	*"We make agreements (for packaging preparation) with the company [...]. If they cannot do it, then we do it."[I1]* *"The local airport was highjacked by the US (United States) army so planes had to go to Dominican Republic and they (medical devices) need to be on trucks and then trucks need to go over the border."[I3]* *"The roads are very bad in that area [...] only that is already a headache for medical equipment which is a bit sensitive."[I6]*	6	•	•	•			•
8	Inconvenient donations	*"We often receive donations from a hospital that is closing [...] but we cannot do anything with them. There is guarantee and that would need to look for contact with that company."[I1]* *"Donations that are country specific force NGOs to invent projects. MSF has the advantage of choosing where to spend the money."[I2]* *"Donors they are ready to pay anything. Like this machine in Nigeria has cost about 50.000 euros, it has been paid for but it's not running."[I6]*	4	•					•
9	Inexistent or inadequate expertise and training	*"If you think of South Sudan, Syria and Congo, there is a very large difference between the level of education of people."[I1]* *"You (referring to trainees) need a lot of experience before you really can assure all the maintenance needed."[I3]* *"So what you will have is a lot of people that have skills, but they don't have knowledge. So they can do a spinal anaesthesia but if they (patients) have a haemorrhagic shock they (nurses) don't know what to do."[I2]* *"We thought anybody can operate a weighting scale. We had about 15 senior nurses who were responsible for the maternity in these facilities and we asked them to weight an object on that weighting scale, and none of them could do it."[I6]* *"The good professionals often leave due to so many professional barriers such as no recognition and bad payment."[I5]*	13	•	•	•		•	•
10	Unclear process of transition	*"Even if you have knowledge (about the diversity of local contexts) it is still making the challenge much higher."[I3]* *"In principle (after donating to Ministry of Health) we try to arrange maintenance or supply for two years. In practice, this does not always happen."[I1]*	4	•		•			

11	Financial and organizational aid dependency	*"Even the cholera set-up [...] there no device is needed [...] it's only about the flow, the cleaning and keeping hygiene. They cannot even take over such projects with simple logistic challenges, and so we cannot leave."[I1]* *"NGOs are doing more than facilitating this process, they are replacing it."[I5]* *"The hospital has no money, that's a major problem. To have somebody flown in from Benin, and then he probably comes there, he finds out there is something wrong, he has to go back to Benin to get some other things…It's very quickly becoming a very expensive story."[I6]*	14	•		•	•	•	•
12	Partial media coverage	*There (in Syria) the needs are huge. And nobody is talking about Syria anymore while to the Philippines, they all donated a lot of money."[I3]* *"Disasters are strongly built images from the media to support donors. They shoot a destroyed palace with 3 houses next to it that are still standing. In the health sector you don't feel it, life goes on. Complications are always the same."[I5]*	2	•				•	
13	Limiting humanitarian principles	*"We have a lot of similarity with the working conditions and specifications with the army but we also have our name and our image, so it's always a bit tricky."[I4]*	1				•		
14	Uncertainty regarding changing phases and priorities	*"After you have the emergency phase then the project is stabilized, and in the end we decided to make the orthopaedic surgery project [...] ideally you should have a better autoclave." [I3]* *"There is one Robustex sterilizer in a 500 bed hospital, that's all. There's no sterilization tape, you cannot see whether something has been sterilized or not. I don't know whether you call that an emergency, but I think it is."[I6]*	6		•	•	•		•
E	Enablers	*Examples*	n=x	1	2	3	4	5	
1	Reduced logistical workload by company clusters	*"They (Medical Export Group) purchase for us. [...] That's an example of a cluster of companies through which we have less procurement work."[I1]*	1	•					
2	Effective agreements with suppliers or manufacturers	*"One solution is not to these kind of programs that requires this kind of high-tech equipment, another thing is to just bring in the equipment necessary and hope it will work as long as possible. When it breaks down you try to find a solution ad-hoc or you just replace it. Or the last thing, what we try to do [...], push the manufacturing industry to make something better and more adapted to our needs."[I3]* *"In emergencies we do relate with some companies and suppliers [...] we have agreements [...] an e-preparation."[I1]*	9	•			•		•

3	Remote or adjusted care practices	*"(The) protocols we are using, are very simple, are based in WHO (World Health Organization) guidelines so they are not based in Harvard or Cambridge guidelines and they are based on what we have in the field."[I2]* *"Most of the work is done from distance [...]. In Jordan you have great hospitals [...] we rent a part of the hospital and we treat Syrians."[I1]* *"The pressure (water pressure from overhead tank) was, according to the specifications, too low but they tested it and it could still run on 0.6 bar."[I6]*	4	•	•				•
4	Management of transition supplies and support	*"The most important supply parts are the breathing circuits, [...] the spirometer, it's located in a very awful place [...] it might break; respiratory filters, that are not included in the machine, because by that we prevent (need to keep) cleaning the breathing circuits; and oxygen concentrators."[I2]* *"If there is service contracts we will also donate whatever time is left over of the service contract." [I4]*	4		•	•	•		
5	Use of standard equipment and kits	*"We are stricter with good products (referring to development aid)."[I1]* *"We have so many projects in so many locations that if we start working with a lot of different brands it is impossible to provide spare parts, training, maintenance all that, that is why we always choose one brand for a longer period of time."[I4]*	12	•	•	•	•	•	•
6	Adequate equipment requirements and choice	*"In Syria we have the case that people cool down very fast in the operating room because there are a lot of complex surgical interventions, [...] and there are specific devices that you can use."[I1]* *"The advantage of TBM (autoclave brand) is that it can operate from different kind of heating sources; Electrical but also gas or kerosene burner."[I3]*	16	•	•	•	•		•
7	Responsibility allocation	*"Companies have contact with local suppliers [...]. We are developing global agreements [...] if they (servicing suppliers) do not come within three weeks they must pay a fine."[I1]* *"I would say that the donor should verify with the local contractor if the machine is running or not. The contractor should not be paid until the machine is running and it has been commissioned (…). In the procurement specifications should be, of course the specifications of the machine, but also assurance of installation, assurance of training and commissioning."[I6]* *"That is how we deal with it (medical device transfer), [...] as a project, with a project leader. Purchasing is just a part of it."[I1]*	5	•					•

8	Versatile supply of spare parts	*"Expats are there for nine or twelve months. They know how our supply system works and they can help to explore the market."[I1]* *"Normally (spare parts) will go via Schiphol (airport) because that is more efficient since we can consolidate all the different products."[I4]*	4	•	•	•		
9	Effective partnerships	*"You can drive but there are huge holes on the way. Devices can break from the vibrations [...]. In the end it was the army who brought it (x-ray device), they had access to the harbour"[I1]* *"For me is crucial to listen to what the people say [...]. I try to collaborate and stimulate the people who are there to improve their own situation and assist in that."[I6]* *"If we have an immediate use for it (medical equipment), we prefer to continue using it rather than store it."[I4]*	4	•		•	•	
10	Improvisation	*"The infrastructure came later with a cargo (lead suit was only safety measure available) so instead of having a lead shielding between the waiting room and the diagnostics room, you build it at 3 meters distance."[I1]* *"We have our own scavenger (exhaust system to release anaesthetic gases from operating room, not included in device). It is like a bricolage."[I2]*	3	•	•			
11	Local adoption of practices	*"Even if our technique is very low-tech, when you arrive to these contexts, our technique becomes the only one available."[I2]* *"Training is investing in capable people of developing themselves, it creates a micro environment where they are given chances to do something and to learn." [I5]*	3		•		•	
12	Logistic capacity and resources	*"Little NGOs that do not have knowhow in this (local misuse of oxygen cylinders) they might use it (oxygen cylinders) but they are not looking at the danger." [I2]* *"There are some overlaps but there are also some differences. Because the army has quite advanced sterilizers for example, but they have their technical staff to keep it running under their conditions [...] that's different than in my situation that I go to a rural hospital which has to rely on their own technicians, on the long-term."[I6]*	5		•			•

10 Systems design perspective of healthcare provision in humanitarian aid [publication 2]

This chapter was published as: Santos, A.L.R., Wauben, L.S.G.L., (2014). "Systems design perspective of healthcare provision in humanitarian aid". Theory and practice of Systemic Design Special Issue, Formakademisk, 7(3), pp. 1-19.

Abstract

This study focuses on the role of systems design in addressing the challenges of healthcare provision by international emergency relief organizations in developing countries. More specifically the challenges related to the safety and performance of medical equipment that is transferred in the aftermath of a humanitarian crisis. The aim of this paper is to describe the transfer of medical equipment and its associated challenges from a systems perspective and to reflect on the value of systems design as an approach to humanitarian innovation, addressing the identified systemic challenges. The concepts of human factors and ergonomics, and product-service systems will be presented as valuable contributions to support designers in handling a larger degree of complexity throughout the design process and to support them to make informed choices regarding this particular context.

10.1 Introduction

The present increase of frequency and complexity of humanitarian crises has a particularly strong and lasting impact in developing countries due to the susceptibility of multiple socio-economic variables to risks (Pelling, Maskrey, Ruiz, & Hall, 2004). International emergency relief is a specialized field of humanitarian aid focused on short-term and life-saving interventions, aimed at the temporary reinforcement of systems (e.g. sanitation, healthcare) jeopardized or disrupted by e.g. a natural disaster or flee from conflict.

Healthcare services in humanitarian crises are essential for the affected population, but they are vulnerable as they are often not able to cope with the overload of patients and the limited infrastructure. The conditions of healthcare provision in humanitarian crises have been poorly explored regarding the safety and performance of medical equipment that are transferred, together with medical staff, to provide care in the affected country. According to Mortier, Bullen and Guillouzic (2010), publications about emergency relief mainly focus on medical aspects of healthcare and often do not include systematic assessments. The use of medical equipment is often, but unsystematically, described in case studies or reports

about disaster response. Medical field experts witness barriers to medical equipment use and it has been shown that medical equipment is not adequate to be used in the setting of disaster response, in particular disasters occurring in developing countries (Owens, Forgione, & Briggs, 2005; Rice, Gwertzman, Finley, & Morey, 2010).

After being used the medical equipment is most often donated to local entities. Although, there is limited information about the outcome of this one-sided transfer, there is evidence that about 50% of medical equipment donated to developing countries lie idle in hospital rooms (World Health Organization, 2010). Several explanations have been proposed, such as device inappropriateness to context or the lack of local expertise in use or maintenance (Lister, 2004; Malkin, 2007). Besides being highly inefficient, this one-way transfer leads to dangerous threats for safety and performance (Santos, Wauben, Dewo, Goossens, & Brezet, 2013). The aim of this paper is to describe the transfer of medical equipment and its associated challenges from a systems perspective and to provide a theoretical background regarding the value of systems design as an approach to humanitarian innovation. As such, the concepts of human factors and ergonomics, and product-service systems will be presented.

Humanitarian innovation

Humanitarian organizations, governments, donors and more recently the private sector, are increasingly aware of the importance of innovation in the humanitarian field (Ramalingam, Scriven, & Foley, 2009). This awareness reflects a concern with the growing need for accountability and transparency in the use of available budgets. Moreover, and as in many other societal sectors, the demand for sustainable practices is present. Humanitarian organizations are driven to be more competitive and learn from their failures. Particularly the private sector has been actively reflecting on the changing character of aid towards a demand driven, beneficiary-centred and competition based aid system that separates donors from service providers (Sanders & Stokkom, 2009). In line with this trend, humanitarian organizations increasingly relate to innovation as a solution to rethink or improve their programs (intertwined system of services and technologies) to meet the permanent and diverse need for aid. Worldwide, several initiatives involving the manufacturing industry and humanitarian organizations have been initiated that focus on the development of new products, destined for use in aid (e.g. Speed-Kits, Shelter Centre, Humanitarian Innovation Fund). In the area of products for medical care, efforts have focused on the development of medical infrastructures, such as ready-to-deploy hospital containers and low cost medical equipment (Jawor, 2011; Tully, Eltringham, Walker, & Bartlett, 2010). However, the approaches used to identify innovation opportunities or to design strategic plans for implementation are mostly unsystematic or not reported.

10.2 Introducing a socio-technical systems design perspective

Systems thinking is a holistic approach to problem solving based upon system theory which describes the configuration of parts, inherent relationships and resulting properties of e.g. activities, biological systems and organizations (Flood & Jackson, 1991). Using Systems thinking to analyse a complex, societal phenomena (e.g. the transfer of medical equipment in humanitarian emergencies in developing countries) results in a non-linear cause-effect reasoning of problems. This process is valuable to explore cyclic events and consequences and can therefore thoroughly measure the impact of those cyclic events in time (i.e. in the short- and long-term) and extent (including all affected parts of the system, such as humanitarian organizations and aid beneficiaries) (Ponto & Linder, 2011). Furthermore, systems thinking broadens the boundaries of such an analysis to focus on dynamic relationships and contributions of system elements as a whole, rather than their independent behaviours (Banathy, 1996).

Socio-technical systems (STS)

Socio-technical systems (STS) have their origin in work analysis within the field of organizational change and situate Systems thinking in a work context of organized human activities that produce, diffuse and use technology. STS sees these organization of activities as systems that depend on the relation between a human and a nonhuman system, that means they depend on humans and on material means for their outputs (Katz & Kahn, 1978; Trist & Labour, 1981). So central to STS is a distinctive ownership of values in which humans play an essential role as empowered individuals and as social entities (Mumford, 2006). Furthermore, STS are open systems, influenced by and influencing an external environment where new technologies, parallel markets and economic trends are developed (Emery & Trist, 1960; Mumford, 2006; Robertson, 2001; Trist & Labour, 1981). STS are generally defined by a complex configuration of defined institutional, socio-cultural, organizational and technological elements, arranged functionally or hierarchically to fulfil a determined social function (e.g. healthcare or humanitarian emergency response). Although, studies have shown diverse models and differences in the focus and segmentation of STS, these models uncover the interrelationship and the mutual influence of the different elements of which change depends on (Carayon et al., 2006; Rasmussen, 1997; Vicente, 2006). Each element involves technical (tangible) and socio-political aspects (intangible) and has a specific contribution or sub-function to the overall system (Banathy, 1996; Geels, 2004). The relationship between the sub-functions of the elements results in system properties, such as safety or sustainability (Gaziulusoy, 2011b; Vicente, 2006).

Socio-technical systems design

In the field of innovation and economics great attention has been given to the shift of a knowledge-based to an innovation-based economy (Berkhout, Hartmann, van der Duin, & Ortt, 2006; Chesbrough, 2003). In this shift, creativity and imagination became a driver for economic growth and competitiveness within existing innovation sectors. With the expansion of knowledge, technology and societies, a new generation of innovation practices appears, characterized by partnerships and interconnected industries and areas of knowledge. Most recently, with a growing societal concern about sustainability, innovation sectors started to question their role for the future: shifting from just focussing on creating innovations for economic growth, towards adopting principles of STS and extending the scope of innovation to reach the whole value chain. This means looking beyond the creation of innovations, to their diffusion and use aiming therefore, to sustainably and successfully achieve societal goals as well (Geels, 2004).

When specifically applied to design, the adoption of STS principles allows designers to integrate known design competencies with knowledge and methods that increase the scale of design practice and its social complexity. Designers are empowered to "think", explore, map and reconfigure complex services and address existing interconnected problems in a human-centred way (Buchanan, 1992; Jones, 2014). STS principles apply to design practice in both focus of design and methodologies, and have been successfully used in the design of new technologies and related work (Clegg, 2000; Davis, Challenger, Jayewardene, & Clegg, 2014). Given that different terminologies and curriculums are used by different schools (e.g. Systems design, System ergonomics Systemic design, or System-oriented design (Nelson & Stolterman, 2012; Sevaldson, 2010; John R. Wilson, 2014)), the authors in this paper refer to Socio-Technical Systems Design as a perspective on the abilities of design (as a discipline) that suggests that the successful implementation of a product, service or policy, designed to take part in a specific socio-technical system, depends on the functioning and interrelationship of the existing system elements. The system elements should, therefore, be considered in the design focus and process to guarantee the realization of its intended function and sub-functions (Elzen, Geels, & Green, 2004; Joore, 2008; Vermaas, Kroes, van de Poel, Franssen, & Houkes, 2011). By admitting that technology shapes and is shaped by the STS it is designed, implemented and continuously used in, design involves not only technical, but also organizational and social considerations (Carayon, 2006; Williams & Edge, 1996).

STS principles influence the design focus and the design process. Firstly, emphasis is given to a range of interrelated social practices or domains that ultimately put the focus of design in "a whole-system ecology" (Dubberly, 2010; Jones, 2014).

According to the problem at hand, the concerns from involved stakeholders and the need to integrate new areas of knowledge, the designer must choose a "placement of thinking" as a starting reference point (what Banathy names the primary system level) and from there (re)design the related system interactions (Banathy, 1996; Buchanan, 1992). When designing a concrete physical object or an abstract polity decision (although not on the same scale or same goal), they can both contribute to shape human behaviour and reach a common societal goal (either by adapting to the physical and emotional characteristics of a user, facilitating a task, or understanding social motivation) (Vicente, 2006). Since any outcome of design affects the whole system, the resulting systems will have different characteristics depending on the chosen primary system level. Secondly, designers need skills to manage a multidisciplinary approach that is iterative and integrative, involving a large number of stakeholders in order to increase the understanding of a systemic problem. This often means coordinating conflicting and dynamic requirements within the system (Mumford, 2000).

From an innovation point of view, the more system elements considered in the design approach, the greater the capacity of the system to address a certain function (Brezet, 1997; Gaziulusoy, 2011b). This means that (re)designing the physical attributes of an existing medical device to improve safety of the healthcare system results in a smaller and shorter-term impact in the system than designing a coherent combination of processes and products to fulfil the same purpose (Gaziulusoy, 2011b; Pourdehnad, Wexler, & Wilson, 2011; Sevaldson & Vavik, 2010; Vasantha, Rajkumar, Lelah, & Brissaud, 2012). With regard to the response to humanitarian emergencies in developing countries, and similar to developing aid, the problems arising from the contrast in healthcare systems do not solely lie on the lack of appropriate technology (robust and low cost devices). They also exist due to poor incentives to make structural aid and to rebuild without the pressure of business (Gaziulusoy, 2011a).

Given that the existing methods to operationalize socio-technical systems design have been mostly designed for a particular market, there is no general and systematic method that prescribes the use of socio-technical systems design (Baxter & Sommerville, 2011). The socio-technical systems design approach has proven difficult to operationalize in all its essence, due to the intertwined characteristics of STS themselves (Clegg, 2000; John R Wilson, 2014). Additional criticism to the approach include: inconsistent terminologies and system elements segmentation, difficulty in integrating contradictory value systems (humanistic and managerial), inconsistent success criteria, greater emphasis on the analysis phase than on the synthesis process phase, perceived inconsistence in keeping up with organization's own developments and unclear definition of the users in fieldwork (Baxter & Sommerville, 2011). Nonetheless, throughout literature, the potential of Socio-technical Systems design to tackle complex problems in the future is acknowledged and its learning is encouraged (Davis et al., 2014; Sevaldson, 2009).

In summary, the authors have (for the time being) purposely limited the definition of socio-technical systems design and selected the following general features to characterize it: alignment of system elements with common goal, focus on system interdependencies contributing to system properties, openness to socio-technical context and societal framing, active impact of human factors in the system, long-term/lifecycle perspective, use of design thinking as a business driven, human-centred "tool" for creativity and problem solving, and finally a resulting "ecosystem" of design outcomes.

10.3 Systemic transfer of medical equipment and its associated challenges

The multilevel design model from Joore (2008) in Reinders et al. (2012) was used to analyse the transfer process of medical equipment in humanitarian emergencies. This descriptive model aims to describe a change process implicit in systems design (i.e. innovation or technology implementation) involving different system elements, hierarchically arranged as system levels, in which an ongoing design process contributes to a larger process. The following levels describe the hierarchy in the multilevel design model (context x, figure 10.1):

— Societal level: framing environment of different socio-technical systems (material, policy, legal, social and cultural components);
— Socio-technical level: stakeholders interaction and system infrastructure;
— Product-service level: diffusion, service, use and disposal by a group of users;
— Product-technology level: production of specific products and technologies.

Each system level comprises of a design process and owns different sub-purposes, different times of development and operationalization and different outcomes (in line with the sub-purposes of a system from Banathy (1996) or the production, diffusion and use sub-functions from Geels, 2004).

The multilevel design model also indicates that all system levels or system sub-functions gradually influence each other (influence represented through V-shape). Hereby, coexisting socio-technical systems (e.g. medical innovation industry and local healthcare system) are positioned in one inclusive societal context that defines the overarching regulatory and value boundaries of a system. The hierarchy of systems levels in which design acts are similar to what Van Patter (2009) proposes when mapping an evolution of design domains, hierarchized by their relative complexity. Here as well, each level has its own strategy, aim and outcome (Jones, 2014; Van Patter, 2009). Taking for example the innovation for a healthcare system, this means that the creation and implementation of a medical device (product-technology level) for surgery (product-service level) will have an impact, not only

on how surgery is conducted, but also in the surgical and hospital infrastructure (socio-technical level) and its regulations (societal level). In turn, implementing a new policy or standard regarding healthcare will exert influence in all levels of the same hierarchy: the infrastructure and management of surgery, the operating room and the equipment that is used.

The multilevel design model is useful to guide a thorough analysis of a context and understand the diversity and interdependency of variables that are involved in the provision of healthcare. In addition, it refers to an iterative innovation process of four phases along which the transformation or change in the societal function takes place (reflection, analysis, synthesis and experience). Similarly to the implementation of new medical equipment, its transfer between different contexts can be problematic if the structures in which it must be included are not prepared (e.g. electrical vehicles without existing charging stations or the implementation of a surgical robot in an operating room which is not configured to accommodate it due to ventilation and light settings). Medical equipment originally developed for a context with established regulating policies and production capabilities, established socio-technical environment and knowledge culture, is confronted with an essentially different context with no capacity to sustain the supply and proper use of the technology. These system levels draw a V-shaped influence line since the adoption of a technology implies the existence of a support system composed of infrastructure, knowledge and regulatory legislation for its effective transfer and use in context.

When analysing the suitability of medical equipment and its use context from a socio-technical systems perspective, it is clear that the transferred technology must be considered together with the personal, technical and organizational sub-systems it is dependent on to function (i.e. services, regulations and cultural values). The particular challenge posed by international emergency relief (figure 10.1) is that it implies a temporary transfer of technology between two inherently different systems (x and y) with long-term effects (y'), rendering the available medical equipment inadequate to function. The transfer of medical equipment is therefore a "systemic transfer" where the medical equipment works as a carrier of those sub-systems, from one to another context. This mismatch, depicted in figure 10.1 with (red) crosses, is the result of differing system levels within contexts that act as barriers for healthcare safety.

In addition, the transferred medical equipment and services are intercepted by different stakeholders at different phases of aid. In order to further understand and specify the particular context characteristics of the response of humanitarian emergency relief to natural disasters in developing countries a systematic literature overview was conducted. The overview was limited to the medical domains of surgery and anaesthesia, for which technology is essential and particularly complex in comparison with other medical domains.

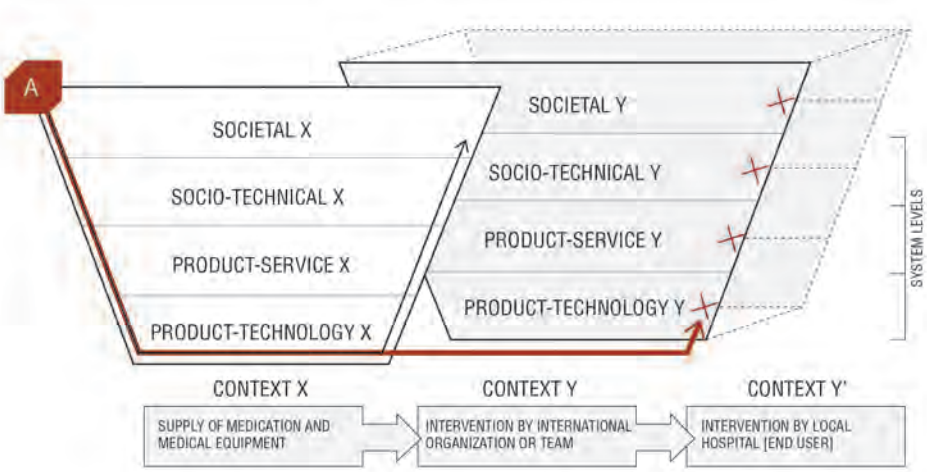
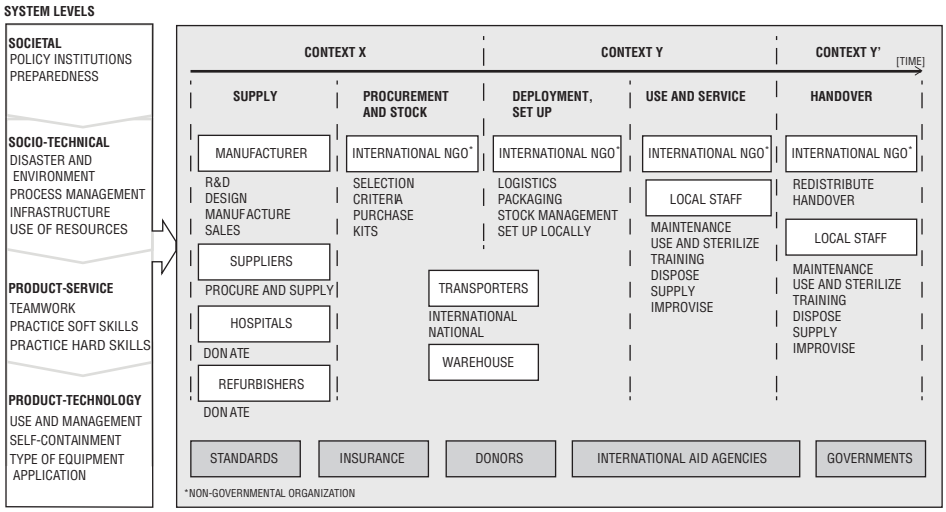


Figure 10.1 Transfer of product A between contexts x, y and y' (adapted from Joore [2008])

Figure 10.2 illustrates a simplified model of the systemic influences on the transfer of medical equipment in humanitarian emergencies based on the systematic literature overview. At the top right of figure 10.2, the main activity is stated in parallel with the respective context location (x, y, or y'). The rectangles below refer to the main stakeholder that is usually involved with the main activity and to the tasks that the main activity requires. Stakeholders that have an indirect influence on the supply are depicted in the dark grey rectangles. The references found in the papers regarding context characteristics of transfer and use of medical equipment were categorized using the multilevel design model. The four levels of hierarchy of the system elements (left side figure 10.2) were further sub-categorized for readability purposes, in clusters named by their common relation or cause. Despite the diversity of medical equipment attributes or business models involved, most products face common issues regarding the way they are transferred.

Two examples

The following factual examples were collected by means of interviews with experts from the international organization Médecins Sans Frontières and a previous observation study performed in Indonesia (Santos et al., 2013). The examples are intended to specify the systemic influence and challenges across the transfer of medical equipment as illustrated in figures 10.1 and 10.2. Both examples refer to a medical device (device A) that is commonly used in international emergency relief. They are designed within and for Europe (context x), with consideration of existing safety regulations, operational healthcare facilities (e.g. sales department, sterilization, waste management), capacity to afford and maintain equipment, task distribution and stable energy supply.



System levels	Common relation/ cause	References
Societal	Policy institutions	1,2,3,7,8,13,20,21,22
	Preparedness	1,2,3,4,5,7,8,9,10,11,12,13,14,15,16,17,18,20,21,22,23
Socio-technical	Disaster and environment	2,3,5,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,23,24
	Process management	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,24
	Infrastructure	1,3,4,5,7,8,9,11,12,13,14,15,16,17,18,19,20, 21,23,24
	Use of Resources	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,24
Product-service	Team work	7,8,10,11,12,13,14,15,17,19,20,21,22,23,24
	Practice soft skills	1,2,3,5,7,8,10,11,13,14,15,17,19,22,24
	Practice hard skills	1,2,3,5,6,7,8,9,10,11,13,14,15,17,18,19,20,22,24
Product-technology	Use and management	2,6,7,13,14,16,17,18,19,22
	Self-containment	2,3,5,7,14,15,8,18,21,22
	Type of equipment and application	3,4,5,7,11,13,14,15,17,18,19,20,21,22,24

Figure 10.2 Simplified model of the systemic influences on the transfer of medical equipment in humanitarian emergencies. References: Blackwell & Bosse, 2007 (18); Brennan & Waldman, 2006 (21); Chackungal et al., 2012 (22); Chen et al., 2010 (19); Chu, Stokes, Trelles, & Ford, 2011 (2); Dewo, Magetsari, Busscher, van Horn, & Verkerke, 2008 (16); Gautschi, Cadosch, Rajan, & Zellweger, 2008 (11); Ginzburg, O'Neill, W.W., Goldschmidt-Clermont, Mahoney & Reutershan, 1987 (1); Marchena, Pust, & Green, 2010 (20); Kaneda, 1994 (9); Kri et al., 2010 (3); Laverick et al., 2007 (24); Lennquist, 2007 (10); Lynch, 2010 (4); Martone, 2006 (23); McIntyre et al., 2011 (12); Owens et al., 2005 (7); Pascal, 2010 (13); Peleg, Reuveni, & Stein, 2002(5); Rahardjo, Wiroatmodjo, & Koeshartono, 2008 (15); Rajpura, Boutros, Khan, & Khan, 2010 (17); Redmond, O'Dempsey, & Taithe, 2011 (6); Rice et al., 2010 (14); Ryan, 2005 (8).

When transferred to an affected region (context y) during emergency relief, international organizations take up a diversity of related tasks, parallel to their use. These tasks include the transport and management of equipment, training and repair. The transferred equipment will face several barriers across the system levels, which represent a threat to the functioning and safety of the overall system.

Pulse oximetry

A pulse oximetry device (figure 10.3a: a device used for monitoring oxygen saturation, designated by the World Health Organization as a minimum requirement for surgery in emergency relief) needs to be packed and transported according to a determined logistical process (socio-technical y) and it might face delays and restrictions at customs (societal y). The dependency on disposable components (i.e. probes) and batteries (product-technology x) implies that these need to be inventoried and purchased. The lack of an inventory and purchasing system leads to their reuse. Often the probes will break faster and require repair that, for lack of tools or support, is replaced by a temporary fixing (product-technology y). Batteries will also require a charger and are often over-reused due to the lack of a disposal system (socio-technical y'). Even though several coping mechanisms are created to address these barriers, equipment tend to malfunction and disrupt the nurses' workflow (product-service y) (Santos et al., 2013).

X-Ray device

An x-ray device (figure 10.3b) is regularly required in natural disasters for victims of orthopaedic lesions caused by accidents, crushes or falls. After the initial needs assessment it is ordered, purchased and sent from Europe to the field where an international expert waits to provide training to local staff (product-service y). The device is held at harbour due to lack of communication and proper transportation means for the damaged roads caused by the natural disaster (socio-technical y) (societal y'). The military is asked to lend resources to transport the device from the harbour to the hospital location (socio-technical y). At arrival, the device requires special facilities to function (i.e. shielding), which are not yet in place (product-technology y). Documents of technical support (made by organization itself) are often made to cope with the lack of expertise to safely install the device (product-service y). Furthermore, this device requires specialized continuous maintenance and tools after donation (product-service y') (product-technology y').

a. b.

Figure 10.3 a. Pulse oximetry in use with temporary fixing (source: ALR Santos); b. Transport of x-ray device (source: Lizette van der Kamp)

10.4 Applying a socio-technical systems design orientation to humanitarian innovation: theoretical discussion

The systemic and complex nature of the problems related to the transfer of medical equipment in humanitarian emergencies justifies a broad approach to problem solving and design. These problems are what Ackoff calls "messes" (Ackoff, 1974) and require to be seen (by systems design) as a system of problems rather than independent parts of a "mess" (Banathy, 1996). Socio-technical systems design is appropriate to address these problems, because it advocates a multidisciplinary approach to address the different perspectives from stakeholders and promotes crossing boundaries of their activities: temporal, cultural, organizational and geographical (Carayon, 2006; Clegg, 2000). Furthermore, as humanitarian organizations look for ways to adapt to the emergent trends of the aid sector and become more competitive, they can benefit from a perspective of Socio-technical Systems design and aim to achieve an "organic structure" that is flexible and resilient to the respective complexity and uncertainty of change (Trist & Labour, 1981; Zink, 2014).

Different methods have been developed to operationalize (Socio-Technical) Systems design and scale design practice to a multilevel spread (mainly found in the fields of human computer interaction and systems engineering). Generalist methods include socio-technical systems design principles (Clegg, 2000), socio-technical systems engineering (Baxter & Sommerville, 2011), socio-technical method for designing work systems (P. E. Waterson, Gray, & Clegg, 2002) and the use of visualizations that map and guide systems-oriented design (Sevaldson, 2011). Existing methods applied to healthcare systems include contextual design (Beyer & Holtzblatt, 1999), human-centred design (ISO 9241-210:2010) and more specifically within system ergonomics tools such as the macro ergonomic

analysis and design tool (MEAD) (Kleiner, 2006), the systems engineering initiative for patient safety model (SEIPS) (Carayon et al., 2006), soft systems methodology (Checkland, 2000) and its adaptation of Shah & Alshawi (2010) for user requirements in medical device design.

This paper does not aim to discuss all prescriptive methods, but rather further define an orientation of socio-technical systems design in the humanitarian innovation context. Given that this paper focusses on the relationship between medical equipment manufacturers/designers and humanitarian organizations, the authors limited their scope to existing concepts that enhance that relationship. Two concepts are proposed as potentially complementary for the joint development of products and services from the perspective of humanitarian organizations.

Product-service systems (PSS): the industry perspective

Within the domain of systems design, product-service systems (PSS) is a business concept describing design as a combination of (intangible) services and (tangible) products/technologies to fulfil a determined societal need. PSS derives from business economics and offers a design framework with multiple tools for companies, manufacturers or suppliers of products to shift from product-oriented business models to models based on integrated technical and social interventions, where different ownership structures and use scenarios are considered (Keskin, Brezet, Börekçi, & Diehl, 2008; A. Tukker & Tischner, 2006). In a traditional business model, a manufacturing company sells a product (e.g. medical device) to a well-defined customer (e.g. hospital) who, besides using the product, is responsible for the services, such as maintenance, insurance, continuous supply of consumables, and disposal. However, the manufacturer of a medical device can also offer these services or create purchase alternatives (i.e. integrated solutions of products and services), making it not only easier (and even safer) for the hospital to install and use the product, but also reduce liability risks and strengthen the relationship with customers (e.g. through research and long term commitment). Companies benefit from product-service alternatives since they increase customer satisfaction (and safety) by offering solutions centred on the needs and capabilities of the customer or end user (Baines et al., 2007; Mont, 2002; Stahel, 1997; Tischner, Ryan, & Vezzoli, 2009).

The available methodologies for PSS development are not specific to the context of companies in the healthcare or humanitarian aid sectors. Even though several cases of PSS can be found in these sectors (Köbler, Fähling, Vattai, Leimeister, & Krcmar, 2009; Mittermeyer, Njuguna, & Alcock, 2011), formal descriptions of the development process is lacking and most described cases focus on the perspective of manufacturing companies

and not on other stakeholders within the PSS (such as governmental agencies or non-governmental organizations). In medical focused humanitarian relief interventions, humanitarian/international organizations are a fundamental actor in PSS since they play a role in distributing, servicing and re-engineering products without control from donor or manufacturing companies. This means that companies, as well as humanitarian organizations must be aligned with societal objectives in order to play a role in innovation for system change (Gaziulusoy, 2011b).

Human factors and ergonomics (HFE): the field perspective

The field of human factors and ergonomics (HFE) applies a systems approach focusing on the "understanding of interactions among humans and other system elements of a system" by developing and applying "theory, principles, data and methods to design (policies, processes and products) in order to optimize human well-being and overall system performance" (Carayon, 2007). In healthcare, as in other critical high risk industries, HFE methods and theory are used through improvement interventions in different system levels and strongly focus on improving users' well-being and overall system performance and safety (Rasmussen, 2000; Reason, 1997; Vincent, Moorthy, Sarker, Chang, & Darzi, 2004). These interventions range from the design of user-technology interfaces to managerial processes redesign (P. Clarkson et al., 2003; Institute of Medicine of the National Academies, 2013).

Similar to (socio-technical) systems design, HFE also argues for a system-aware approach when introducing a technology (new technology or technology transfer). System characteristics, such as multiple actors, multiple choices, multiple task handovers and no ownership, imply that the (re)introduction of a technology creates system wide changes that affect e.g. workflow, communication and personnel self-confidence (Ben-tzion Karsh & Holden, 2007; B-t Karsh, Holden, Alper, & Or, 2006). In technology transfer specifically, the systemic context factors of both provider and receiver of technology should be considered and evaluated in order for the transfer to be sustainable and successful (Shahnavaz, 2009).

HFE principles are a fundamental part of the systemic understanding of the context. HFE have also been applied to the design of medical equipment (Buckle, Clarkson, Coleman, Ward, & Anderson, 2006; Liljegren, Osvalder, & Dahlman, 2000; Ram, Grocott, & Weir, 2007; Rasoulifar, Thomann, Caelen, & Villeneuve, 2007; Shah & Alshawi, 2010). The knowledge generated by HFE methods, serve as input for a user-centred design process of medical equipment, "reducing, as far as possible, the risk of use error due to the ergonomic features of the device and the environment in which the device is intended to be used (design for patient safety), and considering the technical knowledge, experience, education and training and where applicable the medical and physical conditions of intended users (design for lay, professional, disabled or other users)" (EEC, 2007, p. 1).

HFE have been used to successfully help companies design more user-friendly products (and generating knowledge) about the use context, increasing their safety and performance (Edwards, 2000; Martin, Clark, Morgan, Crowe, & Murphy, 2012). In relation to the Multilevel Design model, the HFE approach to design medical equipment is mostly used with consideration for the product-service and product-technology levels since it generally focuses on adjusting product attributes to a determined environment, rather than taking more system levels into account (Edwards & Intelliject, 2000; Martin et al., 2012). Most of the knowledge used in the design process is strongly focused on user requirements and technology-user interface, or microergonomics, whereas macroergonomics (the knowledge about how technology implementation affects organizational and human issues) have not been fully explored (Carayon, 2003; Liem & Brangier, 2012). This means that, likewise the PSS concept, companies from the healthcare sector have not adopted knowledge from HFE to develop their business models. These healthcare companies often do not consider the way equipment is acquired (purchased or leased), serviced and monitored throughout its lifecycle, which can also have implications, though more indirect, to patients and practitioners well-being and safety (Mittermeyer et al., 2011).

A new perspective for humanitarian innovation

Regarding the concept of systems design, HFE have been acknowledged with the potential to be a relevant contribution to the development of PSS as solutions for complex societal problems, such as environmental sustainability or global health (Dul et al., 2012; Engestrom, 2000; Sevaldson & Vavik, 2010; Zink, 2014). The combination of systems thinking and HFE supports designers in handling a larger degree of complexity and to think more steps ahead in a systems design project (Sevaldson & Vavik, 2010). This allows designers to make a more sustainable change by considering a long-term timeframe for requirements, involving stakeholders from the whole value chain and considering "efficiency" in terms of dynamic metrics, such as learning and innovation (Zink, 2014). According to Liem & Oritsland (2006) the user-centred nature of HFE can provide added value to the PSS concept in defining the overarching design problem and scenarios at macro level. The alignment of objectives between PSS and macroergonomics, both focused on overall system performance rather than on traditional incremental improvements, is key for the development of innovative solutions at the functional level of a socio-technical system and for the creation of concrete strategies involving user-centred services and products. Dul & Neumann (2007) state that "ergonomics can contribute to an organization's strategic goals beyond an exclusively health and safety focus. Achieving this may require the ergonomists to take on new roles and to see ergonomics as a means to support organizational development rather than an end in itself" (Dul & Neumann, 2007, p. 1).

HFE and PSS could be combined to support humanitarian innovation, by enhancing the role of organizations as a change actor in systems design, to explore ways to redesign their system, optimize their use of resources and become more competitive and transparent in the way they use medical equipment and how they service the beneficiary of aid. Furthermore, using HFE and PSS could also enable organizations to generate demand driven ideas that can shape their engagement with companies. As an example, in the traditional approach, an affordable and robust pulse oximetry device for Haiti aims to promote rapid access to healthcare by rethinking physical attributes, such as materials and energy sources, which often create barriers. These new physical attributes will ultimately face challenges in the overall system. A socio-technical design approach aims to rethink the use of local resources and the cost structures to formulate a strategic combination of services (alternative distribution channels) and products (universal probes and repair tools) for transitional adoption of the device.

Table 10.1 summarizes the application of a socio-technical systems design orientation to humanitarian innovation and highlights the main contribution and overlap of the proposed concepts PSS and HFE.

Table 10.1 Proposed characteristics for a socio-technical systems design orientation to humanitarian innovation

Awareness of purpose
- Organizations are open systems, aware of the external context (societal framing) of other (national and international) organizations' work, where economies and trends develop that ultimately affect them. Societal framing can be, in this case and amongst others, global healthcare, disaster preparedness, economic growth, empowering information technologies or environmental sustainability. - Organizations understand that the alignment of their goals/strategies within and with other organizations is necessary to achieve a certain system property (e.g. efficiency, sustainability). - Organizations use participatory ergonomics to align own goals with societal goals (Gaziulusoy, 2011b).
Socio-technical complexity
- Organizations are part of the innovation socio-technical system (Clegg, 2000) and as such, they are central change actors in socio-technical systems (prioritizing performance as opposed to prioritizing profit in companies) (Dul et al., 2012; Engestrom, 2000; Liem & Oritsland, 2006). - Organizations understand their systemic construction, recognize system levels, their social and technical dimensions and recognize how these dimensions shape the organization (J.R. Wilson, 2000).
People centred
- Organizations are driven to achieve sustainability through addressing the usability and safety needs of the user group, including the field staff but also the healthcare beneficiary (J. Clarkson, 2009; P. Clarkson et al., 2003).

- Organizations recognize existing coping mechanisms as active ways people adapt to- and change the system and its external environment.
- Organizations can opt to use a range of knowledge applications: from preventive to corrective nature and from micro to macro level (Carayon, 2006; Robert & Brangier, 2009)

Stakeholder (system) engagement/ Context aware

- Organizations actively initiate partnerships (with stakeholders from technology transfer value chain) as a way to build project boundaries and line up stakeholders towards a shared goal.
- These partnerships increase system redundancy and distribute complexity by including international and national organizations, governments, international agencies' programs, motivated individuals, designers and companies that can play new and meaningful roles in achieving a shared goal.
- Organizations are aware of context changes and the effect of those changes in their activities.
- Organizations use validated knowledge and analysis tools specific for the healthcare system structure (i.e. the use of participatory techniques and specific organization models to structure inquiry), (Carayon et al., 2006; P. Clarkson et al., 2003; Mittermeyer et al., 2011; P. Waterson, 2009).
- Close cooperation with designers and organizations helps to reduce the knowledge gap between designer and experts and can build a strong organizational knowledge base.

Long-term perspective

- Organizations think in the long-term and use principles of stakeholder networks, product lifecycle and resource optimization, from disaster response to preparedness/prevention (context x, y, y'), from supply to disposal (Manzini & Vezzoli, 2002; Arnold Tukker & Tischner, 2006; Zink, 2014)
- Organizations see innovation as a constant (integrative and iterative) learning process of (re) design, implementation and monitoring of system changes (Carayon, 2007; Engestrom, 2000; Sevaldson, 2009; Zink, 2014). This implies that universities or other partners must engage in long-term research programs and not just partner up for punctual problem solving.
- Close cooperation with all stakeholders in the value-chain, including the beneficiary of aid, on a long-term basis, increases accountability and decreases liability.

Whole-system ecology

- Organizations recognize that medical devices, due to their dependency on sub-systems, are transferred as carriers of needs and therefore, actively address issues of technology transfer as an "ecosystem of issues".
- Organizations use business logic to support effectiveness, market demand, sustainability and optimization (through innovating business models) (Ceschin, 2012; Gaziulusoy, 2011b; Mays, Racadio, & Gugerty, 2012).
- Organizations focus on seeking opportunities for joint product and service design in organizational issues for the whole systems performance improvement (e.g. training programs, leasing distribution) and are not limited to support traditional incremental redesign of medical devices (Carayon, 2003; Hendrick, 2005; Liem & Brangier, 2012; Manzini & Vezzoli, 2002; Mont, 2002; A. Tukker & Tischner, 2006).

Some of the expected barriers to the adoption of the characteristics of socio-technical systems design as described in table 10.1 include the lack of experience and knowledge about innovation and innovation management, the lack of support for activities and evaluation from donors, lack of time and allocation of experts and lack of alignment of top and bottom levels within the organizations' hierarchy (Nielsen & Santos, 2013). Furthermore, the design of combined products and services is mostly oriented towards companies, whereas in the context of humanitarian aid, the role of international and national organizations is central. The differences between these sectors, such as profit orientation, competition and humanitarian principles might present challenges for the application of this approach.

Finally, it is important to reflect on the role of the "humanitarian" designer. Few academic programs offer a specialized design education to address complex, societal challenges. Besides that, the system orientation of design is not guaranteed and for that, designers have been criticized (Nussbaum, 2010; Tischner, 2006). The socio-technical systems design principles proposed in this paper represent a possible knowledge contribution to equip designers with notions about their practice in a broad context. Nonetheless, and in particular with regard to developing countries, field experience is as fundamental as it is a challenge. Designers must develop skills of diplomatic facilitators of organizational change, identifying leverage contributions, but also skills of knowledge management, research and testing in such particular environments. The "humanitarian" designer, either within organizations or within the medical innovation sector must strive to broaden the scope of his/her practice and be given the freedom to engage and demonstrate through practice.

In conclusion, this study indicated the need for a systems design orientation to humanitarian innovation, geared towards the transfer of medical equipment, which considers not only use issues regarding the interaction of users and medical equipment, but also organizational issues. The concepts of product-service-systems and human factors and ergonomics have been proposed as complementary, dedicated to the development of integrated solutions of products and services to address the barriers of technology transfer during humanitarian crises. A set of characteristics of a systems design orientation to humanitarian innovation have been proposed and will be further elaborated and tested with the purpose of exploring, together with humanitarian organizations, an agenda for humanitarian innovation in healthcare and to identify after using this approach the implications for medical equipment design.

Given that the relationship between international humanitarian organizations, industry and academia become increasingly connected there are opportunities to explore the potential contribution of systems design to perform better and safer aid.

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SAFETY OF MEDICAL EQUIPMENT USE IN LOW-RESOURCE SETTINGS

11 Medical emergency dynamics in disaster-prone regions: implications for medical device design [publication 3]

This chapter was published as: Santos, A.L.R., Wauben, L.S.G.L., Dewo, P., Goossens, R. and Brezet, H. (2013). "Medical emergency dynamics in disaster-prone countries: implications for medical device design". Int. J. Human Factors and Ergonomics. 2(2/3), pp. 87–115.

Abstract

Emergency medical services and surgery are an essential part of the local response to natural and humanitarian disasters. The aim of this study is to identify performance obstacles regarding the use of medical devices in medical emergencies. The case study, conducted in the Dr Sardjito General Hospital in Indonesia, entails semi-structured interviews with surgeons from the Orthopaedics and Traumatology department, as well as exploratory observations in the emergency and operating rooms. A literature-based reporting tool, observable performance obstacles (OPO), was designed and tested. The results demonstrate that data collection through observation yields rich insights that are relevant to the literature on human factors, and to the applied field of user-centred design. This experience also reveals the inherent difficulty of doing research in the dynamic setting of medical emergencies. As a result, several changes to the OPO are proposed for its application in follow-up projects.

11.1 Introduction

Natural and humanitarian disasters are increasingly making societies across the globe aware of their vulnerability in coping with the impact of these hazards or with the recovery that follows. Exposure to such hazards has consequences at a global scale, from sudden natural catastrophes that hinder technical and social development and long-term droughts that affect lives of entire populations to humanitarian crises derived from conflict and epidemics. Catastrophic emergencies of lesser magnitude (e.g. volcano eruptions, earthquakes and accidents involving traffic or industry) occur constantly, harming citizens and destroying infrastructure (Joint UNEP/OCHA Environment Unit, 2009) (United Nations, 2009).

Many low and medium income countries are located in areas that are geographically prone to climate and geological events. Such events tend to cause a greater amount of damage in these countries than they do in other locations. About 95% of disaster-related deaths occur in developing countries (Joint UNEP/OCHA Environment Unit, 2009). Social and structural vulnerabilities (e.g. poverty and political instability) are predominantly responsible for the amplitude of required international aid in disaster response.

The experience of international organizations with large-scale disasters – such as those occurring in Indonesia (2004,-06,-09), Pakistan (2005) or Haiti (2010) – are relatively new (Magone et al., 2011). The response to these disasters is destined to strengthen local response systems, and it involves extensive intervention and cooperation between international and national organizations, governments and volunteers for periods ranging from one month to several years. Depending on each case, assistance is given in different fields: from essential goods such as food and water, to shelter and healthcare. The organizational and physical infrastructure of local healthcare services is greatly affected by disasters, given their role in assisting the affected populations. Although the context of medical response to major emergencies (national or international) has been poorly explored, such studies are necessary in order to improve the efficiency, safety and equitability of the response.

Natural disasters or large-scale traffic accidents often result in many injuries (of various levels of severity) that require immediate intervention from the Emergency medical services (EMS) (Chackungal et al., 2012; Kobusingye et al., 2006). In such situations, the EMS must cooperate and coordinate their actions with several other national and international entities, intervening rapidly to save as many lives as possible, while keeping the overloaded services running (Gautschi et al., 2008; Ryan, 2005). The response to medical emergencies (i.e acute events) is similar to the response to disasters, in that they both call for fast, efficient action and coordination amongst many different organizations, they both involve urgent or lifesaving interventions and the necessity of working with scarce information.

They differ in terms of nature and magnitude, as well as in terms of organizational complexity, the frequency and dispersion of events and the availability of resources with which to operate (Quarantelli, 1987). Furthermore, efficient response is often impeded in low and medium income countries, due to several reasons. Barriers include the large distances between cities and rural areas, the large proportion of people lacking the resources to afford hospital healthcare (many of whom are in weak health condition) and disparities in the quality of healthcare provision. The effectiveness of response to natural disasters largely depends upon the experience of the local response systems (Rahardjo et al., 2008). This underlines the importance of strengthening EMS and surgical care services in low and medium income countries (Kobusingye et al., 2006; Luboga et al., 2009).

Indonesia is one example of a country that is frequently confronted with the problems related to natural disasters, as well as to traffic injuries and other events of lesser magnitude (Dewo et al., 2008). The intensification of traffic has generated a tremendous increase in severe road traffic accidents. Such events account for approximately a quarter of all injury-related deaths, and they are estimated to become the fifth leading cause of death in the next fifteen years (Friesen, 2012; World Health Organization, 2009).

Medical devices in disaster and emergency response

Little is known with regard to the conditions under which medical devices that are deployed and used for emergencies must function. Most medical devices, particularly those used for surgery and anaesthesia, are designed for use within controlled environments. In global practice, however, they are used in many different contexts, including poorly controlled and resourced environments (World Health Organization, 2010). In the case of natural disasters, EMS must often operate in settings in which the infrastructure is often damaged and in which the high number of wounded patients can overload the normal operations of existing services. The extreme character of the work performed in disaster settings is characterized by less time to operate, diversity of urgent patients (e.g. children and adults), reduced workforce and poor condition of local equipment. The devices available on the market are thus unsafe and ineffective, due to various factors, including their vulnerability to and inappropriateness for use in austere conditions and the unreliability of sources of power and water (Giannou and Baldan, 2009; Owens et al., 2005; Rice et al., 2010). The need for multi-agency collaboration, also contribute to the unfamiliarity of practitioners with particular locations, practices and devices. The need to deploy different types of medical devices also implies several challenges related to transport limitations, as well as with regard to the logistical complexity of setting up a safe, clean and complete environment within which to operate. Furthermore, international organizations (e.g. Médecins Sans Frontières, Merlin[1] and the International Federation of the Red Cross) that deploy medical devices usually donate them after an intervention. Although the donation process depends upon punctual agreements with local governments or organizations, such agreements do not guarantee the sustainable functioning of the devices. All of these factors have implications for the performance and usability of the medical devices, and they can have negative consequences for the delivery of medical care.

Research aim

The aim of this case study is to investigate the dynamics of emergency surgical settings in natural disasters by gaining insight into the current delivery of EMS in the disaster-prone region of Yogyakarta (Indonesia). This study identifies technology-related performance obstacles (factors related to the work structure of healthcare practitioners that disturb the execution of particular activities or tasks) and their implications for the safety of healthcare practice. The findings of the study are translated into a set of recommendations that reflect the potential role of medical device design and human factors in the context of medical emergency contexts.

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[1] Since July 2013, Merlin is part of the organization Save the Children.

11.2 Medical devices for emergency and disaster response

The concepts of patient safety and quality of care refer to healthcare provision, based on the work-system approach applied by other high-risk industries (Carayon et al., 2006). In this approach, processes and their environment are seen as parts of an interrelated construction in which interactions between elements result in specific outcomes, either positive or negative. Human factors and ergonomics (and the underlying systems approach) make it possible to analyse these systems. This field has an established presence in patient safety, and it plays an important role in supporting the understanding of various levels of error, organizational learning and the design (and re-design) of technology and processes with the goal of improving healthcare outcomes (Carayon, 2003; Tucker and Edmondson, 2003; Waterson, 2009).

The design of medical devices is increasingly performed through a process of user or human-centred design (Martin et al., 2008; Shah and Alshawi, 2010). These terms are applied broadly to refer to the overall design process, focusing on human-product interaction and involving a variety of methodologies to support the development of products – from the initial idea to the final product/service – that correspond to the specific needs, wishes, characteristics and abilities of their users and respective contexts (Vredenburg et al., 2001). The various methodologies that are available, most of which are based on human factors, support a variety of goals and stages of the design process, and they are aimed at improving the safety of healthcare delivery. The entire process includes such activities as assessing the usability of prototypes or the testing and evaluation of the performance of medical devices with medical experts, the elicitation of requirements and co-design (MDD 93/42/EEC, Clarkson et al., 2003). In contrast to product engineering, the process of design usually addresses problems from their origin,instead of focusing solely on redesign. Devices, services and environments for healthcare based on the principles of human factors reduce the possibility of accidents and errors (Buckle et al., 2006; Clarkson et al., 2003).

The initial phase of any design process involves gaining in-depth understanding of the problem within its context. This phase requires the collection of knowledge from diverse and often dispersed sources of information. Knowledge collection can be supported by several methods, and it often results in large and unsystematic amounts of information that must be translated into an appropriate design assignment and requirements (Martin et al., 2006; Roozemburg and Eekels, 1995). After a list of requirements has been made, designers use creative problem-solving skills to manage all of the available information, making choices that will affect the ultimate form of the product (Cross, 2011).

Gathering this information systematically is fundamental to forming an effective knowledge base that can be recalled during many phases of the design process, thus assuring increased effectiveness in decisions and solutions. Although this approach is relatively new, it is relevant to medical contexts (Buckle et al., 2006).

Challenges for research and medical design

The relationship between medical devices and their users is particularly relevant, given that most of the tasks that a device mediates involve the life of a human being, whether directly or indirectly. Particularly in hospitals, the increasing complexity of the technological landscape clearly reveals the need to design compatible interfaces and to consider spatial integration with other devices and the various uses that may be assigned to a device over time (Wauben, 2010). The characteristics of this field of design make it particularly challenging. First, the designer has no experience as a user of most medical devices, thus creating a knowledge gap between the user and the designer,which can make communication difficult (Nielsen, 2008). Second, the users of medical devices are conservative users, in the sense that they must be familiar with devices in order to work with them safely (Rasoulifar et al., 2007). Third, the industry is reluctant to embrace radical innovations, due to the complex, costly and lengthy processes associated with safety regulations. Finally, the presence of a researcher in the medical environment usually requires specific official permits and ethics documentation.

Medical emergencies also represent a challenge for medical device designers and their methodologies. They must consider uncertainty, dynamic interactions and other characteristics involving changing contextual settings and a diversity of practices and users (in terms of number, experience and cultural background). Furthermore, the restricted and unpredictable access to disaster settings and the need to communicate with a diversity of experts pose additional complications to research in the field. The dynamics of disaster response have been investigated by studying the practice of emergency medical services (Kristensen et al., 2006).

A theoretical approach to identifying performance obstacles in medical emergencies

In order to gain in-depth insight into the interactions of medical devices with the surrounding context in emergency response, the system engineering initiative for patient safety (SEIPS) model of work systems, as described in Carayon et al. (2006), was used as theoretical background for the investigation (figure 11.1). The SEIPS model describes how elements of the work structure, which are given as input to specific processes, result

in patient and organizational outcomes that affect the functioning of the initial work structure. Compared to other descriptive models of the systems approach in the medical context (Bogner, 1994; Vincent et al, 2004; Reason, 1990), the SEIPS model also includes interactions between elements of the work structure, acknowledging that the diversity of interactions is relevant to the redesign of the system (or a part thereof). The SEIPS model provides, facilitates and structures the data collection. The five input elements of the work structure (task, person, technology, organization and environment), the various processes and the potential outcomes can be used to guide the systematic identification and characterizations of interactions within a dynamic setting, which are relevant for designers when translated into design requirements. Additionally, given the difficulty of accessing the field in disaster-response contexts, systematic data collection can provide a base for inquiries and communication with healthcare practitioners (HCP), thus yielding a sound structure for requirements.

In parallel, the input-transformation-output model (Karsh et al., 2006) focuses specifically on the ways in which work-structure interactions affect the performance of HCP. This model specifies and categorizes all components of the SEIPS model: the input, processes and outcomes. Inputs consist of specific interactions of work-structure elements such as physical layout or task demands. Processes consist of the various types of activities such as carrying, perceiving and communicating. Finally, outputs consist of short-term or long-term changes in the physical or mental state of the HCP. These changes ultimately affect the overall sequence and quality of the activities performed (feedback loop).

The "observable performance obstacles" (OPO) tool

The large quantity and diversity that can be expected of information derived from field research justifies the development of a paper-based tool. This tool, "observable performance obstacles" (OPO) (figure 11.2), aims to systematize the data-collection process, to facilitate communication with the users and, later, to translate performance obstacles into design requirements. This tool uses the SEIPS model as a theoretical foundation. It also adapts the input-transformation-output model by categorizing interactions, with a specific focus on interactions related to medical devices (within the work-system elements) and the ways in which they affect the performance of individuals during the process of care.

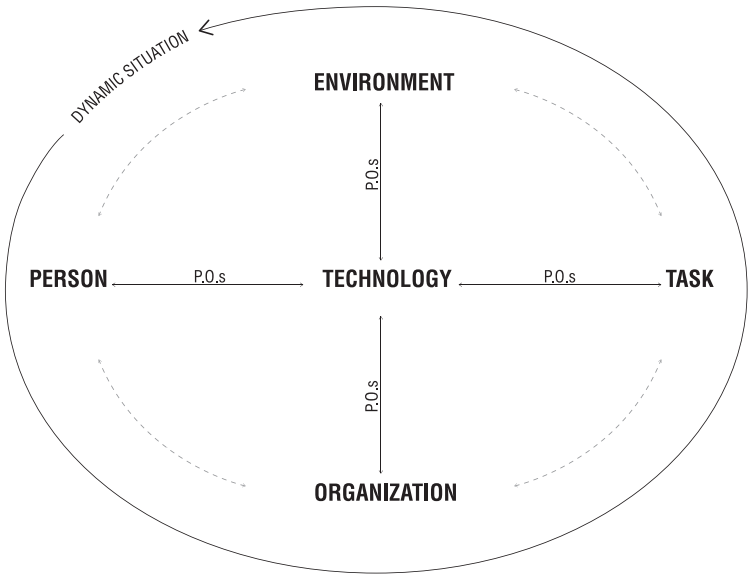

Figure 11.1 Performance obstacles (P.O.s) in the work structure (adapted from Carayon et al.[2006])

The structure of the OPO tool is composed of two headings (figure 11.2). The first heading categorizes interactions of medical devices (technology) with the rest of the work-structure elements (user, task, environment and organization). Device characteristics are also included under the first heading, as performance obstacles might be solely attributable to features or properties of these devices. The second heading sub-categorizes each of the previous listings into types of interaction. The types of interaction were determined based on the previous experiences of the authors, as well as on related literature (Amoore and Ingram, 2002; Buzink et al., 2010; Gurses and Carayon, 2009; Manser and Wehner, 2002; Tucker and Edmonson, 2003). The OPO tool is used as a checklist in which the observer can introduce the time or number of times that an event occurs for each patient.

The proposed structure is expected to facilitate the identification of interactions (thus reducing the amount of time required for such identification) by using categories to reduce interpretation bias, while allowing the introduction of new input. By considering processes and all work-structure elements, this structure leads the observer to look for underlying issues within the dynamic environment. The OPO tool is also complementary to other reporting tools that address the work systems by highlighting the use dynamics of medical devices. The translation from observations to design requirements is also facilitated, as the information that has been gathered is categorized according to features that are 1) related to the needs and capabilities of users and 2) amenable to change by designers. Furthermore, it focuses the design of devices on the activities for which they are used, instead of on their isolated functions. The authors expected this tool to enhance their study, given the

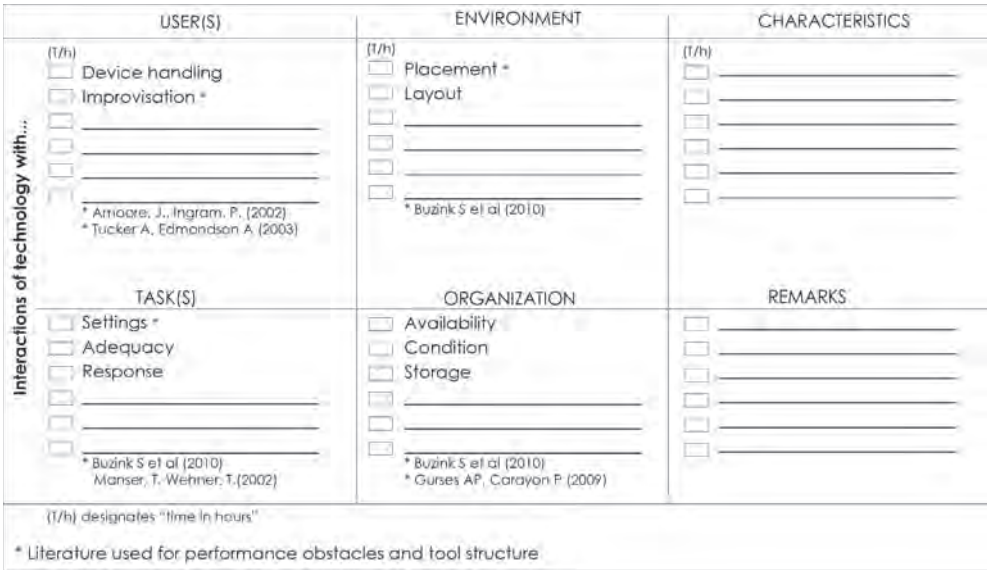

Figure 11.2 Observable performance obstacles (OPO) tool

particular importance of categorizing problematic interactions in poorly resourced settings in which the work systems are particularly deficient. Moreover, the OPO tool provides a clear and effective way of communicating with HCP, who are often subject to a culture of blame within their work settings.

11.3 Methods

This case study was conducted in the Dr. Sardjito General Hospital (DSGH) in the province and city of Yogyakarta, Indonesia. This academic referral hospital is affiliated with Gadjah Mada University. The hospital has experience with disaster response, particularly with regard to the Indian Ocean Tsunami (2004), two large-magnitude earthquakes (2006; 2009) and the most recent eruption of the Merapi volcano (2012). In addition, this hospital receives 15-20 emergency cases each day, 5-10 of which involve orthopaedics and trauma. Traffic accidents form the most prominent cause of emergencies, with extremity fractures constituting the most frequent orthopaedic cases within this category.

Emergency response in DSGH, Yogyakarta: The context of the case study

Emergency cases have several characteristics that distinguish them from elective surgical cases. Emergency shifts are covered by approximately three to four surgical residents from

each of the eight surgical disciplines in DSGH (Oncological, Orthopaedic and Traumatology, Vascular, Burn/plastic, General, Neurology/cervical, Paediatric and Digestive).

Emergency patients are more unpredictable and diverse, often involving multi-disciplinary teamwork (e.g. pregnancy complications and chest trauma). Patients requiring emergency care are usually in an unstable condition, more difficult to diagnose (e.g. hypertension or diabetes) and possibly more prone to contamination given the variety of their injuries or the fragility of their condition). Additionally they might arrive by ambulance, private or public transportation, possibly accompanied by their families. Such patients might have been referred to the general hospital by a district hospital, whether on day of the accident or later.

In case of traffic accidents, bystanders often help injured patients in their vehicle without using proper immobilization techniques (thus causing possible co-morbidities). Patients enter through the emergency room, where they are classified according to priority level. In the event of a large accident involving a high number of victims, the classification process (i.e. triage) can become stressful if there is insufficient response capacity for observing, immobilizing and communicating. In the case of trauma, patients are brought to the resuscitation room for immediate observation, stabilization, blood testing, proper immobilization and, possibly, minor interventions (e.g. sutures, debridement). Patients in need of imaging exams are transported to the radiology department. This is a critical action, as patients are often too weak and require constant fluid resuscitation or oxygen. The distance between the two rooms and the time needed for transportation can threaten the survival of the patient. After the imaging exams, patients are transported to the emergency operating room (OR) for surgery or to the intermediate care room, where they remain under observation for a period of approximately 24 hours. Patients requiring surgical intervention (e.g. polytrauma involving multiple affected structures, dislocation or open fractures) are transported to one of the three emergency ORs (in a location other than that of the elective OR). The operations on these patients must be performed within the "golden hour", thus implying greater risk, as any obstacle could pose a serious threat to the patient.

The hospital is partially dependent upon the donation of medical devices. In order to purchase a new medical device, the hospital must submit an official request to the Ministry of Health where it will be reviewed and evaluated. This process is often time-consuming and inefficient.

Research design

This study was performed over a period of ten days, involving observations in the context of medical emergencies and retrospective interviews with the department of Orthopaedics

and Trauma. The residents in charge of the emergency room and OR were continuously shadowed in their activities, during both day and night shifts.

The methods selected for this study – explorative observations and semi-structured interviews – are a part of the contextual inquiry method (Beyer and Holtzblatt, 1999), and both were supported by the OPO tool. Similar to the critical incident technique (Flanagan, 2003) and the SEIPS model, Contextual inquiry acknowledges the dynamic interactions that take place within human practices, and it describes how to generate work schemes from user/context shadowing. Contextual inquiry is a methodology of data collection that is specifically adapted from ethnography for the field of engineering. It is suitable for informing the design of products that meet the needs of users within their particular work contexts. Because the information yielded by this technique is very rich, however, it is likely to generate an excessive number of outputs and maps that are difficult for users to understand and discuss (Kuniavsky, 2003; Martin et al., 2008).

The observational method offers a way to gain in-depth insight into the "real" context of work. It is commonly used for conducting investigations in the medical field, and it has been applied in order to identify problems related to the use of medical devices. As mentioned, however, this method could be impeded by the uncertainty, diversity and dynamic characteristics of settings such as emergency departments or intensive care units (Carthey, 2003; Martin et al., 2008). To compensate for these potential effects, additional methods such as interviews, focus groups and task analysis can be combined with observations. These can also be adapted for application in macro-ergonomic contexts (Shah and Alshawi, 2010). In this study, the observations were supported with photographic recordings. The observations focused exclusively on interactions of medical devices with other work-structure elements that were directly observable (e.g. the equipment falls or the user is injured). Organizational influences in the environment (e.g. deteriorated infrastructure), interactions between the environment and people (e.g. sound, light, humidity, temperature) and similar factors that are not directly observable were excluded. The observations started with the entrance of a patient into the resuscitation room until the patient left for the OR. The following points of attention were included in the observations: floor use, patient itinerary, different users and different devices (oxygen and fluid, anaesthesia, electrocautery).

Qualitative semi-structured interviews and informal conversations about disaster response were held during the same period. The surgical residents were asked to reflect retrospectively on their experiences with similar events in disaster settings, and notes were taken during these sessions. In parallel, experts in maintenance and disaster management were also involved in these reflections.

Human ethics approval was not requested, given that the observations focused exclusively on the use of devices in the emergency room and OR. For this reason, no information

or recordings involving patients were collected, thus allowing their identities to remain anonymous at all times during the study. Nevertheless, all of the HCP involved were asked in advance for permission to inquire and observe, and the study was conducted with the formal consent of the hospital's director and the head of the Orthopaedics and Traumatology department.

Data analysis

Data analysis consisted of elaborating the categorization of the performance obstacles identified in the observation logs, interview notes and photographic recordings. First, the observation logs and the interviews were transcribed and later reviewed individually by the first two authors. Each author coded the transcriptions based on the categories specified in the OPO tool. In order to organize and divide the findings into subcategories, an affinity diagram was used (Beyer and Holtzblatt, 1999). This tool is often used to process observation notes, as well as for grouping and labelling them in hierarchical levels. The sub-types of interaction were therefore added to the initial OPO structure. In case of diverging opinions, the definition of each category was reviewed, and the options were discussed until consensus was reached. Photographic recordings were coded according to the same principle. All tables were reviewed and approved by the representatives of the Orthopaedics and Traumatology department.

11.4 Results

The results revealed several performance obstacles (PO) that contribute to the structured identification of technology-related problems and the understanding of the working conditions in medical emergencies. Five emergency cases and two emergency surgeries were followed (approx. 12 hours, for a total of approx. 80 hours). Three to four surgical residents (4th year) were continuously shadowed during their shifts, including two night shifts, and five interviews were conducted. The interviewed experts include two surgical residents, one expert orthopaedic surgeon, a maintenance expert and a disaster management expert.

The data collected in this exploratory research were converted into the findings presented in appendix P3, p.165. In this table, the categories of observed PO are described and exemplified, their percentages quantified and the issues common to disaster response identified with an asterisk. In all, 142 interactions were derived from the data that had been collected and coded. Each interaction was assigned to only one category, the one considered most directly related to the actions of the HCP involved. The interactions were divided into a total of 11 categories and 22 subcategories.

Most of the PO observed were related to characteristics of the task (30%) or of the environment (34%). Only 5% of the total were related to specific properties of medical devices. With regard to user characteristics (16.9%), while static physical ergonomics accounted for about 4% of the identified PO, 12% reflected the manner in which the HCP actively integrated problem-solving into their daily work. PO related to the managerial and logistical settings are usually indirectly related to a designer's intervention, accounting for about 15% of all PO. In general, these PO stemmed from 1) donation processes, implying that medical devices with an indeterminate lifetime were in constant use and resulting in an undifferentiated number of models, 2) logistical organization or 3) poor maintenance.

> The emergency OR has less equipment. This changes our methods. (Chief Surgical Resident).

The main differences between the emergency OR and the elective OR were related to the state of the equipment and its availability. The conditions in the emergency OR were the result of poorer management of resources (e.g. not all lamps in the emergency OR were functioning, and only two of the three anaesthesia machines were operational). Poor resource management and maintenance were both reported as reasons for improvisation.

> You don't repair a broken screen on an ultrasound machine, you adapt a normal screen to it (maintenance expert at DSGH).

Maintenance is frequently hindered by the careless use of devices, as well as by improper storage and a lack of tools, software or maintenance staff. Repair is hindered by the difficulty associated with establishing contact with suppliers and the lack of technical follow-up, as well as by the unavailability or incompatibility of supplies and by cost. Finally, about 50% of the identified PO applied to disaster response as well, often on a larger scale and predominantly related to reduced space and fewer resources.

After the findings had been categorized, recommendations were added to the results table. These new rows translate each categorized PO into actionable improvements and priorities for medical device-design requirements. The proposed recommendations provide examples of how the OPO tool can be used to facilitate a more comprehensive identification of relevant priorities for medical device requirements. The recommendations are discussed in the next chapter.

11.5 Discussion

The analysis of the entries made during the observations and interviews led to the extension and sub-categorization of the OPO categories. The sub-categories, which were created with

the affinity diagram tool, should not be included in the layout of the OPO tool, as the extension of the list would impair the legibility of the OPO. When used for analytic guidance, however, the sub-categories can help to explain in detail how the problematic interactions are related to device characteristics, which can be changed through design. The use of the OPO tool in the contextual inquiry approach was useful for structuring the observations and, particularly, in the interpretation of the study results and in communications with the experts who were consulted. The findings both enhance and reduce the complexity of using the systems approach to study work contexts.

Main findings and recommendations for the design of medical devices

The main findings show that most of the PO were related to interactions of medical devices with tasks and the environment. This finding has several implications for medical device design, and it reveals a gap in the consideration of dynamics in medical device design. The OPO tool allowed the identification and further categorization of problematic and highly specific interactions according to their effects on the practice of HCP.

Dynamic tasks and environment

Task related PO accounted for about 30% of all PO observed, thus clearly indicating that devices should be designed with regard to the dynamic character of emergency response, for several reasons. Tasks are composed of operations that require different adjustment of settings. Therefore some adjustments are made more frequently than others. Moreover, these tasks require different devices or consumables, which must be predefined and readily available. Addressing these obstacles requires improvements in both design and organizational effort. In 13% of the cases, PO were related to unaddressed dynamics (e.g. multiple users and different activity densities), which led to an unpredictable disposition of devices in space, as well as to task delays. The organization of tools in direct relation to their activity is known as "taskonomy" (Norman, 2005). Product systems designed to be organized when stored are "ill suited for the direct support of an activity", and they could potentially lead to discomfort of the HCP, and to time-consuming, non-hygienic and dangerous improvisations.

Environment related PO accounted for a larger share (34.5%). Activities in emergency response extend to a variety of locations, involving rooms of varying size, setup and supply. Both devices and people change position as the activity develops, according to the needs of the task, its urgency and the involvement of additional HCP. This leads to changes in the positioning of devices, thus resulting in stacking or the impractical occupation of floor space. Cables that connect devices to the wall or to the patient are also a common problem in the medical environment (Berguer, 1999), and they contribute heavily to obstacles,

potentially leading to the most dangerous consequences. Devices are used with no regard to ergonomic guidelines, thus suggesting that other devices, layout, infrastructure and similar issues play an important role, independent of the quality of device design.

In order to address these issues some recommendations were made, highlighting important factors to have in account when eliciting requirements for medical device design. With regard to the interactions between HCP(s) and device(s), and to assure sufficient flexibility to the different types of tasks (i.e. varying speed and intensity), devices should allow for a comfortable and versatile displacement of consumables and posture of HCP. The design of product-systems should facilitate a functional organization of consumables and devices and anticipate unsafe actions from the HCP by avoiding features that are too specific or require additional attention from the HCP. Similarly to the HCP-device dynamics, also the changes around this interaction should be considered. Devices should facilitate an easy and safe disposition in space by improving shape and volume, by reducing cable dependency, and by replacing certain functions by making use of equipment to module or complement devices (e.g. portable function replaced by mounting device on trolley). Furthermore, devices can circumvent the hygienic threats implicit in the displacement of devices between different environments, by the selection of appropriate materials and maintenance-friendly designs.

Using these recommendations requires a design approach. Bijl-Brouwer and v/d Voort (2009) presented an overview of solution principles currently used by designers of consumer products to address dynamic usability (one size fits all, accessories, adjustable features, adaptive features, segmentation, make use irrelevant). In the future medical device development can benefit from these strategies and tools such as use scenarios to translate the recommendations collected with OPO into more context adequate medical devices.

Maintenance and improvisation

The need to improvise in these settings adds to the findings of Tucker and Edmondson (2003) with regard to organizational learning. Their findings reflect similar behaviour from hospital care nurses. Tucker and Edmondson define two types of problem-solving behaviour. In the first-order approach, the HCP solves a problem superficially by compensating for necessary resources in order to finish a disrupted task (this does not reduce the likelihood that the problem will happen again). In the second-order approach, the HCP communicates and shares ideas about the problem, thus raising awareness within the organization.

As a form of problem-solving, improvisation differs from the previous approaches. When faced with a problem (e.g. poor condition of medical device, cost limitations or time-consuming bureaucracy), users may create temporary solutions (i.e. first-order problem-solving behaviour) that are then systematically adopted by the organization because they

work (e.g. use of a carpenter's drill to replace a surgical drill or the re-sterilization and re-sharpening of single-use instruments). Although the problem is not communicated, it is solved for a longer period of time. Despite the steady increase in the quality of healthcare in Indonesia, the cost and maintenance of medical devices continue to pose a barrier due to the long-term dependency of some devices on supplies or consumables. This means that the medical industry is required to create alternatives to sales and servicing.

The utilization of use scenarios, as proposed above, can be expanded from the focus on the use phase to the whole product lifecycle. Literature about human factors and product service systems design methodology offers several examples of how innovative and valuable solutions are found by developing products based on system redesign and service requirements. Although this approach is still little explored in the healthcare sector, it is a shared strategic orientation by human factor and design engineering (Dul, 2012; Mont, 2002).

Medical devices in disaster response

Within all sub-categories, 50% (n=11) were mentioned by the experts as being commonly used in disaster response. This provides a good indication that justifies designing medical devices that would be appropriate to this context. Nevertheless, some types of interaction that were not mentioned in the interviews might indicate factors of which users are less aware and that can be identified only through structured observation.

In the field, the user's relation to the medical device is often hindered by a lack of familiarity with or confusion between devices (e.g. lack of appropriate tools, insufficient knowledge of assembly/disassembly, unfamiliarity with foot/finger controls), as many relief organizations deploy multiple brands and models of a given device. Not all models follow international standards, nor are they always compatible with other technology in the field. Additionally, surgical residents have fewer opportunities to communicate or discuss treatment alternatives with their team members than in daily practice conditions. This lack of consultation with expert surgeons and the increased number of patients might generate a stressful cognitive state. A difficult decision-making process, the necessity of working with minimal resources and assuring the availability of sufficient equipment for unpredictable patients are issues commonly associated with disaster response (Rajpura et al., 2010; Razzak&Kellermann, 2002). Another common problem involves changes of location (i.e. care is often not provided in a hospital setting) and the sharing of tasks amongst HCP. This creates information gaps and the uncontrolled use of devices. Due to the limited space for response, devices must be versatile enough to be moved from place to place or to be hung from fixtures. Logistics is thus a key factor in disaster response. An adequate stock, short assembly time and freedom from maintenance are important features for devices (disaster management expert at DSGH).

Some performance obstacles were also identified as being exceptional in disaster response. One of the main issues related to the transport of medical devices is their vulnerability to vibrations and shocks, which can cause devices to be non-functional upon arrival. The outside environment makes wounds and devices prone to infection. Most of the obstacles related to hygiene involved improper wound debridement, medication logistics and inexperience of HCP with aseptic conditions. Waste management requires additional safe transport of hazardous waste between the field and the hospitals with operational services. Moreover, it is impossible to guarantee that patients will receive follow-up care.

Limitations of the research design

The aim of this study was to categorize events according to their implications for the design of medical devices. The search for opportunities for solving problems through design can help to establish objective links between problems and their causes, in addition to explaining the levels at which intervention is needed in order to solve particular problems. The limitations of this study largely involve the identification and coding of interactions amongst multiple elements in the work structure, as well as with certain tool characteristics. The resolution of these issues could lead to the improvement of the OPO tool and to the formulation of an improved study set-up for future research.

Use, evaluation and redesign of OPO tool

In a critical review, Waterson (2009) refers to the small number of studies providing details about the interconnectedness of systems. The scarcity of such studies could be attributable to the inherent difficulty in achieving objective coding. The authors' reflections on the factors that complicated the coding of interactions across system levels led to the following observations.

First, when observing in a medical setting, the observer might identify PO in any of three different ways: 1) by directly perceiving a symptom or result that leads to further investigation, 2) by identifying specific interactions when focusing on the use of a specific device, 3) or by identifying independent factors related to the user that affect performance. These different types of "cues" might be perceived differently by different observers, depending upon whether the observer is observing actively (e.g. searching for problems) or passively (e.g. attending exclusively to new events). Second, the observer must classify the events uniformly. This is difficult, as all contributing factors can be seen as input, process or output within the system of ongoing activities. While a delay could be identified as an input for the procedure, it could also be deduced from the identification of unavailability (which results in further delay).

Finally, it is difficult to assign an event to a single category, due to properties inherent in the system. Coding is sensitive to interpretation, as reflected in several examples in this study. The example, "Due to absence of an IV pole, the IV bag is transported by a family member when the patient goes to toilet" was coded as an organizational problem (i.e. the unavailability of IV poles). On the other hand, this entry could also be coded as a task requiring multiple users and/or involving difficulty in use. In such cases, the main or underlying problem was noted as the final category.

Despite the difficulties experienced in this study, it is important to emphasise the relevance of this interconnectedness to the design of medical devices. Although designers have only limited influence on organizational factors, the understanding of organizational limitations might lead to better designs. The triangulation of results, using both qualitative and quantitative methods, could help to decrease bias in the study and achieve a higher degree of accuracy in the outcomes. Furthermore, a usability study that is more specific could be complementary to the methods employed in this study, thus helping to translate contextual problems to a more concrete level, focusing on specific design solutions (Garmer, K. et al., 2002). If it is to be used with a more focused approach, the OPO tool should allow the observer to specify a particular device or user. In this study, the researchers intended to gather general and broad evidence of existing problems. Limiting the observations to a single device or user, however, would make it possible to generalize performance obstacles from a single device, thus reducing the complexity and bias of the study. In addition, there was no pre-established way to introduce PO that occurred more than once, nor was it possible to discriminate amongst different users.

It is difficult to identify particular PO, due to insufficient visibility because of space limitation or due to the lack of medical/technical knowledge from the observer. In this case, video recordings or talk-through techniques offer alternatives in which future analyses could be aided by consultation with the experts. Furthermore, the interpretation and mental coding of an event can be time-consuming. In the future, studies should aim to integrate voice recordings of the observer, in order to reduce the time and burden of writing.

Cooperation of healthcare practitioners

None of the observed events had a negative impact on the treatment of patients. The care observed was of high quality. Nevertheless, many of the reported PO might pose potential problems. At the DSGH, issues such as deterioration and improvisations are associated with additional costs, as well as with the fact that, "when the chain linking these issues with the patient's health is so long, we cannot afford to care" (surgical resident at DSGH).

Understanding the context of users requires their willingness, interest and time investment. Users should understand that all of these interactions affect their work and that surgeons do not become better surgeons when they perform difficult procedures with back pain. The fact that "ergonomics are not a primary issue" (disaster management expert at DSGH) is commonly manifested by HCP, even though the identified performance obstacles were related to human factors and ergonomics (Wauben, 2010). Medical devices should always be designed in cooperation with HCP, and this cooperation is more effective when HCP are aware of the interactions in the OR: "I had never realized that these issues were actually so relevant and that the design of the products could be different" (Chief Surgical Resident).

As indicated by Flanagan (2003), an incident is critical if it has a relevant influence on the aim of an activity. Studying PO might increase the perception of severity and urgency in human-factors interventions, thus helping to make users more aware of their work contexts.

Future research

Following the re-design of the OPO tool, this research will be continued with a similar study in Haiti. The OPO will also be tested as a long-term self-reporting tool. Self-reporting will be studied in order to overcome the limited time available for research, in order to cover more emergency events and the potential bias of communication caused by language. Barriers in self-reporting have been identified (Wauben, 2010). Factors to be considered include awareness, fear of blame, ease and convenience. If experts are to self-assess and report their performance, the tool should be distributed to different specializations within the emergency team (i.e. nursing, anaesthesia and orthopaedics). Future studies should also investigate different hospitals and include distinctions according to hospital size and capacity.

11.6 Conclusion

The use of the systems approach was proposed for the identification of technology-related performance obstacles. This study has revealed some of the inherent difficulties and ambiguities of using the systems approach and considering cross-level interactions within the work structure. The OPO tool was designed and tested, and it was proven advantageous for investigating the context of medical emergencies. The use of focused and structured categories allowed the systematic identification of performance obstacles that reflect implications for the design of medical devices.

Most performance obstacles relate task dynamics, as well as to the placement of medical devices and changing environment. Half of all performance obstacles identified in the emergency setting apply to disaster-response settings as well. The approach proposed in this study has the potential to identify relevant design implications for medical devices that are used in medical emergencies. The authors therefore expect that the identification of implications for medical device design could contribute to a more integrated definition of design problems by medical device engineers.

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Appendix P3. Causes for performance obstacles and recommendations

Causes for performance obstacles in technical subsystem of emergency surgical work structure potentially leading to short or long term user harm or inefficiency of care in terms of time and cost expenditure		**Total% O.P.O.s**
User related 16.9% (n=24) Interactions with devices related with user (patient, healthcare practitioner) anthropometric, intrinsic and cognitive characteristics (reach, size and mood, skills, experience and behaviour)		
Device handling 4.9% (n=7)	**Physical ergonomics** Devices force user into inadequate posture e.g. Bucket for debridement is placed between table and surgeon which forces surgeon to spread legs and bend forward; Standing anaesthesiologist looks back to control vital signs monitor while ventilating patient	4.2 % (n=6)
	(Un) familiarity[*] User is not familiar with device or its accessories e.g. Union of connector from oxygen tubing	0.7% (n=1)
Problem solving 11.9 % (n=17)	**Improvisation[*]** Users create temporary solutions that address unfulfilled needs e.g. Vital signs held with cord to supporting table (figure 11.3a); Use of tape to connect two electric cables (figure 11.3b)	11.9% (n=17)
Recommendations	Enable physical comfort and safety during use knowing that temporary positioning of devices leads to uncomfortable and unsafe body posture knowing that the combined use of devices often results in uncomfortable body posture and unpractical disarray of environment Facilitate use and organized storage in direct relationship with the activity knowing that cables and other devices need to be temporarily bundled or secured knowing that use cues can be identified in user's problem solving (improvisation) knowing that safety of improvisations is rarely assessed	

Task related 30.2% (n=42)		
Interactions with task characteristics (difficulty, stress, variety, length/density of activity)		
Settings 7.0% (n=10)	**Problematic**	4.2%
	Need to make (un)common (re)adjustments with device or its accessories	(n=6)
	e.g. Drag electrocautery unit to switch electric socket; Repeated pressing of buttons (demand response)	
	Frequent	2.8%
	Need to make (un)common (re)adjustments with device or its accessories	(n=4)
	e.g. Adjustment of anaesthetic agents; Adjustment of ceiling mounted lamps	
Dynamics 13.3% (n=19)	**Multiple users [*]**	6.3%
	Action requires more than one user to be performed	(n=9)
	e.g. Lengthy application of splint; Use of manual ventilation balloon	
	Difficulty	4.2%
	Action performed with degree of physical and motor difficulty	(n=6)
	e.g. Insertion of long screw in (heavy) surgical drill; Reach IV pole to hang IV bag	
	Intensity	2.8%
	Actions quickly performed or simultaneously	(n=4)
	e.g. Rapid removal of tracheal tube (misplacement of cables); Simultaneous administration of IV medication and manual ventilation	
Adequacy 4.2% (n=6)	**Presence [*]**	3.5%
	Misplacement at needed moment and location; Insufficient quantity or inadequate type	(n=5)
	e.g. Missing correct size of ventilation mask; Missing debridement supplies (resident repetitively carries overload of supplies	
	Ineffectual;	0.7%
	Device or accessory is present but not required for any of performed tasks	(n=1)
	e.g. Suction device is turned on but not used during procedure	
Response 4.9% (n=7)	**Malfunctioning**	1.4%
	Device and accessories do not function as expected	(n=2)
	e.g. Malfunctioning trolley wheels; Electrocautery unit does not respond on demand (twice)	
	Unintended	3.5%
	Device and accessories function with no intention from users	(n=5)
	e.g. Unlocked bed moves when surgeon leans to reach patient; Electric shock when connecting cutter in electrocautery machine	

Recommendations	Facilitate actions at a rapid pace	
	knowing that disposition and placement of devices is often unsteady	
	knowing that interfaces (e.g. buttons, digital displays) become non-responsive	
	Facilitate access or visibility to device to additional user(s)	
	knowing that disposition and characteristics of devices hinder access and visualization by users	
	Facilitate shared use and long sterilization cycles	
	knowing that devices that are available in insufficient quantity to be frequently used are often not available on requested	
	knowing that the use of devices requires availability of appropriate and sufficient staff	
	knowing that increasing the number of patients using a device might increase efficiency of care	
	knowing that instrument cleaning depends on long sterilization cycles	
	Facilitate locking devices (e.g. breakable wheels)	
	knowing that locking is often misinterpreted to be immobile, resulting in slips or falls of devices	
Environment related 34.5% (n=49)		
Interactions with environment characteristics (external and internal conditions where and how task occurs)		
Placement 18.2% (n=26)	**Positioning**	7.7%
	Devices or accessories are repeatedly (re)positioned	(n=11)
	e.g. Placement of IV syringe on patient's wooden arm support (figure 11.3c); Placement of used needles on patient's chest	
	Disturbance [*]	10.5%
	Devices or accessories fall, collide or become entangled	(n=15)
	e.g. Urinary catheter falls on the floor while surgeon adjusts bed to swap patient and repeatedly steps on it; Adjustment of entangled IV tube before bed transfer	
Layout 16.1% (n=23)	**Avoidance**	5.6%
	Devices or accessories positioning in space hinders dynamics of users and task	(n=8)
	e.g. Stumble on triple electric socket (three times) (figure 11.3d);Proximity of electric socket to debridement water	
	Floor use	2.1%
	(Mis)Use of available free floor space	(n=3)
	e.g. Devices not in use and baskets with medication are pushed to the sides of the room; Devices and cables tightly concentrated around patient's arm (wrist wound)	

	Limitation [*]	8.4%
	(Un)Sufficient space and infrastructure	(n=12)
	e.g. Devices stack up behind surgeon (figure 11.3e); Repositioning devices around OR bed to give space for other bed (figure 11.3f)	
Recommendations	Facilitate displacement of devices in the room or between rooms knowing that cables and other devices constrain floor use knowing that devices attached to a patient or other portable devices add volume and constrains to movement knowing that limited/narrow space hinders displacement of devices knowing that the wheels and form of a device constrain free positioning of other devices knowing that displacement of devices makes them prone for cross contamination Facilitate transportation of devices knowing that vibrations and bumps damage materials and components of devices knowing that stacking and storing requires appropriate packaging knowing that devices are dependent on accessories and cables to function. These need to be packed together. Facilitate simultaneous use with other devices knowing that volume and cable dependency lead to incorrect ergonomic and unsteady positioning of devices knowing that limited electric sockets and central gases outputs on a wall lead to incorrect disposition of devices and missteps over cables. This might disconnect devices or represent a threat to patient and/or HCP safety. knowing that additional devices from the environment can replace certain functions of one device	
Organization related 15.4% (n=22)		
Interactions with organization characteristics (managerial and logistical settings and decision-making)		
Availability 9.8% (n=14)	**Not available [*]**	3.5%
	Required devices are not available in hospital stock and cannot be timely acquired or accessed	(n=5)
	e.g. No location or light table to observe radiography (in resuscitation ward); Surgeons purchase needle type on their own due to unavailability	
	Storage [*]	6.3%
	Location of stored devices and accessories in hospital	(n=9)
	e.g. No discrimination of closets' content in resuscitation ward; Blood pressure device stored in centralized closet at entrance of emergency ward	

Condition 5.6% (n=8)	**State [*]**	4.2%
	Poor, old or deteriorated devices and accessories, incomplete, broken or not calibrated	(n=6)
	e.g. Deteriorated cable connectors; Ceiling mounted lamps do not maintain adjusted position	
	Hygiene [*]	1.4%
	Devices and accessories are subjected to cleaning practices	(n=2)
	e.g. Intubation suction device is not emptied and cleaned between procedures; Floor not cleaned between cases	
Recommendations	Facilitate simultaneous use with devices of previous models or versions	
	knowing that interfaces from previous models or versions (cables, connectors, digital interface) are counter-intuitive	
	knowing that outdated models hinder integration of needed supplies or consumables	
	knowing that energy requirements hinder the use of devices due to incompatibility with other technology	
	knowing that the need for special infrastructure (e.g. safety shielding) inhibits use of device	
	knowing that donations should be monitored with medical device donation standards[1]	
	Facilitate storage of a device	
	knowing that distance of stored supplies or devices to location where they are used influence efficiency of on demand use	
	knowing that clear labelling of stored supplies or devices influence efficiency of on demand use	
	knowing that stored devices are vulnerable to dust, humidity and temperature	
	Provide feedback warning about their condition when used uninterruptedly	
	knowing that devices that do not indicate clear need for maintenance or repair are less likely to be handled	
Device related 3.5% (n=5)		
Interactions with physical characteristics (material, dimensions, components)		
Characteristics 3.5% (n=5)	**Properties [*]**	3.5%
	Differing models of devices and accessories; Dimensions and capacity; Devices dependency in accessories; Function intuitiveness	(n=5)
	e.g. Undifferentiated device models in the recovery room; Long tubes fall out of packaging on the floor	

Recommendations	Use adequate materials and shapes
	knowing that breakable materials cannot be repaired and parts must be replaced
	knowing that grooves and porosity tend to be dirty
	knowing that portable devices are more exposed and may therefore be lost
	Design adequate components
	knowing that the dependency of specialized components and accessories limits the use of a device
	knowing that the need for special maintenance or repair tools inhibits use of device
	knowing that cables, as opposed to alternative energy sources, constrain movements of HCP
	Design adequate packaging
	knowing that the location where devices are unpacked often leads to hygiene threats
	knowing that packed long and rolled tubes or cables might lead to falls on the floor

O.P.O. Observable Performance Obstacles

[*] Performance obstacles occurring likewise in disaster response (retrieved from retrospective interviews)

1. WHO, 2000. Guidelines for Health Care Equipment Donations, Evidence and Information for Policy (EIP), Organization of Health Services Delivery (OSC); Partnership for Quality Medical Donations, 2011.Resource Library. Retrieved at http://www.pqmd.org/resource-library

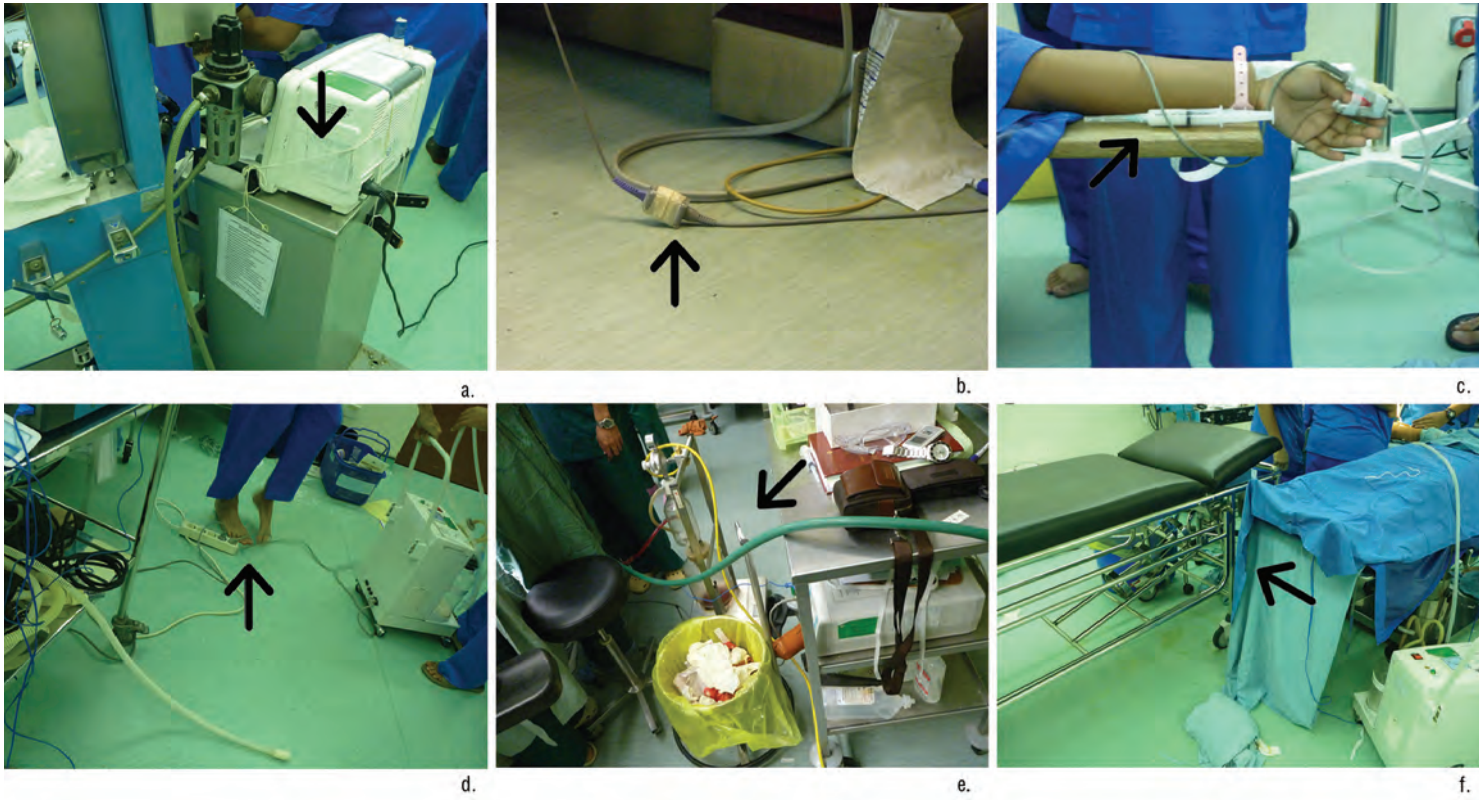

Figure 11.3 Illustrated examples of performance obstacles a. Vital signs held with cord to supporting table; b. Use of tape to connect electric two cables; c. Placement of syringe on patient's arm support; d. Stumble on triple electric socket; e. Devices stack up behind surgeon; f. Repositioning of devices to have more space

12 Safety challenges of medical equipment in nurse anaesthetist training in Haiti [publication 4]

This chapter was accepted as: Santos, A.L.R., Wauben L.S.G.L., Guilavogui S., Brezet, J.C., Goossens R., Rosseel P.M.J. (2015). "Safety challenges of medical equipment in nurse anaesthetist training in Haiti" Applied Ergonomics (*in Press*)

Abstract

Safety challenges related to the use of medical equipment were investigated during the training of nurse anaesthetists in Haiti, using a systems approach to human factors and ergonomics (HFE). The observable performance obstacles tool, based on the systems engineering initiative for patient safety (SEIPS) model, was used in combination with exploratory observations during 13 surgical procedures, to identify performance obstacles created by the systemic interrelationships of medical equipment. The identification of performance obstacles is an effective way to study the accumulation of latent factors and risk hazards, and understand its implications in practice and behaviour of healthcare practitioners. In total, 123 performance obstacles were identified, of which the majority was related to environmental and organizational aspects. These findings show how the performance of nurse anaesthetists and their relation to medical equipment is continuously affected by more than user-related aspects. The contribution of systemic performance obstacles and coping strategies to enrich system design interventions and improve healthcare system is highlighted. In addition, methodological challenges of HFE research in low-resource settings related to professional culture and habits, and the potential of community ergonomics as a problem-managing approach are described.

12.1 Introduction

Human factors and ergonomics in healthcare

The value of using human factors and ergonomics (HFE) to study medical environments is well described in literature (P. Carayon, 2007). The HFE discipline is an expanding field in healthcare and has contributed significantly to a holistic understanding of user-medical device relationships and interventions, related to medical infrastructure and services. HFE is divided into subdomains that focus on different scales of the interface between people and other elements of the healthcare system. Macroergonomics is the subdomain focused on the overall work system at an organization scale (P. Carayon et al., 2013).

The aim of macroergonomics models of healthcare quality is to integrate the entire system of an organization, guiding its integral analysis and redesign. The systems engineering initiative for patient safety (SEIPS) model, complemented in this study, defines healthcare services composed of a work structure and care processes (P. Carayon et al., 2014). The work structure is a system of interrelated elements that influence each other and that are complementary for the safe functioning of the entire system (Rasmussen, 1997; C. Vincent, Moorthy, Sarker, Chang, & Darzi, 2004). The arrangement of system elements can be either hierarchical or functional, but generally includes the following elements: organization, environment (physical and external), tasks, individual/team, and tools/technology (P. Carayon, 2007; Rasmussen, 1997). These elements are involved in dynamic and non-linear care processes and their combination results in determined outcomes for patients and the healthcare institution.

Sensitization and understanding of these system elements and their relationship is of particular importance to obtain a safety culture and manage the quality of healthcare provision (C. Vincent et al., 2004). A safety culture - or context - in healthcare promotes the continuous reduction and prevention of risks and medical incidents that result in patient harm and can have profound impact on the outcome of healthcare (Group of WHO Patient Safety, 2009; Mitchell, 2008). Medical incidents result from a sequence of associated failures in different system elements and care processes, and often lead practitioners or technicians to error (Mahajan, 2010; Reason, 2000; C. A. Vincent, 2004). Therefore, many efforts are made to understand and breakdown the systemic reasons behind medical incidents (Spath, 2011).

The identification of performance obstacles is an effective way to study the accumulation of latent factors and risk hazards and to understand its implications in practice and in the behaviour of healthcare practitioners (P. Carayon et al., 2014). Similar to what Tucker & Edmondson (2003) call a "problem", performance obstacles are factors related to the work structure of healthcare practitioners that disturb the execution of particular activities or tasks (affecting to a certain degree time, comfort or result), leading to a deviation from the safety standards (P. Carayon et al., 2014). Investigating performance obstacles is a proactive way to look at healthcare safety since it allows getting a rich understanding of the accumulating causes, not only of accidents but also of decreased quality of working life of healthcare practitioners (Gurses & Carayon, 2007; R J Holden, Rivera-Rodriguez, Faye, Scanlon, & Karsh, 2012). These performance obstacles are associated with either system limitations or incompatibilities (e.g. infrastructure, staff, and management) or with problem-solving mechanisms triggered by the impediment of treating patients and complying with the standards in the first place. Problem-solving mechanisms are named coping strategies in HFE literature and can include safety violations and workarounds (P. Carayon et al., 2014).

A system of gaps

Healthcare provision is not homogeneous worldwide. Low-income countries are generally characterized by an uneven distribution of quality of healthcare services (public versus private, urban versus rural) and the prevalence of low-resource settings. These characteristics make healthcare management more complex and challenging. In low-resource settings, both healthcare structure and care processes are typically characterized by significant shortcomings, or functioning gaps, that result in worse healthcare outcomes and in a higher chance for medical incidents to occur.

The concept (theory and practice) of community ergonomics (CE) stems from the macroergonomics subdomain, and extends the application of HFE theories to complex societal systems (Smith et al., 2002; Taveira & Smith, 1997). CE focuses on distressed community settings where certain groups of people have disadvantaged access to resources and participation in their surrounding (societal) environment, for example due to inequities created by power hierarchies or social rules. CE offers a people-centred design approach of community-environment interfaces, bringing contextual relevant aspects to the integrated design of community (capabilities) and environment as a whole. Although it was not specifically formulated for healthcare in low-resource settings, its application is rather flexible to accommodate the uncertainty and unpredictability, inherent of such distressed settings. Figure 12.1 illustrates the relation between the HFE domains, models and tools referred in this introduction. Given the potential offered by CE to address macroergonomic problems, the approach will be further discussed in chapter 12.5, p.188.

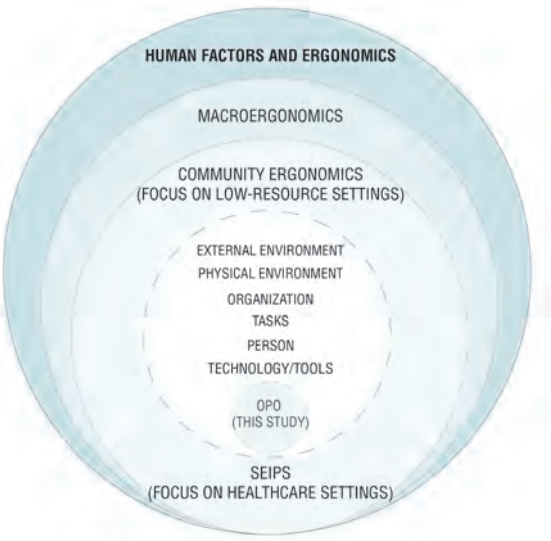

Figure 12.1 Relation between referred domains, models and tools within human factors and ergonomics

12.2 Research focus and aim

Healthcare safety in Haiti

Haiti offers an interesting opportunity to study healthcare safety due to the prevailing poverty and socio-economic challenges that impact the healthcare system. Haiti has a long history of conflict and natural catastrophes and ranks as the poorest country in the Western Hemisphere and one of the 15 most susceptible countries to the impact of a natural disaster in the world (Guly, 2004; United Nations Development Programme, 2014; World Risk Index, 2011). After a devastating earthquake in 2010 and the following cholera outbreak, recovery is slow. Until today the main public hospital in the capital of Port-Au-Prince has not been rebuilt and there is limited information regarding existing healthcare infrastructure. Generally, the access of the population to healthcare is low due to a combination of financial affordability, remoteness, lack of functional services and cultural aspects (Guly, 2004).

Healthcare structure and care processes

The gaps in both healthcare structure and care processes in Haiti affect anaesthesia outcomes negatively. Regarding the healthcare structure in Haiti (i.e. expertize, tasks, technology, environment and organization) there is a large shortage of experienced medical staff. The existing staff is disproportionally concentrated in healthcare facilities in the Port-Au-Prince metropolitan area (Pan American Health Organization, 2012; United Nations Development Programme, 2014) resulting in a strong dependency of rural hospitals on the presence and donations of numerous international aid organizations. This contributes to a lack of standardization and reliability regarding skills and techniques (e.g. frequent exchange of visiting staff, short working week), but also of medical equipment and drugs (e.g. differing drug concentrations, recurrent supply shortages). Gaps in infrastructure include insufficient facilities and accessibility and lack of diagnostic and therapeutic means, or even basic resources (e.g. fuel, telephone). The distinction between care processes, such as emergency and elective cases is in the given context, largely undefined due to, for example, delays in seeking care. The lack of coordination resources also contribute to an uncertain planning, record-keeping and follow-up of medical procedures.

The technology system element

HFE show that innate human factors influence work performance on a daily base and that the most effective way to overcome this potentially negative influence is to systemically minimize the chances of human error to occur, through the design of user-friendly, fail-safe medical devices, implementation of standard operating procedures and improvement of workspace layout (Buckle, Clarkson, Coleman, Ward, & Anderson, 2006; Martin, Clark,

Morgan, Crowe, & Murphy, 2012; Shah & Alshawi, 2010). In HFE, medical devices and supplementary medical equipment make up the "technology" system element. The study of technology in healthcare is important, because medical equipment have become essential in modern healthcare for the diagnosis, treatment, monitoring and follow-up of patients (European Commision, 1994). Furthermore, studying medical equipment is an effective vehicle to evaluate the performance of a system, especially if the interrelationship of micro- and macro-ergonomic aspects are considered (e.g. infrastructure, maintenance and supply inventorization) (Liem & Brangier, 2012; Mittermeyer, Njuguna, & Alcock, 2011). However, the application of HFE in healthcare in low-resource settings has been rather poorly explored (O'Neill, 2000; Shahnavaz, 2009; World Health Organization, 2010). In low-resource settings, the reliance on donated medical equipment of various origins is one of the factors determining the extent to which care is delivered. There is evidence that ergonomic guidelines are not followed in this context and that a large amount of donated medical equipment is not functioning. Studies are lacking that focus on the safety of the remaining functional medical equipment (Dzwonczyk & Riha, 2012; Rice, Gwertzman, Finley, & Morey, 2010; World Health Organization, 2010).

Aim

This study focuses on understanding the safety contexts of human interaction with medical equipment in low-resource settings from a HFE perspective. The aim is to identify concrete safety challenges of medical equipment use, by identifying performance obstacles related to medical equipment during the training of nurse anaesthetists in Haiti.

12.3 Materials and methods

This study is a follow-up of a study about the dynamics of medical emergencies (Santos, Wauben, Dewo, Goossens, & Brezet, 2013). This case study was conducted in the hospital L'Hôpital Bon Sauveur in Cange (HBSC), Haiti during a training program of nurse anaesthetists (Rosseel, Trelles, Guilavogui, Ford, & Chu, 2009). This hospital is administered by the Haitian subsidiary organization of Partners in Health in collaboration with the Haitian Ministry of Health Care (MOH). The training program was organized in cooperation with Médecins Sans Frontières (MSF).

Hospital setting

HBSC though being a peripheral hospital situated in a remote area, has built a high reputation and has well known and attended surgical and obstetrical services (Ivers

et al., 2008). The hospital has offered surgery since 1993 and has seen a fast increase in number and variety of surgical procedures. At present, the surgical service of HBSC has been transferred to the new Hôpital Universitaire de Mirebalais in a small village, half way between Cange and Port-Au-Prince, also administered by Partners in Health and MOH. At the time of this study approximately 50 -70 surgical cases were performed each month, with a variety of cases, with hernial repairs and caesarean sections being the most frequent. There were two operating complexes, one for general surgery, incorporating two operating rooms (OR) and another separate OR in the maternity ward building. There was no recovery room or Intensive Care Unit. The hospital's infrastructure included inpatient wards, an outpatient clinic, an infectious disease unit and complementary services (e.g. women's health, dental, radiology and ophthalmology clinics, laboratories, pharmacies and a blood bank).

The training program of nurse anaesthetists

In Haiti there is a shortage of midwives, intensive care nurses and nurse anaesthetists (Hoyler, Finlayson, McClain, Meara, & Hagander, 2013). A universally accepted solution for the severe lack of specialized staff, in particular in rural settings, is task shifting. In task shifting nurses from varying background are trained to substitute anaesthesiologists (Ivers et al., 2008; Rosseel et al., 2009). While the official training program of nurse anaesthetists in Haiti was not functional anymore MSF implemented a comparable training program because of (local) staff shortage. And although training is often performed by international aid organizations, it is not their core task and therefore their training programs do not necessarily comply with international standards. The aim of the nurse anaesthetists training program by MSF (performed in HBSC) was to select and train registered nurses to become nurse anaesthetists capable of practicing autonomous anaesthesia without the regular presence of anaesthesiologists. Seven training cycles of 18 months each were held between 1999 and 2012 and 40 nurse anaesthetists have been successfully trained by a full time expatriate anaesthesiologist. Each training comprised of theoretical and practical training in pre-, per- and post-operative anaesthesia care, including handling medical equipment and aspects of quality control and teamwork. During the seventh training program, at the time of this study, a total of 238 procedures involving different types of anaesthesia were administered by 11 nurse anaesthetists.

The observable performance obstacles (OPO) tool

Given the exploratory nature of this case study, and in order to get a rich understanding of the performance context in real settings, a qualitative approach was used. The SEIPS model was chosen amongst several tools available from the HFE toolbox that could be suitable to

this purpose (e.g. contextual inquiry, event tree analysis, walkthrough or cognitive task/work analysis, timeline or critical path analysis) (Cacciabue, 2004; Stanton et al., 2005). The SEIPS model was chosen because of its flexibility to be used as a tool and as a framework, because it is a thoroughly validated tool and because of its distinct visual simplicity (P. Carayon et al., 2006; Gurses & Carayon, 2007; Richard J. Holden et al., 2013). As such, the SEIPS model allowed 1) a practical application to guide observations and interviews as well as structuring the data analysis, 2) acknowledging the dynamics of the system rather than a time-based or retrospective approach and 3) communication with participant healthcare practitioners.

So a tool called Observable Performance Obstacles (OPO) was developed to systematise the collection and analysis of information about the systemic relations of medical equipment (figure 12.2a). The OPO tool is a complementation to the SEIPS focusing exclusively on the technical subsystem (Technology and Tools) and the respective relations with the elements of the work structure (Person, Task, Environment, and Organization) (figure 12.1) (P Carayon et al., 2014). According to the suggestion of Waterson (2009) (Waterson, 2009) to research cross level relationships in HFE, the exclusive focus on the technical subsystem should contribute to enrich the understanding of the healthcare system. In addition, the principle behind the Input-Transformation-Output model (Karsh, Holden, Alper, & Or, 2006) was used to categorize the ways in which the performance of healthcare practitioners is affected by the relations of medical equipment with the system elements during the process of care.

The categories of performance obstacles in the OPO tool are amenable to be addressed by ergonomists and designers, because they relate to needs and capabilities of users, providing information about medical equipment embedded in activity rather than in isolated functions. Observation logs, photographic records or surveys may be used to collect information. Figure 12.2b illustrates the used format for data collection, derived from the original OPO tool (figure 12.2a). The OPO categories were iteratively defined after a previous case study (Santos et al., 2013) where the OPO tool was used and discussed with participant experts. The definitions of the OPO categories were further revised by the first two authors until consensus was reached. During its use, the OPO tool is useful to provide a clear and effective way of communicating the research purpose and process. In the previous case study, “improvisation” has been discussed in the authors’ earlier study as a mechanism of problem-solving in which temporary solutions are created to work around a problem (e.g. insufficiency of medical supplies or poor condition of medical equipment) and are systematically adopted by healthcare practitioners and the organization (Gosbee,

2002; Spiess et al., 2014; Tucker & Edmondson, 2003). In this paper, coping strategies and improvisations are discussed separately from performance obstacles and some modifications of the tool are introduced.

Research design

The study was performed over a period of six days and consisted of observations and photographic recordings during evaluation sessions in the ORs. Three consecutive days were dedicated to observations of surgical procedures in which different nurses were shadowed in their activities. The observations, made by the first author, included the activities occurring during a full day in the OR (i.e. defined by the time the patient is in the room) and excluded the remaining activities (i.e. call of patients and assistance in recovery room).

Exclusion criteria

Data collection focused on identifying the origin of performance obstacles (as defined in chapter 12.1) occurring in the independent relations of the elements user, task, environment and organization, with medical equipment. Systemic relations not including medical equipment were excluded, such as organization-task or user-environment relations. Furthermore, context variables, such as type of procedures, type of anaesthesia, the number and type of devices per procedure, the age and experience of the nurse and the number of team members were not retrieved and are only mentioned if relevant for the description of a performance obstacle.

Ethics approval

Authorization was required by both MSF and Partners in Health in which the ethical aspects of the research and visit were clarified and approved. A human ethics approval was not requested since no patient or staff information were recorded and patients remained anonymous. Furthermore, inquired nurses or other professionals were asked permission for inquiry and observation. In case of disagreement, they could refuse answering or participating in the study.

Data analysis and modifications to previous tool

Data analysis was targeted at the categories of the performance obstacles from the OPO tool. The tool has been iteratively designed and was subjected to some modifications (table 12.1) since the previous study (Santos et al., 2013).

Table 12.1 Improvement changes in OPO tool

Former OPO tool	Current OPO tool
22 subcategories	Converted in 14 categories divided in "person", "task", "environment" and "organization"
Subcategory "physical ergonomics"	Renamed "ergonomics" to include a broader scope of ergonomics
Subcategory "improvisation"	Removed. "Improvisation" is discussed separately
Category "adequacy"	Includes the subcategories "presence" and "ineffectual"
Category "response"	Includes "malfunctioning" and "unintended"
Subcategory "positioning"	Includes "floor use"
Subcategory "disturbance"	Renamed "avoidance"
Subcategory "limitation"	Renamed "infrastructure"
Category "device properties"	Given the focus of this study on cross-level relationships of the technical subsystem, the category was removed due to redundancy, since all OPOs are inherently related to tools/technology

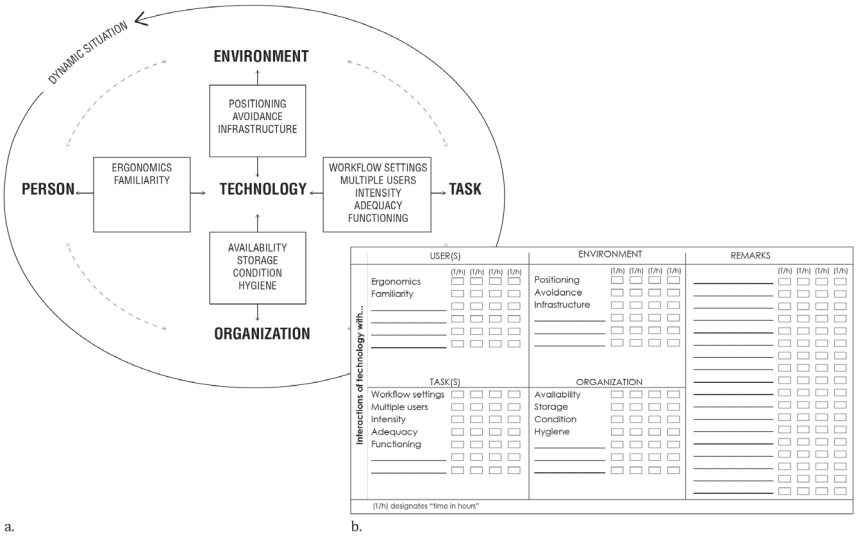

Figure 12.2 a. Observable Performance Obstacles tool (adapted from Santos et al [2013]); b. Format example of OPO tool for data collection and analysis

A distinction between procedure-specific and general OPOs was made. Procedure-specific OPOs include issues that were identified once during a specific procedure and general OPOs include issues that were identified more than twice or reflect therefore a common practice in the hospital. The final OPO tool is depicted in figures 12.2a and 12.2b and a full description of the OPOs can be found in table of observable performance obstacles (appendix P4).

The OPOs registered in observation logs and photographic records were categorized according to the existing table of OPOs using a coding technique (Saldaña, 2013). Each OPO was coded in the most prominent category. In case of diverging opinions regarding the association of OPOs to different work system elements, the definitions of each category and code were reviewed by the first two authors and the options were discussed until consensus was reached. All categorizations were reviewed and approved by all authors.

12.4 Results

The results revealed several OPOs that characterize the dynamic and challenging working conditions of nurse anaesthetists in Haiti. In total, 13 surgical procedures were observed (table 12.2). A table of OPOs was generated from the observation logs and photographic records. These were coded and quantified in 14 different categories (see table of observable performance obstacles in appendix P4, p.194). In total, 123 OPOs were included. Figure 12.4a-h illustrates examples of identified OPOs.

Of the total 123 OPOs, the most frequently experienced were related to relations of the medical equipment with the work structure elements Environment (n=59/123; 48%) and Organization (n= 31/123; 25%) (figure 12.3a). Within the environment-related OPOs, 25/59; 42% (n=25/123; 20.3% of the total OPOs) were related to the category "avoidance" which defines incidents, such as falls, collisions or entanglements. 17/59; 28.8% OPOs (n=17/123; 14% of the total OPOs) were related to inadequate "positioning" of medical equipment and 17/59; 28.8% OPOs (n=17/123; 14% of the total OPOs) to "infrastructure" limitations.

Table 12.2 Observed surgical procedures

Type of surgical procedure according to MSF training categorization	Observed procedures
Orthopaedics: fractures and luxations n=3	Osteosynthesis Closed fracture Elbow Closed fracture Leg
Specialized: Eye, nose, throat; Neurosurgery n=3	Cataract Head hematoma Throat/trachea
Visceral: Hernia; Exploratory laparotomy n=5	Hernia repair (n=3) Appendicitis Hernia/haemorrhoids
Gynaecology: Caesarean section; Fistula n=2	Fistula Caesarean section

* OR – Operating Room

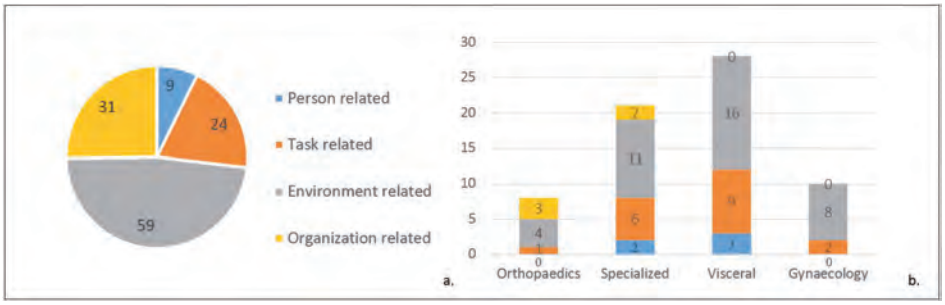

Figure 12.3 a. Number of OPOs per work structure element; 3b. Distribution of performance-specific OPOs per type of surgical procedure

Within the organization-related OPOs, 13/31; 41.9% (n=13/123; 10.5% of the total OPOs) were related to a poor, old or deteriorated condition of medical equipment, 9/31; 29% (n=9/123; 7% of the total OPOs) were related to unavailability of medical equipment which resulted in sharing medical equipment or adapting domestic solutions for its replacement. 5/31; 16.1% (n=5/123; 4% of the total OPOs) and 4/31; 12.9% (n=4/123; 3% of the total OPOs) were related to hygiene practices and lack of designated storage location respectively.

Of all the reported OPOs, 67 were procedure-specific (54%) and most of these (n=39/67; 58.2%) were related to environment (n=39/123; 32% of the total OPOs). The distribution of performance-specific OPOs in figure 12.3b shows how environment-related OPOs are equally distributed across the type of procedures. Of the 56 remaining general OPOs (46%), 26; 46.4% were mainly related to organization (21% of the total OPOs). The OPOs with least expression were related to unfamiliarity with medical equipment (n=1; user-related OPO), multiple users (n=3) and intensity of activity (n=3) (both task-related OPOs).

12.5 Discussion

This study shows there are different ways how work dynamics affect the performance of nurse anaesthetists in Haiti. The identified OPOs demonstrate a strong relation between human factors, tasks and available equipment that might potentially contribute to the occurrence of life-threatening medical incidents by delaying a procedure, diverting attention, introducing errors or worsening work conditions (Santos, Wauben, L.S.G.L. Guilavogui, & Rosseel, 2014). The authors consider the context described in this study also illustrative for other hospitals in low-resource settings.

Figure 12.4 Illustrated examples of identified OPOs a. Placement of medicines on low stool (environment-related); b. Placement of sterile instruments on vacuum device (environment-related); c. Placement of medicines on arm rest (environment-related); d. Unused supplies on anaesthesia machine (task-related); e. Inappropriate posture of the nurse (user-related); f. Unused medical equipment is stored in corridor at entrance of OR (organization-related); g. Inappropriate posture of the nurse (user-related); h. Placement of pulse oximetry on the floor (environment-related).

Environment and organization related OPOs

Similar to the results of the previous study, environment-related OPOs were the most frequently experienced (n=59; 48%).

Environment-related OPOs include equally relevant aspects like limited infrastructure (e.g. insufficient electric sockets or power loss occurrences) and dynamic organization of equipment in space (e.g. improper arrangement). These characteristics are expected to be comparable to other hospitals in low-resource settings since facilities are often not specifically designed to function as ORs.

In addition, training settings imply the presence of additional people (i.e. supervisors, trainees). This, besides resulting in crowded small spaces, increases the chance of stumbles, falls or uncoordinated disposition of medical equipment. Also, the presence of idle equipment in the workspace forces nurses into inadequate body postures and causes delays. Nurses arrange medical equipment in space mostly as a consequence of the dynamics of their activity. The lack of appropriate infrastructure leads to using medical equipment as e.g. an instrument table or arm rest for the patient. Mobile lamps or vacuum devices are arranged across the room according to the availability of electric sockets which means cables will block or endanger the movement of nurses. Furthermore, this misplacement, sometimes intended to facilitate sharing equipment between ORs, clearly puts hygiene and safety at stake (e.g. nurse crossing sterile area to use trash bin, or glove package containing used needles on the floor). Due to the unequal number of procedures in each OR in this study (table 12.2), it is not possible to identify a systematic difference between the types of procedures.

The second most frequent experienced OPO's were organization-related (n= 31; 25%) and included hospital management and logistic limitations. Amongst these, the condition of medical equipment was the most frequently observed problem. The use of old or domestic equipment does not necessarily impede, but limits nurses' performance and comfort. Some medical equipment is not used because it is noisy (i.e. air compressor) or it is deprived of some functions (i.e. malfunctioning air conditioning). Other organization-related issues include the lack of clear hygiene policies and of allocated storage place outside the OR. Several types of donated supplies exist in surplus (e.g. surgical drapes) while others (e.g. batteries, oxygen stock) are lacking.

Studies in anaesthesia proved that medical equipment related incidents are more severe when related to human factors (i.e. inappropriate use, poor maintenance and use of obsolete devices) than to medical equipment failure (Beydon et al., 2010; Donaldson, Panesar, & Darzi, 2014). The results of this study demonstrate that medical equipment relates with medical practice in a variety of ways that contribute to increased chances of medical incidents. The results also help to understand the order of performance obstacles that may contribute to human error and provide evidence for a fundamental role of often overlooked environmental and organizational factors in safety of healthcare (Hoff, Jameson, Hannan, & Flink, 2004).

Coping strategies

In the context of healthcare quality and safety, work-arounds and safety violations are coping strategies defined as "deliberate acts (from patients or healthcare practitioners) that deviate from (or break) rules and standards" (P. Carayon et al., 2013 p.15), policies or established protocols of practice in response to the latent misfit of macroergonomic problematic factors and bad work system design. As mentioned earlier, improvisation is a form of problem-solving, similar to a workaround, resulting in equipment-related solutions that are eventually adopted by healthcare practitioners as common practice. These "practical solutions", such as the use of alternative equipment to compensate for unavailability or the repeated use of equipment as a table (figure 12.5a-c) are adopted because they may address these problems effectively and timely.

Unlike errors in healthcare, few studies describe task-disrupting problems, performance obstacles and problem-solving behaviour (Gurses & Carayon, 2007; Spiess et al., 2014). Nonetheless, these issues offer evidence about system malfunctioning. This implies that problem-solving behaviour must be acknowledged and taken into account when addressing safety in low-resource settings. Another coping mechanism related to infrastructure limitations, is the need to provide and coach nurse anaesthetists with knowledge, complementary to training skills. In contrary to skills (i.e. ability to carry out planned action steps), knowledge (i.e. underlying understanding of action) is key to be able to find solutions when equipment malfunctions. This problem-solving behaviour reflects the compromise between not treating a patient or treating a patient with increased risk and an uncertain degree of safety or comfort.

Figure 12.5 Examples of improvisation a. Use of microwaves (device underneath electrocautery unit) to heat blood; b. Use of inappropriate tool to unscrew bolt of oxygen cylinder; c. Use of sterile glove to cover the battery of the surgical drill

The compromise between the advantages of coping strategies and their associated risks for patients, healthcare practitioners and institutions, usually protected by standards, raises important opportunities for future research regarding the balance between a highly regulated and a resilient practice (Dekker, Bergstrom, Amer-Wahlin, & Cilliers, 2012). In the future such HFE research has the potential to contribute both to the fields of design and policymaking.

Limitations and improvements of the OPO tool use

This study has both practical and technical limitations. First, the characteristics of a training setting, such as the imposed administration of one type of anaesthesia over another for educational purposes, the concentration of nurses in the workplace and the pressuring presence of an evaluator limit the number of observable procedures and the generalization of this study. Nonetheless, it is relevant as the training setting is a common practice of aid organizations working in low-resource settings. Possible solutions to overcome this would be to involve local researchers or nurses to create a sense of ownership of the research or, integrating such a study into the training program. Second, the study is hampered by technical limitations. The frequency of recurrent performance obstacles was not quantified but it is important to assess the risk associated with each performance obstacle. Further, context variables were not considered critical for the identification of the origin of performance obstacles, they are meaningful to be retrieved and investigated in future research in order to measure and quantify the OPOs in terms of variance per procedure and per location. Finally, the coding of OPOs as listed in the table of observable performance obstacles (appendix P4, p.194) are subject to interpretation regarding their association to the different work system elements, despite the descriptiveness of the categories. This can derive from the fact that the OPO categories were created from a design engineering perspective. Nonetheless, validity efforts were made by testing two iterative cycles with feedback from participant experts and discussion amongst the authors (chapter 12.3, p.177). These reliability limitations should be addressed in future research on the use of the OPO tool. Case studies offer a good opportunity to study the applicability and validity of the OPO tool because they focus on in-depth insights of practice and therefore, on the differences between use settings, which are particularly relevant in emergency settings. Furthermore, possible improvements to the research design include introducing video recording or assigning more observers with a different focus. This would lead to the possibility to introduce multiple layers to the study which would facilitate the analysis of a dynamic setting. Additional layers of this study could include e.g. different room configurations and mapping of existing infrastructure using technology assessment and surveillance tools (Markin et al., 2014; Polisena, Jutai, & Chreyh, 2014; World Health Organization, 2006). In addition, the optimization of the OPO tool could benefit from a

stronger association with the SEIPS model during its use, and an evaluation of its distinct value in comparison with other tools available within the HFE toolbox. Focused and individual interviews with the nurses would offer a chance to exchange feedback regarding the research design and results.

Methodological and practical challenges of HFE research in low-resource settings

Several authors suggest that additional skills and considerations are needed to perform HFE research in low-resource settings. During this study some challenges were identified, which contribute to the literature of HFE (Dul et al., 2012; O'Neill, 2000).

Change culture

There is, in the perception of nurse anaesthetists, a large gap between the perception of problems or safety threats, and the occurrence of an accident. This leads the nurses to oppose to the existence of problems if no accident occurred. "Was there a problem with the oxygen? No, there was not, why refer to it?" (nurse anaesthetist reaction to the author's observation). In the same manner, the nurses were reluctant to answer when asked about comfort. This affects not only the nurse-observer relation but also the reliability on the results. Language can be an additional barrier due to a perceived power distance, common in humanitarian work. "Not even my creole (local language) will help to convince him (the local biomedical technician) that we need an honest answer" (visiting surgeon). The unawareness or rejection of the need for change might be caused by 1) absence of reference standards, 2) job security (Johnson et al., 2007) and 3) fatigue of trying to change "It's the organization you need to convince regarding change ideas, most people give up insisting and cope" (visiting surgeon). It is important for a researcher to consider the "invisible rules" by which practitioners guide themselves to bypass problems.

Cultural bias

An open and clear relation about culture is needed in order to avoid incorrect findings (Gurr, Straker, & Moore, 1998; Hofstede, 2001). Although there is value in HFE as an external point of view and guidance of policies and standards, in this context "ergonomic guidelines or standards might exist but that does not mean they are used" (training supervisor). The difficulty in following safety policies, is an indication of a lack of appropriate quality indicators in this setting. The observer is susceptible to bias not only in technical but also in cultural aspects. Examples include reluctance to dialogue in multicultural teams or differing practices towards hygiene. Healthcare-related research also requires attention to ethics and protection of both patient and practitioner. This is particularly relevant in training settings given the implicit additional pressure amongst trainees. These aspects are common in

humanitarian work and offer opportunities for future research. Additional time should be considered for the researcher to accustom with the surroundings and engage with the subjects being studied, creating a shared awareness of problems (Coelho, 2012).

Macroergonomics in humanitarian practice

The HFE approach states that safe healthcare implies compliance with minimal requirements regarding infrastructure, expertise, effective communication, and standardized practices. This study shows a vast number of challenges at different levels of healthcare provision. Some of the challenges identified in this study are comparable to challenges occurring in hospitals in highly developed countries (e.g. Germany) (Matern & Koneczny, 2007). Others however, relate to characteristics of low-resource and humanitarian aid settings where safety standards are seldom applicable and problems are worked around. Many low-resource settings, comparable to Cange in Haiti, depend on international aid organizations and foreign missionary groups for much of the healthcare infrastructure, services (in the form of training or complementary and specialized services). Given this important role of aid organizations, there is much room for improvement regarding healthcare safety.

The earlier mentioned concept of community ergonomics (CE) is an interesting approach to look at the work settings of humanitarian organizations as it could help to refocus aid interventions to address the high incidence of environment- and organization-related OPOs (results from chapter 12.5). The concept of CE has also been applied in the international cooperation context for development and trade, where corporations transfer technology to low-income countries (Derjani-Bayeh & Smith, 2000). In this application of the CE approach, businesses should be redesigned to fit local multicultural dynamics as a key condition for the "survivability, acceptability and long-term success of the corporation". Although aid organizations often share similar challenges with corporations, and amongst themselves, they work and manage their quality differently (Hilhorst, 2002). Besides that, there is a certain degree of unpredictability inherent in their work regarding budget, type and length of assistance (short-term emergencies or long-term development). Budget and mandate restrictions inhibit a more structural approach that goes beyond mere replacement of absent or insufficient services and aims at building a sound and resilient healthcare system. The compliance to minimum equipment standards and basic treatment and management processes, such as the highly recommended availability of a pulse oximetry in surgery by WHO, are essential for a safe transnational healthcare system. Their assurance can contribute to an effective handover of knowledge and services after the programs are completed. This aim does not depend alone on aid organizations but should involve host governments and institutions.

CE proposes an organizational re-orientation of practices towards the community of users. CE is action-oriented and highly participative. This means that the participation of a large diversity of actors in a CE design intervention, in this case the aid and formal local health sectors, requires diversity and conflict management. An important characteristic of the CE approach is the role of a professional facilitator who is responsible for the coordination of efforts and equitable participation of different actors. Furthermore, this facilitator is intended to encourage learning and empower leadership by transferring skills and know-how to the participants. In this case, aid interventions could benefit from a facilitator that engages participants from aid and formal local health sectors in adopting, through safety-related ergonomics, a holistic perspective of their interventions. Such a holistic safety focus should lead collaborative partnerships to overcome organizational barriers by crossing the hierarchy and tackle different phases of a healthcare system. A macroergonomics perspective, can promote the anticipation of system gaps (through identification of latent and active system failures) and inform the design of safeguard barriers (e.g. standardization of equipment and processes, workplace regulation) along care processes and work structure.

The role of the professional facilitator can further ensure the sustainability of aid-related CE design interventions through the empowerment of self-regulation and feedback mechanisms that enable formal local health sectors to independently innovate and manage problems, addressing, on the long-term, emerging challenges in continuously changing and turbulent settings. The contribution of CE in particular, raises awareness and supports the fact that, efforts in teaching and implementing ergonomics in healthcare programs and aid partnerships (e.g. by integration of continuous research, review and dissemination of HFE) would contribute to the development of a safety culture (Gosbee, 2002). This would facilitate a mutual communication and beneficially inform technology development or donation processes.

12.6 Conclusions

This study attempts to be an original contribution to the literature related to safety in healthcare. Performance obstacles, specifically focused on medical equipment, were observed and reported during the training of nurse anaesthetists in Haiti. The results show how the safety of medical device use is affected by the relationship between medical equipment and other elements of the work structure, in particular Environment and Organization. In addition, the results illustrate the vulnerable healthcare working environment in low-resource settings. Finally, several opportunities were uncovered for future research within the field of application of HFE in low-resource settings, namely in regard to the coping strategies and the concept of community ergonomics.

Acknowledgements

The authors thankfully acknowledge the permission conceived by Paul Farmer and Maxi Raymonville from Zamni Lasanté Hospital, and by Médecins Sans Frontières and the dedicated welcoming and collaboration of the nurse anaesthetists in training. This project is financed by a dissertation grant from Fundação para a Ciência e Tecnologia (PTDC/SAU-SAP/118838/2010).

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Appendix P4. Table of observable performance obstacles

	Number OPO's	Percentage	Observable Performance Obstacles (OPOs)
Total	123	100%	
Person related OPOs			
Technology relations with user (patient, healthcare practitioner) intrinsic characteristics (reach, size, mood, skills, expertise and behavior) n=9 (7.3%)			
Ergonomics Device or accessory leads to inadequate posture or discomfort of user	8	6.5%	Inappropriate posture due to incorrect workplace ergonomics (anaesthesia machine and medication behind nurse) (figure 12.4e)
			IV support too high for nurse to reach
			Incorrect monitor position for visualization by nurse (short nurse does not adjust monitor and seems not to be aware it is possible)
			Inappropriate posture (nurse writes on the lap) (figure 12.4g)
			Inappropriate posture (nurse sits with bended back)
			Nurse expresses annoyance, because bed is not high enough
			Nurse complaints about strong incident light on back of patient
			Closet of supplies is too high for nurse to reach
Familiarity User is not familiar with device or accessory	1	0.8%	Confusion with anaesthetic dose (adult/child)
Task related OPOs			
Technology relations with task characteristics (dynamics, variety and density of activity) n=24 (19.5%)			

Workflow settings	8	6.5%	Difficult access to adjust bed
Workflow settings [cont.] Difficult or uncommon (re) adjustment of device or accessory leads to additional or extended tasks			Arm rest is adjusted to give space/mobility to nurse Difficult adjustment of arm rests by nurse Difficult adjustment of arm rests by nurse After surgery, the patient is difficult to position due to attached cables, large weight and sudden involuntary moves Difficult coordination in handling trocar and needles leads to drug spill resulting in loosing track of administered dose Lengthy replacement of new oxygen cylinder (approx. 15 minutes dragging and replacing oxygen cylinder Pulse oximetry, Foley catheter and access to bed adjustments are covered by surgical drape
Multiple users Action requires more than one user	3	2.4%	Interchange of balloon operator Circulating nurse is shared between 2 ORs (the observer was asked to help to open needle package) Nurses help each other
Intensity Action performed quickly or simultaneously	3	2.4%	Nurse multitasking (nurse writes while ventilating patient) Nurse multitasking (nurse holds mask/head of patient while lifting bed) Nurse multitasking (nurse holds mask/head of patient while ventilating)
Adequacy Device or accessory is misplaced, insufficient or ineffectual at needed moment and for specific task	5	4.1%	Lack of resources to warm up patient and avoid hypothermia (high air-conditioning) Microwave (used to heat IV solutions is not available in the room and must be collected in different building) Unused supplies over anaesthesia machine (figure 12.4d) Ineffectual use of pulse oximetry (left idle on the floor) Crowded workspace of anaesthesiologist
Functioning	5	4.1%	Pulse oximetry stops working and reinitiates again after opening the battery lid and fiddling with the batteries

Functioning [cont.] Device or accessory does not function as expected or responds with no intention from user			Two backup pulse oximetries malfunction
			Lamp detaches from wheeled feet when nurse holds it (wheels malfunction)
			Blood pressure device is replaced
			Portable and extra pulse oximetries are available due to frequent malfunctioning of OR pulse oximetry
Environment related OPOs			
Technology relations with environment characteristics (external and internal conditions where and how task is undertaken) n=59 (48.0%)			
Positioning Device or accessory is temporarily arranged for convenience of user in uncommon or dangerous position	17	13.8%	Fixation of cables under patient's head
			Placement of sterilized instrument containers on vacuum device (figure 12.4b)
			Pulse oximetry is placed on the ground (figure 12.4h)
			Pulse oximetry is placed on the ground due to lack of space and confusion
			Placement of diverse supplies and paper registries on anaesthesia machine
			Placement of surgical devices on vacuum machine
			Placement of supplies on vacuum machine
			Placement of medicines on low stool (figure 12.4a)
			Equipment piled up on each other (and used during procedure)
			Placement of medicines on arm rest used as table (figure 12.4c)
			Cables crossing room
			Used glove package left on the floor containing needles (over which observer stepped)
			Nurse crosses OR (and sterile area) to use trash bin
			Nurse crosses OR (and sterile area) to use trash bin
			Sharp container in a corner
			Battery charger on the floor
			Lamp socket is replaced making cable cross over room

Avoidance Device or accessory falls, collides or becomes entangled causing direct hindrance or disturbance of performance	25	20.3%	Pulse oximetry falls Near fall of plate with syringes Pulse oximetry falls during stressful situation Pulse oximetry probe falls Lamp collides with microscope Scissor falls and is not picked up (no nurse available to pick it up) Tube falls when extubating patient Blood pressure cable stuck when patient gets up for administration of spinal anaesthesia Blood pressure and package of vacuum pump probe fall Laryngoscope falls IV fluids fall Cable rolled around nurse legs Entanglement of vacuum device and stool due to limited room space Cables blocks wheels of surgeon's chair Stethoscope falls and gets entangled in cables Cables from anaesthesia machine contribute to a messy environment Stumble causes plugs from devices to be disconnected from wall socket Stumble causes plugs from devices to be disconnected from wall socket Stumble over electric cable Stumble causes instability of IV pole Surgeon is surrounded with buckets and devices on the floor Electrocautery cable crosses room Nurse reaches behind unused oxygen cylinder to access to the electric socket Stumble over lamp legs Wheeled feet of surgical lamp in the way of circulating nurse

Infrastructure Lack or limitation of required infrastructure, space or energy supply	17	13.8%	Followed[1] blackouts (power loss)
			Followed blackouts (during approximately 3 minutes)
			Followed blackouts (one time including generator power loss)
			Vacuum device cannot be plugged in, due to occupied electric socket
			Warming unit (Bear Hugger) must be switched off in order to turn on vacuum
			Blackout forces the electrocautery to be replaced
			Limited space to walk due to overload of people
			Limited space to adjust two surgical tables
			Overload with people in OR (given supervisor explanation)
			Overloaded with people in OR (given complexity of procedure)
			No space to move behind two nurses
			No space to walk around surgical table
			Lamp adjustment requires changing light socket
			Limited space to pick up fallen equipment from the floor
			Busy floor around nurse
			Nurse writes in the dark, using mobile telephone light due to blackout
			Lack of space to write (nurse writes while standing)
Organization related OPOs **Technology relations with organization characteristics (managerial and logistical settings and decision making) n=31 (25.2%)**			
Availability Required device or accessory is not available in hospital stock and cannot be timely acquired	9	7.3%	Medication is shared between ORs due to stock insufficiency
			Laryngoscope is shared between ORs
			Paper notes taped are on the wall due to missing white board
			Sharp container is shared between two ORs
			Use of microwave to heat up blood

Availability [cont.]			Use of inappropriate tool to tighten bolt of oxygen cylinder
			Use of sterile glove to cover battery of the surgical drill
			Different pulse oximetry models available
			No standardized oxygen stock (pure oxygen instead of air mixture)
Storage Lack of designated storage location for device or accessory	4	3.3%	Locked storage cabinet containing urology equipment stored in OR and of forbidden use for other disciplines
			Unused cylinders in OR
			Unused vacuum devices (n=3) and lamp (n=1) are stored in corridor at entrance of OR (figure 12.4f)
			Old and broken radiology device kept at entrance of OR
Condition Poor, old or deteriorated device or accessory; incomplete, broken or not calibrated	13	10.6%	Nurse replaces batteries with other batteries (old) which does not seem to work
			Three lamps (not fully operational)
			Rusty bed
			Overused batteries
			Deteriorated and unlabelled cylinders
			Domestic refrigerator used as blood bank
			Broken lamp
			Use of tape to secure lamp transformer
			Air conditioning is either on or off
			Use of tape to repair electric cables
			Noisy vacuum pump and air compressor
			Idle wall clock
			Notes from maintenance on anaesthesia machine

Hygiene Device or accessory is subjected to (inadequate) cleaning practices	5	4.1%	Nurse repacks unclean suction tube Unclear shoe cover policy Domestic method of sterilizing devices Door between ORs is kept open Presence of (flying) insects in OR

"Followed" OPOs occurred more than once during the same procedure
OR - Operating Room;

MEDICAL EQUIPMENT IMPROVEMENT THROUGH SYSTEMS DESIGN

13 Key challenges of product development for humanitarian markets [publication 5]

This chapter was published and presented as: Nielsen, B.F., Santos, A.L.R (2013). "Key Challenges of Product Development for Humanitarian Markets". In: Proceedings of the Global Humanitarian Technology Conference 2013: California, USA.
(Both authors are first authors)

Abstract

There is a clear increase in the frequency, complexity and length of humanitarian crises. This trend has driven the attention of donor governments to the private sector in search of more cost effective solutions for the provision of aid. While the challenges that emerge when humanitarian values meet business interests in the humanitarian market have been explored, little is known about the perspective of enterprises from the private sector and how they approach the humanitarian aid context. This study aimed at exploring how characteristics, specific to humanitarian aid affect product development activities. In fact, mismatches between business and humanitarian systems go beyond the creation of logistical systems and extend to product development activities and adjacent servicing. We consider the findings a contribution to the definition of priorities for the future collaborative development of products and services by private sector and humanitarian aid stakeholders.

13.1 Introduction

The occurrence of humanitarian crises, such as conflicts, natural or industrial disasters, triggers the response of multiple international stakeholders to provide different kinds of assistance to the affected populations. This international response generally implies the deployment of products and services that temporarily strengthen or even replace disrupted local activities. A market emerges in the aftermath of the crisis, heavily represented by international and national non-governmental organizations (NGOs). It also includes donors, service providers and enterprises that develop, purchase and distribute goods such as food, shelter, medical equipment and energy generating devices. We define this as the humanitarian market. In this paper, we focus on the humanitarian market in developing countries, where the distribution and adoption of products and services in the aftermath of a crisis is particularly challenging.

There is general agreement that humanitarian aid and therefore the humanitarian market is guided by the belief that humanitarian aid should seek short-term solutions as opposed to development aid's traditional focus on long-term goals. Since 2000, the humanitarian share of international official development assistance (ODA) has ranged from a low of 7.5% in 2001 to a high of 10.2% in 2005. With the clear increase in frequency, complexity and length of humanitarian crises, donor governments are looking to the private sector for cost effective solutions for the provision of emergency aid (Binder & Witte, 2007; Tomasini & Van Wassenhove, 2009; White & Lang, 2012).

For enterprises, the humanitarian market represents challenges different from traditional consumer markets. In fact, the development of knowledge in the humanitarian field is said to be lagging behind the private sector (Thomas & Fritz, 2006). Distinct characteristics of humanitarian logistics and management include, but are not limited to: high levels of uncertainty and lack of information, the diversity, ambiguous objectives and location of ad-hoc stakeholders who often have poor oversight and unclear authority, time to respond to an immediate need, and limited and often devastated human and capital resources. These factors necessitate a rapid shift of priorities, conditions and supply chain elements. Furthermore, there is often unanticipated and inappropriate delivery of equipment, as well as personnel. The humanitarian field is also characterized by intense media involvement, an independent funding structure and a highly politicized environment. There are no guaranteed wins and no accommodation for the return of products through the same logistics systems to solve end-of-life stages of products (Overstreet, Hall, Hanna, & Rainer, 2011; Sharman, n.d.; Thomas & Fritz, 2006; Tomasini & Van Wassenhove, 2009; Whybark, Melnyk, Day, & Davis, 2010).

Academic research has focused mainly on describing logistical factors and supply chain management within humanitarian systems (Oloruntoba & Gray, 2009; Overstreet et al., 2011). Mays (2012) argues that "instead of starting with logistics systems designed for maximizing business effectiveness […] academics could better contribute to the science of humanitarian logistics by starting with deeper understandings (of) humanitarian work and pursuing new designs from the "ground up" that can support goals and constraints driven by humanitarian values" (Mays, Racadio, & Gugerty, 2012).

With this study we aim to contribute to this field by exploring, from the perspective of enterprises, how these mismatches affect product development. Are mismatches between the private sector and humanitarian aid limited to logistical issues, or are there other challenges within this system that affect the ability of enterprises to be involved in this market? Are there particular challenges, from the enterprises' perspective, that need to be taken into account when attempting to redesign the humanitarian-enterprise relationship as Mays suggest?

13.2 Method

This exploratory study is based on a group of semi-structured interviews (n=11) with product development enterprises from multiple representative sectors in humanitarian aid including healthcare, energy and water provision. The products used in these sectors (e.g. anesthetic devices, lighting solutions, emergency water tanks) require specific technical knowledge to perform and are often cost intensive. A requirement was that the participants were all responsible for or highly involved and familiar with the product design process within the company. The enterprises selected further base their supply on mass production rather than small scale local production. Each participant was interviewed alone and all interviews lasted for between 45 minutes and one hour. Three of the interviews were conducted through skype, the rest in person.

Graphic Elicitation

During the interview a graphic elicitation tool was shown to the participants. Then, the interviews were aided with graphic elicitation in which the interviewees were asked to prioritize into three distinct levels of keywords. These levels (figure 13.1) represented concepts which need to be considered when developing products for humanitarian aid purposes. The supplied keywords (n=18) were based on literature about sustainable product development and describe the key factors relevant to product life-cycle (Crul, Diehl, & Lindqvist, 2009; Roozemburg & Eekels, 1995).

The following keywords were used: “safety”, “cost”, “robustness”, “manufacturability”, “maintenance”, “logistical factors”, “integrated functions”, “resources needed for use”, “cultural aspects, “lifespan”, “standards”, “degree of innovation”, “brand image”, “aesthetics”, “adjacent services”, “degree of innovation” and “ergonomics”.

The participants were asked to argue their choices, explain how they address each key factor and what challenges they face doing so in this specific market. The use of graphic elicitation as a visual support tool to facilitate discussion and stimulate the interviewees to think out-loud has been used and referred to in other similar situations with the purpose of understanding decision processes and reflect around these (Bagnoli, 2009; Crilly, 2006).

Data collection and analysis

The data was collected though voice recorders and included the prioritization of keywords and the recorded reflections of the participants. The interviews were recorded for the purpose of transcription and qualitative coding. From the prioritization of keywords a percentage analysis was illustrated in a graphic (figure 13.2) that shows the results of all the data collected.

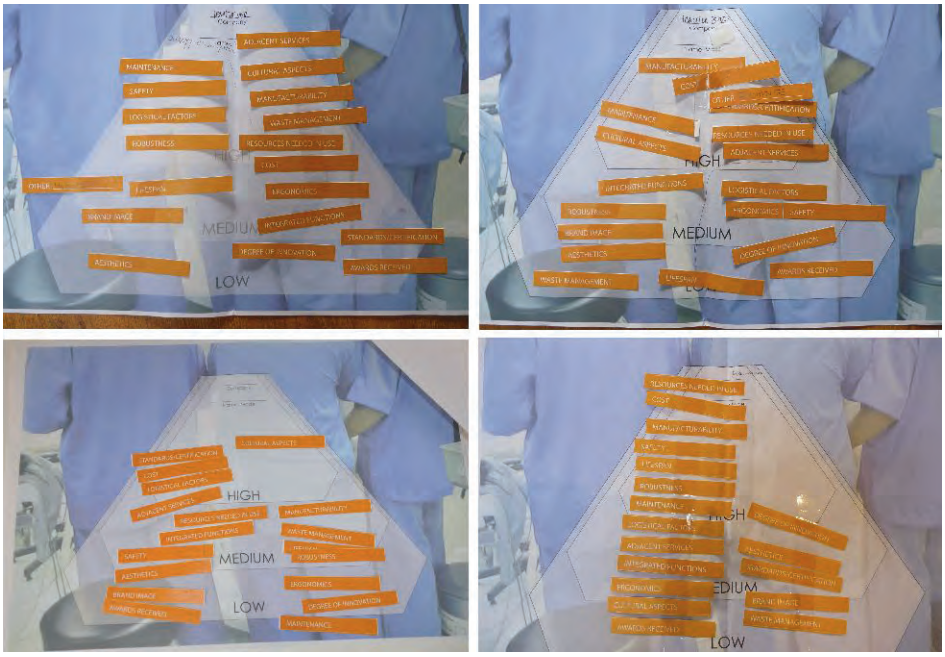

Figure 13.1 Graphic elicitation tool: four examples

The percentages are discussed in the findings chapter of this paper. Due to the limited scope of this paper the relative prioritization of keywords and the comparison between product sectors will not be discussed. Codes were generated from the interview transcripts. For each keyword, challenges were identified by the participants. Afterwards codes were iteratively clustered into general categories of challenges, by the two first authors, separately. Both authors discussed the final categories of challenges until consensus was reached.

13.3 Findings

Figure 13.2 describes the absolute prioritization of all enterprises interviewed. Safety, manufacturability and robustness were described by 64% of the interviewees as a concept having a high priority. On the other hand, awards (73%), waste management (45%) and degree of innovation (55%) were the three keywords with the lowest priority classification. These classifications of keywords into high and low priority, demonstrate that low priority keywords include factors which enterprises have little control over. Keywords classified as high priority were controllable characteristics which are often mentioned by humanitarians as fundamental product attributes. The most discrepant keywords, where there was no uniformity amongst enterprises prioritization, were “adjacent services”, “cultural aspects”, and “aesthetics”. These were also considered not applicable by the different enterprises.

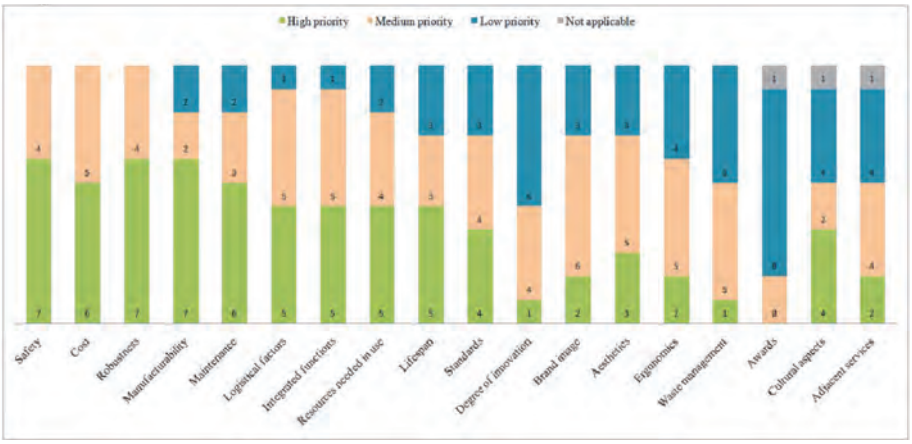

Figure 13.2 Prioritization of key factors in product development for the humanitarian market

This data does not allow us to specify whether these aspects are dependent on the enterprise, business and/or sector. Further investigating these discrepant keywords will allow the creation of an understanding about which variables exist amongst sectors, how systematic they are, and how they can be distinguished from traditional consumer markets. Contradictions, such as safety not being seen as dependent on ergonomics, or maintenance being seen as the only relevant adjacent service, are interesting findings but do not belong to the scope of this paper. Additional sector specific studies with larger sample should be conducted.

The reflection of the interviewees made during the prioritization exercise allowed the authors to derive the recurrent challenges related to each individual keyword. By categorizing quotes that referred directly to the customer-enterprise relationship in the humanitarian market, the authors were able to identify four key challenges that are particular for this market: time and context, finance, stakeholder network, supply chain and information flow.

Key challenge I: Timeframe and context

The humanitarian aid timeline is structured by mandates and is composed of different phases. There are several nomenclatures used, but in general the humanitarian community refers to immediate relief, transition and recovery and development. Usually these phases are assumed to be sequential, but it is not uncommon for phases to occur simultaneously or populations to shift between one phase and another. In addition, there is no specific timeframe for the length of each phase, so there is no way to plan for the end of one phase and the beginning of another.

The specific crisis, and environmental context will determine which product needs to be supplied and whether or not the product will be appropriate for that community.

For example, a water tank created for use in a disaster relief situation might not be the best solution for a refugee setting with stable water access. Most products distributed in an emergency phase will be donated. They will not be reused by the same organization for another emergency purpose. In this scenario, it is likely that products that are not self-sufficient in terms of energy or maintenance will not last. It is not clear to enterprises how long products need to last, and due to the limited time of an organization's mandate, this results in short term thinking and limits interest in investing in durable and thus more cost-intensive solutions for both enterprises and customers.

Key challenge II: Finance

By finance we mean the structure of costs (cost and responsibility) throughout the products' lifecycle, including the product development cost to end-of-life costs. Throughout this process there are different services that need to be planned, outsourced, and paid for. According to the participants, the humanitarian market is strongly driven by donor priorities. These priorities determine the allocation and timeframe of budgets. Most of the budget is allocated to shipping and handing over the product. "Cost is dependent on the type of client" (interviewee M2). For enterprises, this results in poor oversight of costs for product development processes and for the affordability of products. Concept development, use and end of life typically have no allocated financial, physical or human resources from the donor or customer side. However it should be noted that these resources are particularly limited in this market. "Whole life costs are an absolutely vital area […]. When you have organizations running on annual budgets they will purchase these at a relatively cheap products but which cost a fortune over the next years" (interviewee M1). "People need a lot of time to decide, especially in Africa and NGO so financing is a problem" (interviewee M2). By not facilitating the iterative design process this lack of support inhibits the ability to improve products. Budget limitations leave no room for alternative product attributes such as eco-friendly materials. According to the participants, instead of increasing product sustainability, enterprises are led to decrease lifespan to fit budget agendas. "Robustness is important […] you must balance it with cost. The more robust a product is the more expensive. If it is an emergency, then it is of absolute priority that the product delivers work without risks" (interviewee M4). "Lifespan is unfortunately medium/low priority. You must balance it with the costs it implies" (interviewee M4). Finally, this short term thinking prevents long term engagement and investment in building local capacity or partnerships that could support product development (e.g. business expansion).

Key challenge III: Stakeholder environment

"There is no single intergovernmental mechanism providing policy elaboration, coordination, governance and strategic management of humanitarian and humanitarian-related matters across the United Nations system" (interviewee E1).

The humanitarian market is influenced by the complex and unpredictable setup of active stakeholders. This network involves multiple international and national actors, development agencies and host governments throughout the different phases of aid. All of these stakeholders are present in different numbers, types, intensity of intervention and capacity to relate with other organizations. There is poor oversight over available resources through different phases of aid. "Most of locations, countries I go to, there's no servicing at all […] it depends on where used and what sort of environment whether or not there will be people paid to do it and whether or not manufacturers will be willing to go to that location" (interviewee M1). "Maintenance technology that is required per amount of maintenance, it's good to keep that in mind as we continue to develop the product" (interviewee M3).

Enterprises face difficulties finding suitable business models and long term, trust-based relationships. This is due in part to the varying demands amongst stakeholders and inter-agency dynamics, and the distinct requirements amongst locations and circumstances. Furthermore, enterprises which manufacture and export products must operate within an environment restricted or supported by political priorities determined by the country of registration. "If a company in India or China will apply the same concepts we do here this works fine, otherwise all it becomes are barriers to trade […] increases the cost for one and not for the other" (interviewee M1). This particular relationship between the enterprise-customer in the humanitarian market results in poor product performance. This may further be a barrier to innovation and sustainable markets that we will elaborate upon in a separate paper. The complexity and constant change of customers to relate to and the lack of expert knowledge about local technological systems make it challenging to hold a stakeholder accountable for product shortcomings and quality control. Consequently, this affects the necessary trust in and reputation of enterprises in this market.

Key challenge IV: Supply chain and information flow

A supply chain is a system of organizations, people, activities, information and resources responsible for moving a product between enterprise and customer. The humanitarian supply chain affects product development from purchase to handover. Information flow concerning the products' supply is regarded as a part of this challenge, since it is limited by the humanitarian supply chain design.

Humanitarian customers typically purchase products based on generic needs assessments and product availability. Normally product requirements are derived from practical supply and packaging restrictions such as stock availability, quantity, dimensions and weight. As seen in figure 13.1 this results in a consensual prioritization of self-explanatory requirements such as "robustness" or "safety". Enterprises who use standards and certification as a way to define requirements claim that the available standards do not correspond to reality. "There's a small clause in the Medical Device Directive that says: the equipment must be suitable for its environment […]][and] for the level of skills of the operator. Everybody ignores that. There are no qualified doctors […] they did a really good job, but technically they're not allowed to use the equipment" (interviewee M1).

Designing for humanitarian markets involves a process of one way communication, funding and products. This system does not facilitate the return of products nor information after distribution. The enterprises approached in this study claim there is no access to important knowledge about product lifecycle phases such as use and end of life. The needs and characteristics of the end user context are not a priority according to the participants. Demand is driven by donors and policies more than customer or end-user preferences. This lack of knowledge about the user phase of a product leads to a lack of context specific products. "We don't have control over who is using it, but we can control how our products can be used" (interviewee M3).

For enterprises, this is a highly inefficient model for product development in terms of cost and time invested even though it may not affect the customers. At a product level, this information limitation leads to a follower approach to the market in which the product development is based on existing and tested solutions rather than product improvements.

13.4 Final remarks

The research findings from this study support the suggestion made by Mays et al. (2012) that many challenges originate in the fact that businesses and humanitarian systems mismatch and that this needs to be solved for humanitarian goals to be met in effective and efficient ways. This study has shown that this is highly affecting the design process and may be an obstacle to innovation and impact of technological innovation. This study is a contribution to the body of knowledge about specific challenges of humanitarian work. As shown in this study, business effectiveness is not only dependent on addressing logistics from the "ground up", but also aspects such as policy, coordination and information. Besides acquiring a deeper understanding of humanitarian values, the redesign of humanitarian logistics can benefit from learning from the experience of enterprises presently involved in the humanitarian market.

Four interlinked key challenges were identified in this study, which provide insights that show how products are being prevented from contributing to more effective humanitarian work. The humanitarian sector can benefit from an awareness and understanding of the long term implications of distributed products and services: how will products be used, maintained and disposed of and by whom (e.g. local healthcare facilities or households).

Enterprises can have a stronger impact by playing a more participative role, and the humanitarian sector should create mechanisms to facilitate access to enterprises. Further research should focus on collaboratively building precise and industry specific indicators and strategies to address the challenges identified in this paper. This can be done by initiating and supporting pilot projects that extend beyond the traditional timeframe. These projects must involve both stakeholders and enterprises in order for enterprises to demonstrate that product development can play a role in achieving more sustainable and efficient models for humanitarian work (Ramalingam, Scriven, & Foley, 2009). Academics can play a key role in bridging knowledge and practice in these projects through an interdisciplinary effort to systematically design, implement and evaluate these projects. "You first need to prove that it works with a business attached to it, there is more interest to finance the start, idea on paper doesn't work, I always start building" (interviewee M2).

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14 The value of collaborative design to address the challenges of the humanitarian sector [publication 6]

This chapter was published and presented as: Santos, ALR., Capet L., Diehl, J.C. (2013). "The value of collaborative design to address the challenges of the humanitarian sector". In: Proceedings of the International Conference on Integration of Design, Engineering & Management for Innovation: Porto, Portugal.

Abstract

This paper proposes an innovation approach based on collaboration and design thinking to address the challenges faced by international aid organizations in humanitarian disasters, through the co-development of products and services. The proposed approach was iteratively designed and used in two international workshops. The results show that collaboration and design thinking tools can empower the humanitarian sector to identify opportunities for innovation and create a shared vision for a more sustainable and efficient aid.

14.1 Introduction

International aid organizations such as Medécins Sans Frontières or the International Federation of the Red Cross are increasingly involved with innovation. With the growing number and complexity of humanitarian disasters and the pressure to professionalize, the humanitarian sector is driven to reinvent itself by adopting business management approaches involving a more sustainable and efficient use of resources through more standardized and formalized work practices. The need for transparency and accountability are key values for organizations to be competitive amongst the sector. At the same time, the increase in visibility of high-profile emergencies such as the Indian Tsunami (2004) or Haitian earthquake (2010) has led to an emerging humanitarian market, in which the private sector participates by providing complementary services (i.e. logistics) or making in-kind (i.e. immediate aid supplies) or monetary donations. This is a highly asymmetric market formation where the consumer (i.e. the aid recipient) and the producer have an indirect relationship since the transaction between them is not financed (nor chosen) by the customer but by public or private donors. Furthermore, there is a strong focus on high profile emergencies rather than chronic emergencies or development aid. The distance to the customer and end-beneficiary leads to a forced adoption and dependency on a specific brand or technology at the cost of focusing on real needs. Although there is little research

in this field and no conclusive evidence of the drivers and strategic aims for the engagement of private sector in humanitarian crises, Binder (2007) suggests four drivers behind this engagement: build a positive brand, involve and stimulate staff, gather business intelligence, and, finally, a desire to "do good". In their analysis of corporate engagement cases, there is a trend among companies in the field towards a more strategic and long-term planning, and a recognition of the need for consistent learning. Nonetheless, recent reflections from business experts suggest that the sector is changing towards a demand driven sector, in which the beneficiary of aid plays a central role in defining how aid is provided (Sanders, 2009).

Innovation initiatives such as the Humanitarian Innovation Fund, the Shelter Centre and Speedkits accentuate the relevance of the collaboration between humanitarian and industry stakeholders to address these challenges. These innovation initiatives range from the development of appropriate technology to process and service redesign. They rely on an information network of humanitarian organizations with different focuses and make use of different but mostly unsystematic or not reported approaches to bring innovations to implementation. However, these initiatives face several challenges, inherent to the humanitarian sector that inhibit their capacity to effectively innovate. Firstly, the unpredictability and diversity of possible emergency scenarios and the different disaster locations makes the response systems very complex. Humanitarian organizations have strict operational programs relying on their own experience, often not flexible for process change. Furthermore each organization belongs to a hierarchy within the sector and each owns individual, non-standard regulations (Brigaldino, 1996). Companies in the field have expressed difficulties in supplying this market because they often face conservative and contradictory conditions regarding the formulation of requirements and testing conditions, required for the innovation process (Nielsen, 2013). This is the result of a complex network of stakeholders including international and national organizations, donor entities, governments and local partners, that have different and often conflicting mandates, and that depend on media attention and funding to operate. The humanitarian principles are also often mentioned as a limitation for a long term involvement since, being associated with - and thus favouring - a determined supplier or organization, could mean compromising neutrality and impartiality. Finally, the lack of required expertise within the sector makes them have a reasonable reluctance in dealing with the involved risk and a strict budget allocation that limits any parallel or tentative activities (Ramalingam, 2009).

The context of humanitarian transition

This research proposes an innovation approach that focuses on a particularly challenging phase of humanitarian interventions: the "transition" phase. This phase is bounded between

short-term focus interventions (i.e. the international response to a sudden earthquake) and long-term focus interventions involving reconstruction efforts and the empowerment of the beneficiary community. This "transition" is critically important and often troublesome. It is characterized by unclear boundaries in terms of time and responsibilities, and it involves a complex process of transferring services between multiple stakeholders.

Figure 14.1 shows the case of varying healthcare quality as an example of aid provided in humanitarian crises to illustrate the process of humanitarian "transition". Humanitarian crises are defined as sudden events that disrupt on-going systems with a variable scale and frequency. The degree of socio-economic development but also factors such as political stability and infrastructure development affect the capability of a country to withstand the impact of such a sudden event. When e.g. a natural disaster or flee from conflict occur in the capital of a developing country such as Haiti or Sudan, the quality of healthcare services decreases drastically due to several systemic factors that lead to disruption and overwhelming of on-going services: Urban overcrowding, poverty and inequality, poor building and road infrastructures. These circumstances are shared by several countries, which in addition, are often located in disaster-prone regions, making them particularly vulnerable to the imminence of a crises.

The intervention of international emergency relief organizations is mandate driven and mostly dependent on donor financing with a specific end. These interventions are short-term focused and aim at the immediate life-saving operations but can also be sustained if a sudden crisis becomes chronic due to continuous instability, disorder or if local entities do not take over responsibilities. In order to operate, international emergency relief

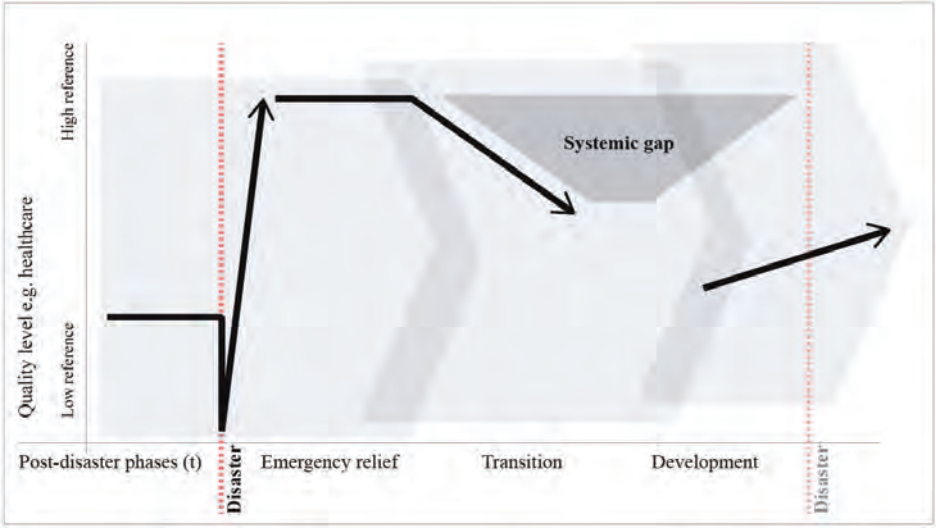

Figure 14.1 Time-line and transitions in post-disaster humanitarian aid (specific case of healthcare)

organizations must raise the quality of healthcare much above the previously existing one by deploying and setting up a resource-full yet temporary reinforcement or replacement system. High quality care can be provided by international teams with experience to deal with the emergency medical and logistical challenges (Emergency relief in figure 14.1). When, and if, the normal circumstances are re-established after the emergency (period that can take months to years), the international emergency relief teams retrieve and most often donate the initially deployed products to local organizations or authorities.

Several systemic context factors regarding this one-sided transfer are not taken into account. First there are environmental and economic implications that hinder the proper adoption of these products. Second the products will have a handicap of relevant services that are not established or are malfunctioning e.g. maintenance and respective tools, supply. These services are impeded by the lack of technical knowledge, responsibilities and regulations. This is particularly relevant in healthcare where donated medical devices pose safety threats when misused, not maintained or missing disposable supplies. Consequently this results in a progressive decrease of the quality of healthcare. In the next phase of the time-line (Development in figure 14.1) it is up for development agencies to support the affected populations to reconstruct their livelihoods. These organizations generally work with a long-term perspective and are focused on goals to build sustainable healthcare structures.

The amplitude of the changes in quality, in this case of healthcare, to which populations are subjected to throughout this time-line and the loss of potential resources and opportunities by organizations is what is addressed as "transition" between the emergency relief and development. This phase involves not only a technological gap but also an organizational one, where several systemic context factors play an influence, including policies, socio-technical infrastructures and knowledge (Systemic gap in figure 14.1). Exit and handover strategies, responsibility and funding are some of the key issues subject to currently on-going discussions (Lloyd-Jones, 2006; United Nations, 2006). Similarly to healthcare, the same issues can be broadly highlighted in the fields of e.g. education, water and energy provision, shelter and food.

14.2 Challenges for innovation in humanitarian transition

Humanitarian collaboration

The complexity of humanitarian collaboration is related with the involvement of many stakeholders for the planning, implementation and monitoring of humanitarian projects, in any intervention phase. Different organizations must rapidly coordinate to fill in the gaps of services, properly manage resources and avoid double work. For this communication,

sharing information and working in consensus is essential. The required logistic and organizational knowledge of these organizations is mostly based on their past experiences and therefore have established logistic mechanisms to cope with uncertainty. Because this knowledge is complex, diverse, and unsystematic it becomes difficult to share it. In addition to their number and size there is also the variety of geographic locations, of cultures and languages, which can difficult collaboration. Often this collaboration involves political negotiations (Hehenkamp, 2013) which are not determined by the same humanitarian principles, this increases the degree of uncertainty and efficiency of aid. The effort to make a smooth and sustainable transition between phases lays at the intersection of very complex humanitarian activities, and therefore a high level of collaboration is required.

The need to define transition

The humanitarian transition phase described above is poorly understood, and therefore poorly addressed, in terms of the needs and barriers of transfer of products and services. There is a difficulty in defining requirements for this phase and understanding the different perspectives of the multiple stakeholders involved. Furthermore given that there is no allocated budget for this phase, responsibilities tend to blur and evolve unsystematically. Nevertheless, understanding this phase is essential condition to assure the impact of humanitarian interventions and a positive reputation of aid as an activity focused on real needs. Intervention in the "transition" phase should not solely rely on relief organizations, whose scope and expertise is limited, but also in the efforts of local governments and organizations to take over responsibilities, and of companies to deal with risks such as liability and staff security. The initiative behind this research is focused on identifying opportunities in transition to address issues such as product lifecycle and handover of products and services by adopting a systems perspective to understand the context, involving stakeholders from both short- and long-term focused aid phases.

Competitiveness driven aid

Academic research about humanitarian work has mainly focussed on describing logistical factors and supply chain management within humanitarian systems while there is little information available about the context of transfer of products and services on the long term. Although the "humanitarian market" is an emerging field, there is no description of a systematic approach for the development of products and services for the humanitarian context (Ramalingam, 2009). This paper aims to contribute to the dialogue on "humanitarian innovation" by offering a space for discussion about transition through innovation. The authors describe a systematic approach to product and service development focused on needs identification, exploration and recognition of opportunities. The triangular grey

area market in figure 14.1 (Systemic gap) intends to demonstrate the scope of possibilities, overarching different systemic context factors, to ideate a solution, inherently adequate for both approaches. This approach is intended for the use in collaborative initiatives involving humanitarian organizations, field practitioners and aid beneficiaries, academic and professional design experts.

14.3 Methodology

In order to overcome these challenges and explore innovation opportunities in the humanitarian field, the Design for Sustainability Research Programme at the Faculty of Industrial Design Engineering from Delft University of Technology (DUT) (Delft, Netherlands) and the D-Lab from the Massachusetts Institute of Technology (MIT) (Boston, United States) joined forces to develop and test an approach based on the design and engineering experience of both Universities: "Rethink Relief" (RR). Three main goals were defined to address: 1) Facilitate discussion between stakeholders with different perspectives of aid, creating a platform for interdisciplinary collaboration, 2) use design thinking focused on specific problem solving and evaluation of trade-offs to enable the co-creation of a shared mental model of "humanitarian transition" in which consensus is reached from both sides of transition and finally, 3) create a systematic process focused on the development of combined products and services to explore competitiveness added value of the resulting solutions that promote a discussion of whether and how design thinking can contribute to the improvement of humanitarian aid.

Consequently two international workshops were organized in sequence (2011 in Delft and 2013 in Boston) in order to iteratively develop, evaluate and improve the proposed tools. Both were attended by twenty-five experts from both the design engineering field and from emergency relief and development organisations. Amongst the different backgrounds and nationalities there were also participants who experienced the humanitarian transition phase themselves. The participants were invited to reflect on the unmet needs in the humanitarian technology space, and to address specific problems using the proposed approach. During a full week, they exchanged practices and experiences, guided through mediated discussions and a design process that includes activities from problem analysis to detailed concept development (figure 14.2). The expected outcomes were a series of concepts that represent the basis for a discussion about transition.

The role of collaborative design

The proposed innovation approach is based on systems and design thinking and is focused on problem framing for needs identification during the development of products and

services. It uses a collaborative design methodology for co-development of products and services. Design methodologies use a holistic approach to problem solving and involve an in-depth understanding of complex socio-technical systems, combining existing practice standards and policy with life-cycle and user-centred design. With the actual broadening of the design practice to follow up with societal demands of the present such as environmental and social driven design, design practice has turned towards integral human activities, wishes and experiences (Buchanan, 1992; Dorst, 2006). This leads to an increase in the relevance of participatory approaches, involving and empowering new and different stakeholders as decision makers throughout the design process, allowing them to influence the end product by sharing their experience and perspective as experts in use.

Nowadays, the management of communication and collaboration became a critical quality in design (Kleinsmann, 2008; Mattelmäki, 2011). Another key aspect of design is the way a problem is re-framed, since the designer does not work with the problem as given but elaborates on a higher and more abstract level and reviews objectives (Cross, 2011). The complexity of the emerging focus of design in social problems demands that design broadens its scope of action to more than redesigning products to overcome certain barriers (e.g. energy consumption or affordability) towards a scope focused on a combination of systemic changes that, combined, result in more sustainable and effective value for stakeholders. Developing products and services in parallel and in collaboration with multiple stakeholders leads to strategic integrated solutions (Lockett, 2011) in which e.g. products are configured in a way to facilitate the efficiency and future transition of a supply chain, and that have a larger potential to create more change.

Interdisciplinary collaboration

Exposing a diversity of stakeholders with different backgrounds and expertise to new perspectives and practices that have the potential to create impact in the improvement of current practices. The collaborative format allows gathering divergent opinions from the discussion of parties rather than independently consulting them. Its interactive character and its focus on specific problems of technology life-cycle, as opposite to policy-level issues, enables the stakeholders to effectively share and disseminate their knowledge.

Design thinking tools

— The followed process uses design tools to come to consensus when framing problems. The process is initiated with a "blue-sky thinking" approach, strongly focused on the understanding of a problem rather than being constrained by re-design of pre-existing technological solutions.

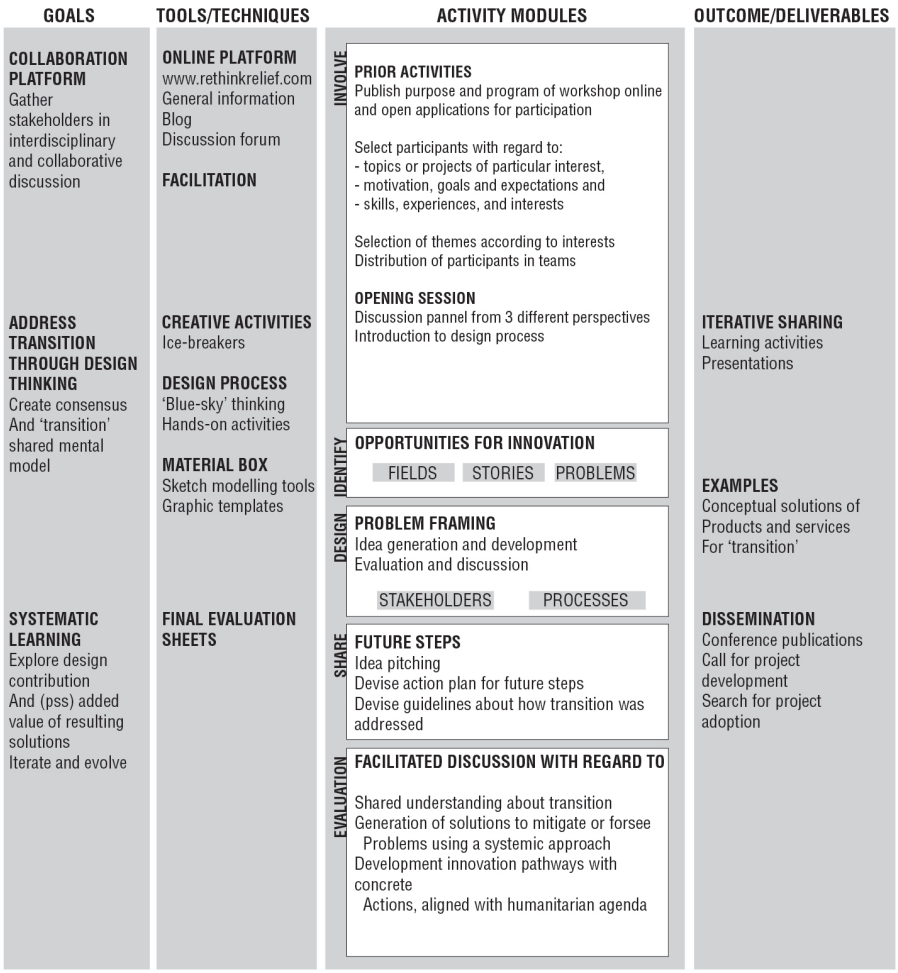

Figure 14.2 Outline of the proposed approach and its main characteristics

— "Hands-on activities" such as the materialization of ideas in small-scale models (i.e. mock-ups and prototypes) allow participants with different abstraction capabilities to understand each other and discuss openly.

— Designing a tangible solution within a team composed of different stakeholder perspectives allows participants to iteratively building a shared mental model of the aid system by collectively choosing the necessary trade-offs to come to a solution.

— This collaboration places the recipient of aid in the centre of the discussion and innovation process. The resulting concepts of products and services have therefore an added value given that they are demand driven and result from a bottom-up approach to understand barriers from different systemic context levels.

Experimentation character

The chosen approach can be systematically followed by facilitators and repeated in different contexts.

14.4 Results

Eleven concepts of new product and services have been developed based on the shared visions from the participants of the two international workshops (Santos, 2013). Table 14.1 provides an overview of the resulting projects, organized by theme. These projects represent pilot concepts that embody the concerns expressed during the interactive sessions regarding the role of humanitarian technology in the transition phase of humanitarian interventions. They are meant to sensitize the different stakeholders and facilitate the discussion amongst emergency relief and development. In order to illustrate how the resulting concepts addressed transition, one example is described in box 14.1.

In order to establish a learning mechanism for the systematization of the proposed approach, an analysis was made of the eleven resulting concepts to derive recurring issues at both solution and process levels and translate them into key attributes or strategies to address humanitarian transition (appendix P6, p.226).

Table 14.1 Overview of projects from RR 2011 and 2013

Project theme	Description
Water	System for rainwater collection and distillation
Water	Versatile installation water duct and flexible piping system
Water	Tap stand design with spillage collection
Healthcare	Compact and modular concept of hospital stretcher with storage and hanging space
Healthcare	Alert system to mitigate loss to follow-up in patients with mobility aids
Protection	Personal portable lighting solution developed to protect the vulnerable in the dark
Energy	Customizable energy platform collected from multiple sources from community practices
Transport	Low cost, modular and scalable transportation unit, coupled to multiple means of transportation
Packaging and waste	Solar water disinfection box as a solution for the waste accumulation in post-disaster settings
Education	Educational game about how emergency prevention
Economic power	Co-creation centre to generate awareness within community about use of resources and skills

Box 14.1 RR'13.W01. Water Related Well-being in Relief - RR 2013

by Chanthan Hel, Joos Van Den Noortgate, Mogboluwaga Olubunmi and Swarnika Prakash

Problem Focus: In refugee- or internally displaced people camps, aid organizations typically provide 15 to 20 litres of water per day per person, out of which only 2 to 3 litres are used for drinking. However, about 10-20% of water is wasted due to inefficient usage. This quantity of water is provided by quickly deployable kits composed of a piping system and taps that need to provide it in a safe manner to reduce risk for contamination in highly populated settings like refugee camps.. Poor access to – drinking and washing - water has serious public health impacts

Aim and shared vision of transition problem: Optimize water consumption in order to generate improved health and well-being.

Solution description: The team created a simple solution to optimize water consumption through collection, that follows the standards of Médecins Sans Frontières and can be integrated in existing emergency kits. A tap and articulation filling arm were designed to be attached to the existing piping system that requires no contact with hands (potential source of contamination). The original crate used to transport the emergency kit is used as a spillage collector which allows the water to be reused for numerous purposes such as flush latrines and agricultural fields and prevents the formation of a puddle under the taps. The concept also involves the conversion of water distribution points into communal zones where different water related activities can be carried out such as hygiene, laundry and dishes.

Problem framing addressing transition: This concept has been developed with different priorities in mind: Firstly, the core of this concept is a tap designed to fit in the existing crate, in accordance with emergency relief practices, logistics and standards. It is modular and because it uses existing resources (crate) it can be set up very quickly, as opposite to the currently used concrete tap stand and spillage container. The new system saves water by re-thinking usage practices and it has an added value for safety, reducing risk of contamination on the tap and on the floor. Regarding the transition phase the concept "grows". It allows the installation of different ways of using spillage water, and it is flexible to take into account cultural diversity, offering choices about how to shower. It is located in community place stimulating sense of ownership so that maintenance is assured. For the development phase the concept has in consideration the creation in the future of complementary solutions such as irrigation for vegetable gardens using high quality water (filtered) to reduce the dependency in food related aid and eventually allow the generation of income by garden owners.

Competitive added value: This concept has focused on the reuse of existing resources and usage optimization rather than on solely technological solutions. As such it represents an incremental step, organizational wise, to the current practices of Médecins Sans Frontières implying low financial investment. Relocating and re-purposing the water-related activities, creating a recreational area allows people to make part and responsibility of the change, which is assumed to facilitate the adoption process. This focus has allowed the group to create a product that offers more than water, but offers opportunities.

The list presented in appendix P6, p.226 is not intended to be extensive but to illustrate the interdependencies in the discourse of the participants. They do not cover issues such as manufacturing or business profit although their value for the humanitarian market stakeholders are discussed in the next paper chapter.

14.5 Discussion

The mismatched allocation of resources by emergency relief and development organizations leads to large changes of amplitude of quality of life of communities affected by disasters and to an unsustainable use of resources. Technology has proven to have an essential role but not when it is considered in isolation of other organizational and human aspects. The results of the proposed approach to bridge the "transition" phase of humanitarian disasters and use of design thinking during the RR activities provide evidence that this approach can effectively accomplish the following points:

A needs-centred approach

Using beneficiary needs in the "transition" phase as central focus and a design approach with simple terminology, empowered participants from multiple cultural and professional backgrounds to create tangible and new solutions to address unmet needs. Participants from multiple backgrounds were able to communicate their ideas and concerns through the hands-on activities and above all, be exposed to the different perspectives about transition. In addition, participant teams created broad problem statements and solution visions based on the insights from the interdisciplinary collaboration. The teams successfully addressed the problems with a rich perspective, involving considerations for different phases of aid intervention and highly focused on goals rather than technology. This is reflected in their in-depth list of criteria for evaluation of concepts and the social and organizational components of the presented solutions. The designer played an important role during RR as central mediator of humanitarian innovation. Expertise in creative thinking and idea materialization can effectively facilitate the combination of different perspectives into a coherent knowledge base.

The common threads

The identified common threads provide a framework to systematically approach the opportunities and challenges of the humanitarian transition context. Relevant context issues such as the importance of existing coping mechanisms and social environments were revealed and characteristics such as scalability, function and modularity are recurrent

in several concepts. The authors suggest exploring the value of these issues as guiding criteria to iteratively evaluate and select ideas during the design process, activity which was until now left up to each individual group to create. Furthermore, the list of common threads works as a tool to systematically collect relevant information that contributes to the continuous focusing and improvement of the approach. The analysis made to generate it lead to interesting insights and raised multiple questions that have the potential to be researched further. How do the challenging conditions (i.e. cultural and professional discrepancies) of a collaborative design process influence the output of that design process? Can cultural discrepancies in the teams contribute to more cultural-aware solutions? What does innovation literature mention about the key positive features of collaboration, and how are those compared with these findings? This research is relevant because its results might have implications that are applicable to similar approaches involving multiple stakeholders.

Impact of presented concepts

The role of "champion" beneficiaries and the industry sector are essential to assure adoption and follow up of initiatives. The experience of participants representing the beneficiary group is fundamental to understand the implementation challenges of each technology, knowledge which should also be included in the design process. The RR initiative has focused on the perspective from users and has intentionally excluded donors and the private sector. The approach was developed to explore unaddressed needs as a way to understand transition challenges from the operational field perspective. Future engagement with the private sector is acknowledged to be important in terms of their understanding of value in markets and potential role as financiers. However challenges such as profit focus and operational timelines need to be overcome. Both DUT and MIT are dedicated to find private sector partners to explore possible collaborations and help develop the concepts further, using their available resources such as student projects and research platforms.

Future steps

The projects developed in RR are dependent on the open mindfulness of all participants. It should be clarified in the humanitarian agenda that product development is a process and not an end. In the future the same approach will be used locally but include a stronger module of business and strategy thinking. This requires continuously rethinking the roles of ex-participants and creating a structure using academic resources: A finance structure for different phases of the projects and to support further development of prototypes and a long term commitment translated in time and availability to promote such design activities and assuring the continuation of tools being developed for this context.

14.6 Conclusions

In line with the trend mentioned by Sanders (2009), the humanitarian sector has the chance to become more competitive and efficient by engaging with local partners as a long-term commitment. This requires international organizations to rethink their structure and practices, from providers to transferor. Donors and governments need to acknowledge these efforts and align their agendas with broader societal goals. Through the involvement of the humanitarian field, academia and industry, collaborative design can offer the humanitarian sector a neutral, yet differentiating space for discussion about humanitarian innovation and also contribute to establish a lasting commitment for an effective co-development of suitable product and services.

Acknowledgements

The authors would like to thank the resources and financial support provided by both Universities, and in particular to Cees de Bont, Ena Voûte and Amy Smith.

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Appendix P6. Common threads at solution and process level of RR concepts

Solution level (Product/service characteristics, identified opportunities or strategies)
Well-being of disaster victims was highlighted by the participating partners as an emerging priority issue since many intangible needs from affected communities might have long term negative effects therefore the focus must be on people rather than products.
Community shared places (i.e. refugee camp) and social function (i.e. education) offer opportunities for product innovation.
Whole aid system and life-cycle of products considers interdependencies and implications around product use/adoption of social, organizational and infrastructural nature. In this case, the life-cycle of products includes the phases of product design, manufacturing and distribution, the use phases linking relief to development (and development to relief) and the end-of-life of the products.
Value of existing coping mechanisms allows to create products that reinforce instead of replacing existing solutions, reducing therefore dependency on aid solutions.
Disaster specific characteristics such as climate and geographic location affect the usability of products (e.g. type of water type of sun exposure, type of terrains) and must be taken in account when focusing a problem.
Culture, value sets and common practices such as religious believes, behaviours and practices, family size, scale of community integration and specification of individual users influence the potential of a product, deployed/donated by emergency relief to be used.
Logistics and standards should be integrated within solution to increase the chance of success in both short and long term interventions since those management practices and knowledge is already established.
Functional modularity is a strategy to design versatile and compact products where the same components serve different purposes (e.g. lighting, hanging).
Component modularity results in products that can be phased in or out between phases, allowing its transformation/conversion into locally made.
Embrace growth is a property that allows users to expand or use products for their own interest/purpose.
Scalability is a property that allows a product to be purchased/acquired accordingly to income, size and type of household/community.
Materials used in product manufacturing matter, not solely in terms of environment resistance and endurance but also products that can be recovered locally and reused after one or after multiple uses.
Life span is a property of expanding the value of the product either by increasing its durability, robustness, ergonomics (handicaps), recycling or upgrading.

Process level (Challenges or adopted strategies)
Establish clear goals and tasks. This is needed in order to manage expectations and to help participants focus on their tasks. Participants and teams are highly dependent on a process roadmap and group dynamics management.
Understanding and framing the problem. One obstacle identified by the designers was the complexity and dynamics of the system around one product in the context of the humanitarian gap. There is a high discrepancy in the terminology and definitions used by participants, and an overwhelming quantity of issues regarding products used in the humanitarian field. Taking the time and elaborating on the problem framing phase of the design process had a direct impact on the self-confidence of participants about their solutions.
System focus. The design of combined products and services needs to be aided with specific tools that improve decision making and guide participants along the integration of different systemic context factors in their solution.
Cultural differences: Besides the different professional background of participants, cultural background and nationalities enriched the process and discussions. However, there is a tendency for people to be more or less assertive when it comes to express ideas or take control of the process. The use of "hands-on" activities helped to balance participants to be engaged at a more equal level.
Technical and creative divergence: To the most technical participants the creative exercises during the design process represented a challenge due to differing capability of participants to deal with abstraction. The constant provision of examples and sketch modelling exercises had a great impact on the ability of the teams to visualize, discuss and come to a consensus regarding their ideas.
Academic and professional divergence in design: Whereas non-designers have benefited from the simplified language to present the design process, others considered the given information superfluous or not objective. As such designers must assume the lead of the team and independently choose the design tools they are most comfortable with. The diverse design cases presented throughout the workshop provided, in an inspiring manner, a good overview of design process alternatives and constrains.


RETHINK RELIEF
UGANDA 2014
D-Lab
IDIN
USAID GLOBAL DEVELOPMENT LAB
MITMECHE


Safe
Water
Vessel

Glossary of relevant concepts

Systems thinking [40, 42, 63, 94, 98, 100, 106, 109-111, 122, 133]

System thinking, as an analysis tool, promotes the comprehensive understanding of a system as a whole, rather than through individual elements composing the system. Systems thinking is overarching of theories that share its general principles, such as cybernetics (Ashby 1957), complexity theory (Cilliers 1998) and sociotechnical systems (Trist 1981), and has been used by fields as diverse as biology, engineering and organizational management (Peters 2014). In the field of organizational management, systems thinking aims to use systems theory to address complex problems typically found in "real world" settings, such as the ones found in the humanitarian aid sector (Jackson 2007; Ackoff 1974). The use of systems thinking implies a shift in the mentality of international humanitarian organizations, from a goal-centred orientation to a continuous adaption orientation, in which processes and activity outcomes (e.g. achievements, barriers) are seen as emerging and uncertain (Senge 1990b; Stacey 1995; Adam & Savigny 2012).

Sociotechnical systems [31, 32, 38, 42, 43, 126]

Sociotechnical systems have their origin in work analysis within the field of organizational change and situate systems thinking in a work context of organized human activities that produce, diffuse and use technology. Sociotechnical systems sees these organization of activities as systems that depend on the relation between a human and a nonhuman system, that means they depend on humans and on material means for their outputs (Katz & Kahn, 1978; Trist & Labour, 1981).

Complex vs. complicated [98]

To the eyes of a non-technical non-medical individual an anaesthesia machine is a complicated system composed of a large number of related components with different functions. Nevertheless this system is divisible into its constituents and assembled together in an understandable way but an individual, given that that individual has the specific required knowledge and its functioning principle is possible to describe. A complex system however, goes beyond engineering specifications and reliability predictions (Dekker et al., 2011). The anaesthesia machine becomes a complex system when it is embedded in a highly regulated surgical processes, carried out in different contexts and subject to influencing factors and such as workload, team structure and cross-cultural differences (Vincent, Moorthy, Sarker, Chang, & Darzi, 2004).

Medical equipment ecosystem [11, 12, 23, 32, 61]

The safe functioning of each medical equipment relies on a large number of other interdependent technologies that include direct and indirect relations, such as energy or supplies, sterilization and waste management equipment. These group of interdependent technologies form the medical equipment ecosystem.

Complex medical equipment [13, 23, 34, 36, 42, 43, 96, 100, 104]

Complex medical equipment refers to the combination of general surgical devices that are, according to Medical Device Directive classification, active, multi-purpose and mostly invasive (European Commission 2010), and their ecosystem (i.e. the interdependent infrastructure, complementary accessories and supplies, such as suction device, electrocautery, anaesthesia machine and autoclave).

Global health [11, 15, 16, 85, 133, 134]

Jeffrey Koplan and colleagues define global health as "an area for study, research, and practice that places a priority on improving health and achieving equity in health for all people worldwide." (Koplan et al. 2009). Global health is based on the idea that health-related issues, such as communicable diseases or political unrest resulting from inequity, are not limited by boundaries of geography, time and culture but serve the "shared" interest in varying degrees and ways, of the whole world (World Health Organization 2015). Global health is not the same as "international health" which defines instead the international assistance, through cooperation and co-financing, from wealthy countries aimed to enable poorer countries to improve their public health (Ooms et al. 2011).

Humanitarian emergencies [10-27, 31-43, 52-58, 68, 69, 93-111, 122-130]

Humanitarian emergencies include natural or industrial disasters and conflict situations that require immediate intervention and assistance to thousands of people. Often an emergency situation can result in an extended or chronic condition due to e.g. an epidemic or political instability, leading to the need to extend the settlement of camps. According to the classification of the Centre for Research on the Epidemiology of Disasters (CRED) adopted throughout this thesis, 'disasters' are the convergence of hazards and vulnerabilities. It is important to acknowledge that there are different classification systems for humanitarian emergencies, often due to their ambiguous and difficult characterization. For example, the term 'natural' disaster can be controversial in the sense that it gives more emphasis to the natural phenomenon as a cause for the disaster rather than the vulnerable socio-political context and aggravating factors in the affected regions. Similarly, it should not be understood by the term 'complex' disaster that that are other non-complex disasters.

Humanitarian emergency response, or humanitarian aid [Page 10-13, 16-18, 22, 23, 27, 31, 34, 35, 41, 42, 56, 60, 62, 64, 66, 69, 70, 83, 84, 97-102, 106, 109, 110, 120, 122, 131, 136, 188, 202-206, 214, 217]

Humanitarian emergency response, or humanitarian aid, involves the mobilization of a global network and complex system of actors to provide assistance to populations affected by natural disasters, technological accidents and complex emergencies. Humanitarian emergency response is carried out in three different phases – emergency relief, (humanitarian) transition (also known as early recovery) and reconstruction.

Humanitarian transition [11, 16, 17, 26, 48, 49, 213, 215-217, 220, 222]

Humanitarian transition (also known as early recovery) refers to the period between the immediate short-term intervention and the stabilization or even improvement of life standards by development. This implies a shift of focus and priorities (United Nations, 2006). Several publications indicate the existence of a "gap", between short-term humanitarian relief, and long-term development, pointing to the lack of sustainability in funding, management and delivery (Lloyd-Jones, 2006).

Sustainable development aid [16-18]

Sustainable development aid is aimed at addressing on the long-term structural health barriers, such as poverty. Activities related to sustainable development aid have particular donors and priorities, distinct from humanitarian aid.

Humanitarian innovation [13, 14, 27, 38, 43, 48, 49, 52, 53, 55-57, 59, 61-63, 68, 70, 120, 121, 130-136, 213, 216, 222, 224]

Humanitarian Innovation defines the change in aid delivery processes and adaption of technologies with the aim of improving the way how the needs of affected people in humanitarian emergencies are addressed (Bessant et al. 2014).

Humanitarian market [12, 14, 32, 35, 36, 47, 48, 104, 202, 203, 206, 209, 212, 216, 222]

In humanitarian emergencies, international humanitarian organizations create a parallel system to the institutional one (i.e. with established political, commercial and public channels, amongst others). They create an "humanitarian market". There is a different producer-consumer relationship because, instead of the consumer buying the goods/services, these are financed by private or public sectors (quasi-market). Companies often have less responsibilities regarding servicing and training staff, since this must be done in contexts organizations have strict access to. Moreover, the consumer, as in other professional sectors, represents, but is not the end-user. The end-user of medical equipment are, on one hand, healthcare practitioners temporarily in the field, and on the other hand, the ones under a Ministry of Health or a privately administered institution in low and middle-income countries after the handover.

Low-resource settings [11, 24, 30, 34-44, 47, 48, 52, 54, 55, 61, 69-71, 85, 98, 100, 143, 172, 174, 176, 182, 184-189]

The worldwide differences between nations are defined in several ways, from both an economic and a social perspective. The terms "developed" and "developing" determine a large difference in the standards of quality of life and the development of industry practices and capacity of countries, i.e. from primary to tertiary/quaternary sectors. In rough terms, this terminology divided wealthy Organisation for Economic Co-operation and Development (OECD) countries from non-OECD countries.

With the increase in the differences between non-OECD countries in terms of economic and political participation, the gap that existed two decades ago in the world is filled in with a diversity of countries that are expected to further development. As the World Bank classification indicates, there are now low-income, middle (lower and upper) and high-income countries. Another classification is the Human Development Index, published by the United Nations Development Program, and that uses the dimensions of gross national income per capita, life expectancy at birth and mean and expected years of schooling to rank countries in low, medium, high and very high human development levels. More relevant in the context of this thesis is the term "low-resource settings" which is a term adopted by the medical community to define contexts with limited conditions to practice healthcare which also include countries where, despite the increasing income per capita, the inequality of income and access to services is also increasing.

Technology transfer [14, 52, 58, 70, 94, 97, 98, 132, 135, 136]

> Technology – defined in terms of physical products, techniques, know-how, information, skill, labour, and organization – is an integrated part of a country's structure […] consistent with sociotechnical systems theory, any changes in technology have an impact on the social, political, and economic systems (Shahnavaz, 2002, p. 313).

Technology transfer is usually associated with the progress and industrialization of low and middle-income countries. Technology transfer designates a process involving shared decisions from a source and a recipient country aimed at ensuring that the technology being moved, has the maximum benefit to the technical, and socioeconomic development of the recipient country. In this thesis, the term is used to describe the process of moving technology (i.e. medical equipment, the required medical and technical knowledge to operate and repair, etc) from one (institutional) context to another with the purpose of using it and then donating it (Williams, 2008). This process is usually hindered by "the lack of scientific and technological infrastructures and training facilities for improving the workforce's level of education, skill and understanding of safe effective operation, maintenance, and development of the imported technology"(Shahnavaz, 2002, p. 322).

Sustainability (in context of humanitarian emergencies) [11, 13, 15-18, 55, 63, 109, 122, 123, 133-135, 189, 207, 217]

> Sustainability in humanitarian aid refers to the duration as well as to the concept of the assistance to be offered, with the latter including the general integration of measures to imbue a developmental orientation into emergency and disaster aid (Mühleisen et al., 1999, p. 3).

Sustainable system innovation [30]

"The sustainable system innovation method takes the total system involved as a basis for innovation, aiming at creating synergetic advantages between solutions and actors, combining needs and opportunities which are handled separately in a regular innovation process. The aim of this approach is to create smart combinations of needs and functions to improve the effectiveness and sustainability of the total system" (Joore, 2008).

Human factors and ergonomics [28, 43, 44, 54, 120, 121, 132, 136, 144, 147, 161, 172, 174]

The field of human factors and ergonomics applies a systems approach focusing on the "understanding of interactions among humans and other system elements of a system" by developing and applying "theory, principles, data and methods to design (policies, processes and products) in order to optimize human well-being and overall system performance" (P. Carayon, 2007). In healthcare, human factors and ergonomics is divided into subdomains that focus on different scales of the interface between people and other sociotechnical system elements, all of which have contributed to healthcare systems improvement, as in other critical high risk industries. Human factors and ergonomics methods and theory are used through improvement interventions in different system levels and strongly focus on improving users' well-being and overall system performance and safety (Rasmussen, 2000; Reason, 1997; Vincent et al., 2004).

Macroergonomics [44, 45, 133, 172-174, 185, 188, 189]

Macroergonomics is a subdomain of human factors and ergonomics, focused on the overall work system, at an organization scale. The aim of macroergonomics models of healthcare quality is to integrate an entire system of organizations, guiding its integral analysis and redesign.

Safety (in the context of healthcare) [23, 28, 34-36, 38, 43-48, 50, 52-55, 62, 66, 67, 71, 96, 97, 99, 102, 107, 108, 120-134, 145-148, 165, 168, 169, 172-176, 184-190, 205, 206, 209, 215, 221]

The Institute of Medicine defines patient safety as "the prevention of harm to patients" and places emphasis on the system of care delivery that (1) prevents errors; (2) learns from the errors that do occur; and (3) is built on a culture of safety that involves health care professionals, organizations, and patients (Mitchell, 2008). This means that, in order to

accomplish patient safety, a permanent and firm safety culture -or context- is needed, that promotes the reduction and prevention of medical incidents through different channels either human cognition, emotions and behaviours. In this thesis a broad definition is used, that includes consideration for the influence and applications to organizational, environmental, team, task, individual and patient aspects: "Patient safety is a discipline in the healthcare sector that applies safety science methods toward the goal of achieving a trustworthy system of healthcare delivery. Patient safety is also an attribute of healthcare systems; it minimizes the incidence and impact of, and maximizes recovery from, adverse events" (Emanuel et al. 2008, p.6).

Performance obstacles [38, 45-47, 55, 68, 144, 146, 148-151, 154, 159-162, 165, 172, 173, 176-181, 184-186, 189, 194]

Performance obstacles are factors related to the work structure of healthcare practitioners that disturb the execution of particular activities or tasks (affecting to a certain degree time, comfort or result), leading to a deviation from the safety standards. These performance obstacles are associated with either system limitations (e.g. infrastructure, staff, and management) or with problem-solving mechanisms triggered by the impediment of treating patients and complying with the standards in the first place.

Design [28-30]

Design can be the defined as the act to conceive an idea for an artefact or system of artefacts, and to express that idea in embodied form, properties, function, use and needs and values. Design methods and tools are applicable to designing material products, services, strategies, programs, and brands (adapted from Roozemburg & Eekels, 1995).

Research in design [35]

Research in design is defined as a domain-independent and context-specific research approach that uses determined background disciplines and their respective methods to explore and understand design-related phenomena. Research in design is common in industrial design engineering research practice to generate knowledge about the relationships between people, artefacts and their surroundings.

Summary

The response to humanitarian emergencies, or humanitarian aid, involves the mobilization of a global network and complex system of actors. Healthcare is one of the services generally provided in humanitarian emergency response, alongside with shelter, sanitation and food. International humanitarian organizations transfer, i.e. organize and transport, a variety of medical equipment and staff to an affected area with the purpose of reinforcing or even replacing disrupted healthcare activities.

The unsustainability of the transfer process of medical equipment in humanitarian emergencies is the motivation behind the research in this thesis. Most of the medical equipment used by international humanitarian organizations is designed to operate in controlled environments and therefore not suitable to be transported, used, maintained and disposed in austere and low-resource settings. Ultimately, characteristics of medical equipment, such as fragility and dependency on supplies to function, will result in a mismatch with the settings present throughout the whole transfer process in humanitarian emergencies.

This mismatch problem is twofold. Firstly, medical equipment has a limited capacity to function in the variety of context settings implicit throughout the transfer process (i.e. different countries or regions represent different challenges). Secondly, in order to temporarily reinforce disrupted healthcare systems, a support 'ecosystem' needs to be in place for the equipment to function.

The aim of this thesis is to investigate how a systems design approach can contribute to a more sustainable transfer of medical equipment in humanitarian emergencies. This thesis includes an introduction of the research context and main assumptions in chapters 1 and 2. In chapter 3 a sociotechnical perspective is introduced to frame the exploratory study about the transfer and use of medical equipment in humanitarian emergencies, and of humanitarian innovation. In chapter 4 the goal and research questions are described. The overall main findings of the research are described in chapter 5, and are based on six publications included in this thesis (chapters 9-14).

Publication 1 describes barriers and enablers of transferring medical equipment in humanitarian emergencies, from the perspective of interviewed experts from international humanitarian organizations. These findings are analysed with a system thinking lens in order to be able to describe the complex nature of the humanitarian aid context. Publication 2 further elaborates on how to understand the challenges of technology transfer in the humanitarian aid context using in particular the concept of socio-technical systems. This theory helps to explain that a successful transfer of medical equipment depends on the consideration of systemic interdependencies in the different contexts, implicit in the

transfer process. Human factors and ergonomics and product-service systems are presented as complementary concepts in a systems design orientation to humanitarian innovation, geared towards the transfer of medical equipment transfer. A set of characteristics of a systems design orientation is proposed.

Publications 3 and 4 describe the field studies that were carried out in Indonesia and Haiti in order to study safety challenges in low-resource, and disaster-prone settings. Both studies focus on surgical practice. A data collection and analysis tool called observable performance obstacles was iteratively designed and used for the purpose of these studies. The tool is based on a macroergonomic perspective for the characterization of system functioning and identification of performance obstacles related with medical equipment. The findings from the studies show that most performance obstacles relate to environmental and organizational issues and that the provision of healthcare is dependent in several work-arounds.

Publication 5 uncovers the priorities and the practical challenges of developing products and services for the humanitarian context, as experienced by product development companies from relevant sectors, involved in product development for the humanitarian market. The findings show that companies prioritize self-explanatory and controllable requirements like safety and robustness whereas there is discrepancy regarding relevance of e.g. adjacent services and cultural aspects. In addition, four challenges of concern from companies are identified that show how product development could benefit from a shared agenda with humanitarian organizations: timeframe and context, finance, stakeholder environment and supply chain and information flow. Publication 6 introduces an approach to humanitarian innovation used in an academic initiative called Rethink Relief which was carried out in three locations. The publication positions design practice in humanitarian aid and presents the product-service concepts resulting from a collaborative design approach.

Chapter 6 presents a systems design approach to the transfer of medical equipment in humanitarian emergencies, as a conclusion from the main findings. Furthermore, the implications of such approach to design practice and education are described. Chapter 7 provides an overview of methodological considerations, followed by recommendations for future research and design in chapter 8. The knowledge presented in this thesis, and the systems design approach contribute with a holistic view to the humanitarian innovation agenda.

Samenvatting

Humanitaire hulp wordt ingezet bij humanitaire rampen en brengt de mobilisatie van een wereldwijd netwerk en een complex systeem van acteurs met zich mee. Gezondheidszorg is één van de services die bij humanitaire rampen wordt verstrekt samen met onderdak, sanitaire voorzieningen en voedselsteun. Internationale humanitaire organisaties regelen deze mobilisatie, zij organiseren en vervoeren verschillende medische apparatuur en personeel naar het rampgebied, met als doel de verstoorde gezondheidszorg te versterken, of zelfs te vervangen.

De onduurzaamheid van het overdrachtsproces van medische apparatuur in humanitaire noodsituaties is de motivatie achter het onderzoek in dit proefschrift. Het merendeel van de door internationale humanitaire organisaties gebruikte apparatuur is ontworpen te functioneren in een gecontroleerde omgeving. Het is daarom niet geschikt om te worden vervoerd, gebruikt, onderhouden en afgevoerd op een locatie met minder technische en operatieve capaciteiten. De kenmerken van medische apparatuur, zoals kwetsbaarheid en afhankelijkheid van verbruiksmateriaal, resulteren uiteindelijk in een "mismatch" met de situaties die zich voordoen tijdens het gehele overdrachtsproces bij humanitaire noodsituaties. Deze "mismatch" is tweeledig. Ten eerste, medische apparatuur heeft een beperkte capaciteit om te functioneren in verschillende omgevingen gedurende het gehele overdrachtsproces (verschillende landen of regio's vertegenwoordigen verschillende uitdagingen). Ten tweede, om verstoorde gezondheidszorgsystemen tijdelijk te versterken, is een support 'ecosysteem' nodig, zodat apparatuur kan functioneren.

Het doel van dit proefschrift is te onderzoeken hoe een "systems design" aanpak kan bijdragen aan een duurzamere overdracht van medische apparatuur in humanitaire noodsituaties. Hoofdstukken 1 en 2 beschrijven de introductie van de onderzoekscontext en de belangrijkste aannames. Hoofdstuk 3 introduceert een socio-technisch perspectief om een kader te schepen voor de verkennende studie over humanitaire innovatie en de overdracht en het gebruik van medische apparatuur in humanitaire noodsituaties en van. In hoofdstuuk 4 worden het doel en onderzoeksvragen beschreven. Hoofdstuk 5 beschrijft de belangrijkste onderzoeksresultaten en is gebaseerd op zes publicaties opgenomen in de hoofdstukken 9-14.

Publicatie 1 beschrijft de barrières en ondersteuningsmechanismen van de overdracht van medische apparatuur in humanitaire noodsituaties vanuit het perspectief van geïnterviewde deskundigen van internationale humanitaire organisaties. De onderzoeksresultaten werden geanalyseerd met een "system thinking" lens om zo de complexiteit van de humanitaire context te kunnen beschrijven. In publicatie 2 wordt door middel van "socio-technische systemen" verder ingegaan op de uitdagingen van technologie-overdracht bij humanitaire hulp. De onderzoeksresultaten toonden aan dat een succesvolle overdracht

van medische apparatuur afhankelijk is van systemische onderlinge afhankelijkheden in het overdrachtsproces en in de verschillende contexten. Ergonomie en "product service systems" worden gepresenteerd als complementair in een "systems design" oriëntatie voor humanitaire innovatie gericht op het overdrachtsproces van medische apparatuur. Een set van kenmerken van een "systems design" oriëntatie wordt voorgesteld.

Publicaties 3 en 4 beschrijven de veldstudies uitgevoerd in Indonesië en Haïti. Ze bestuderen de uitdagingen voor veiligheid op een ramp-gevoelige locatie met beperkte technische en operatieve capaciteiten gericht op de chirurgische praktijk. Een "observable performance obstacles" tool is iteratief ontworpen en gebruikt voor het verzamelen en analyseren van informatie. De tool is gebaseerd op een macro-ergonomisch perspectief voor de karakterisering van de werking van het systeem en de identificatie van prestatie-obstakels met betrekking tot medische apparatuur. De onderzoeksresultaten toonden aan dat de meeste prestatie-obstakels omgevings- en organisatorische kwesties betroffen en dat de gezondheidszorgvoorziening afhankelijk is van een aantal "work-arounds".

Publicatie 5 beschrijft de prioriteiten en praktische uitdagingen voor het ontwikkelen van producten en diensten voor de humanitaire context, zoals ervaren door productontwikkelingsbedrijven uit relevante sectoren voor de humanitaire markt. De onderzoeksresultaten toonden aan dat, terwijl bedrijven prioriteit geven aan vanzelfsprekende en controleerbare eisen, zoals veiligheid en robuustheid, er een discrepantie is met betrekking tot de relevantie van bijvoorbeeld aangrenzende diensten en culturele aspecten. Daarnaast worden vier uitdagingen voor bedrijven geïdentificeerd die laten zien hoe productontwikkeling kan profiteren van een gezamenlijke agenda met humanitaire organisaties: tijdsbestek en "context"; financiën; belanghebbenden; productieketen en informatiestroom.

Publicatie 6 introduceert een ontwerpaanpak die gebruikt wordt in een academisch initiatief, "Rethink Relief", die tot nu op drie verschillende locaties gehouden is. De publicatie positioneert ontwerppraktijk in humanitaire hulp en presenteert de product-dienst concepten ontworpen tijdens het 'Rethink Relief' initiatief.

Hoofdstuk 6 beschrijft een "systems design" aanpak voor de overdracht van medische apparatuur in humanitaire noodsituaties, als conclusie van de belangrijkste onderzoeksresultaten. Bovendien worden de implicaties van een dergelijke aanpak voor de ontwerppraktijk en het onderwijs beschreven.

Hoofdstuk 7 geeft een overzicht van de methodologische overwegingen, gevolgd door aanbevelingen voor toekomstig onderzoek en ontwerp in hoofdstuk 8. De kennis in dit proefschrift, en de "systems design" aanpak dragen bij aan een holistische visie bij de humanitaire innovatieagenda.

Acknowledgements

This PhD thesis is dedicated to all the people who helped me throughout the last four years. This thesis is the result of their support and contribution. As someone I admire very much said, writing a book is a lonely act but what allows the writing to be carried out, is life with others.

First of all I would like to thank my first promotor Han Brezet for the singular role he played in promoting my work, and motivating me to explore and discover my place in this complex field. His inspiring ideas and music are much appreciated. I would also like to thank my promotor Richard Goossens for his sharp and positive advices that go back to my graduation as a master student in Delft. And of course, I would like to thank Linda Wauben who maintained her cheerful, always precise support throughout the years, and who became a friend to keep. I thankfully acknowledge the support from the Portuguese government through Fundação para a Ciência e Technologia with which this research was carried out.

I would like to thank the people who co-authored my articles and made my field studies possible, namely Dr. Punto Dewo, Dr. Peter Rosseel and Dr. Sedu Guilavogui. They have enriched my work and allowed me to expand my personal limits. My field studies would not have been possible without the participation of the residents from the Orthopaedics and Trauma Department in the Dr. General Sardjito Hospital, Indonesia, and the nurse anaesthetists in l'Hôpital Bon Sauveur in Cange, Haiti. These residents and nurses struggle every day to guarantee the best possible quality of healthcare in low-resource settings. They were very generous to welcome me in their workplace and tolerating my missteps. I would like to thank Brita Nielsen for her ideas and support. I wish her strength to finish her PhD and look forward to work together in the future.

In addition there are several experts who in their own distinctive way, took the time to help me, to explain and share their valuable experiences. I would like to thank Lizette van der Kamp, Miguel Trelles, Vincent Maure, Joos van den Noortgate, Jan Huijs, Marten van Wijhe, Nelson Olim, Robert Neighbour, Rolof Mulder, Ilja van Kinderen, Gabor Szántó, Joost van Engen, Keita Ikeda, and Kelly Mcqueen.

I would like to thank my first Rethink Relief'ers Amy Smith and Lise Capet who showed me what it is to make something truly awesome happen, and also to Martha Thompson who contributed with important feedback on my draft. Thanks to Angelina Westbroek for her enthusiastic support, and to the RR community of organizers, speakers and participants.

It has been a long journey for me, my DfS colleagues and friends. Some finished, some didn't, but all contributed to my learning and fun.

First of all, a shouting thanks to J.C. Diehl for his breath-taking enthusiasm and dedication to new and old challenges, to Jairo da Costa for the support and companionship when organizing the PSS course. And to Wouter Kersen for his always-timely hotch potch propositions and new words. Thanks to Milene, Sietze and Paula, my paranymphs without borders. Thanks to Arno, Daphne, Duygu, Shauna, Feng, Jotte, Natasha, Renee, Sarah, Satish, Ingrid, Armagan, Marijke, Kasia and Ana. Thanks to Annemarie, Cecile and Lye who shared a great year with me. Thanks to the first aid providers at TU Delft and the masters at the TOL for the chance they offer to be part of such remarkable work.

I also thank Professors Jo van Engelen and John Dobbelsteen who were very supportive with advice. Peter Joore and Peter Vermaas contributed with important reflections about my work. And Maaike Belien asked the utmost right questions to help me tell my "story". And finally, during the past four years I met several students, most of them graduated by now. They have been very brave to take on their challenging projects. It was a pleasure to work with Ana Lopez, Gboluwaga Olubunmi, Frenk Stockman, Marta Bariain, Guido Jetten, and the groups from the Sustainability Minor, Joint Master Program and Product-Service Systems course.

I thank my family and friends for the remarkable importance they take on. My parents Maria de Lurdes and Carlos above all, for immeasurable reasons. My mother who gave me the daily confidence that this would work, and my father who visited me in the Netherlands with 'delícias' he knows I love. To Rui, for the conversations and editorial advises, to Paula and to Luís. I am lucky to be part of a "family plus" extending from Lisbon, to the Netherlands and to Germany. The friends I call, with whom I eat and drink, and walk in the forest, shape what I am and do.

And as a last word, I thank my husband Lennart for his unconditional help pushing forward (!), to which no Yoda or Hitchhiker's guide wisdom compare, for the biting through the tough reading, for the go-to-sleep-storytelling and for the late evening inspirational thought dwellings. We're moving on and on.

Photography credits

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(From top to bottom)
Men carrying water purifier, Indonesia, 2004 (Nelson Olim)
Flooded medical station, Indonesia, 2004 (Nelson Olim)
Camp in Port-au-Prince, Haiti, 2012 (A.L.R. Santos)

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View of operating room, MSF Hospital, Tabarre, Haiti, 2012 (A.L.R. Santos)

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Use of carpenders drill during surgical procedure, Indonesia, 2012 (A.L.R. Santos)

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(From top to bottom)
Ebola high risk operating room, St. Joseph Hospital, Monrovia, Liberia, 2014 (Jan Huijs)
Health clinic in Pader, Uganda, 2014 (A.L.R. Santos)
HIV councelling area, health clinic in Pader, Uganda, 2014 (A.L.R. Santos)

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Discussion panel at Rethink Relief in Pader, Uganda, 2014 (A.L.R. Santos)
Creative exercise at Rethink Relief in Pader, Uganda, 2014 (A.L.R. Santos)
Final exhibition at Rethink Relief in Delft, the Netherlands, 2011 (Job Jansweijer)

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Sketch modelling at Rethink Relief in Delft, the Netherlands, 2011 (A.L.R. Santos)
Team presenting mock up at Rethink Relief in Delft, the Netherlands, 2011 (Job Jansweijer)
Health team results, final exibition at Rethink Relief in Pader, Uganda, 2014 (A.L.R. Santos)

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About the author

Ana Laura R. Santos (Lisbon, 1983) graduated in Arquitectura do Design in 2007 from the Technical University of Lisbon after an internship at Iberomoldes group (Portugal), for the design and development of plastic components, content development and graphic design of a website platform. For her study performance she received the award Mestre Daciano da Costa. A Leonardo da Vinci scholarship brought Ana Laura to the Netherlands for an internship where she met Professor Brezet and the Design for Sustainability Department at the Faculty of Industrial Design Engineering of Delft University of Technology. She was engaged in the organizational support of research workshops and a concept design proposal for sustainable tourism stimulation in the Dutch region of Friesland. The final work was submitted and presented at a competition from Cartesius Institute in Friesland (Netherlands). Ana Laura has pursued her studies in Delft. In 2010, she obtained her Master degree from the same faculty with a medical design project: the development of a surgical light device. In the sequence of her graduation, she became research assistant at the Biomedical Engineering Department, Faculty of Mechanical Engineering, for the validation and optimization of her surgical light device (published research). After her experience with medical design, and intrigued by the international medical assistance to the Haitian earthquake in 2010, Ana Laura started her own research proposal as a PhD researcher in the same university with a focus on the adequacy of medical devices to humanitarian aid and emergency relief contexts. During the period 2011-2014 she gave lectures, organized a short-term education program, established connections with international experts and supervised several student projects. Next to her research, Ana Laura is one of the founders of the Rethink Relief international initiative, a yearly design collaboration of humanitarian partners, aid beneficiaries, design scholars and professionals. Rethink Relief was successfully organized three times, in collaboration with D-Lab from MIT (Delft, Boston and Uganda), and it involved participants from dozens of different nationalities. The resulting concepts and discussions are continuously developing. In 2011 Ana Laura was selected as one of the 10 most inspiring, ground-breaking and innovative cases for the TU Delft Highlights. She currently works as case manager at Médecins Sans Frontières Sweden Innovation Unit.

Humanitarian emergencies like the natural disasters in Nepal, Haiti or Pakistan or the thousands of refugees and internally displaced people fleeing from long-term conflict in Syria or South Sudan are likely to increase.
To provide healthcare assistance, international humanitarian organizations transfer a variety of medical equipment and staff to an affected area with the purpose of reinforcing or even replacing disrupted healthcare activities. The replacement system they transfer is usually of a high quality standard, and therefore not suitable to be transported, used, maintained and disposed in austere and low-resource settings.
In comparison to providing food or shelter assistance, providing safe healthcare in such situations is particularly challenging
due to the level of medical and technical expertise required.

In this thesis, the unsustainability of the transfer process of medical equipment in humanitarian emergencies is addressed by describing and analysing how the transfer takes place. Furthermore, two field studies in Indonesia and Haiti are presented. The humanitarian sector is increasingly challenged by the need to become more efficient and competitive.
The recent adoption of the 'humanitarian innovation' concept, defined by words like "sustainable", "beneficiaries", and "long-term" brings an encouraging view ahead towards a more sustainable transfer of medical equipment.
A combination of field, interview and literature studies, led to the development of a systems design approach to the transfer of medical equipment in humanitarian emergencies that

TU Delft
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Product development and Research in Healthcare
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FCT Fundação para a Ciência e a Tecnologia
POPH
QREN Quadro de Referência Estratégico Nacional
Governo da República Portuguesa
União Europeia Fundo Social Europeu