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Ana Laura R. Santos, Linda S.G.L.Wauben

## Systems Design Perspective of Healthcare Provision in Humanitarian Aid

### **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.*

**Keywords:** Systems Design, Socio-Technical-System, Human Factors and Ergonomics, User-Centred Design, Product-Service Systems, Medical Equipment, International Emergency Relief, Humanitarian Innovation

### **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, for example, natural disasters or populations displaced by 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 lies 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.

### **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 purposeful wholes, such as 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). 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; 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; 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 inconsistency in keeping up with the organization's own developments, and unclear definition of the users in fieldwork (Baxter & Sommerville, 2011). Nonetheless, throughout the literature, the potential of Socio-Technical Systems Design to tackle complex problems in the future is acknowledged and learning about Socio-Technical Systems Design 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 a 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.

### **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 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; and
- 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; VanPatter, 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 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 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.

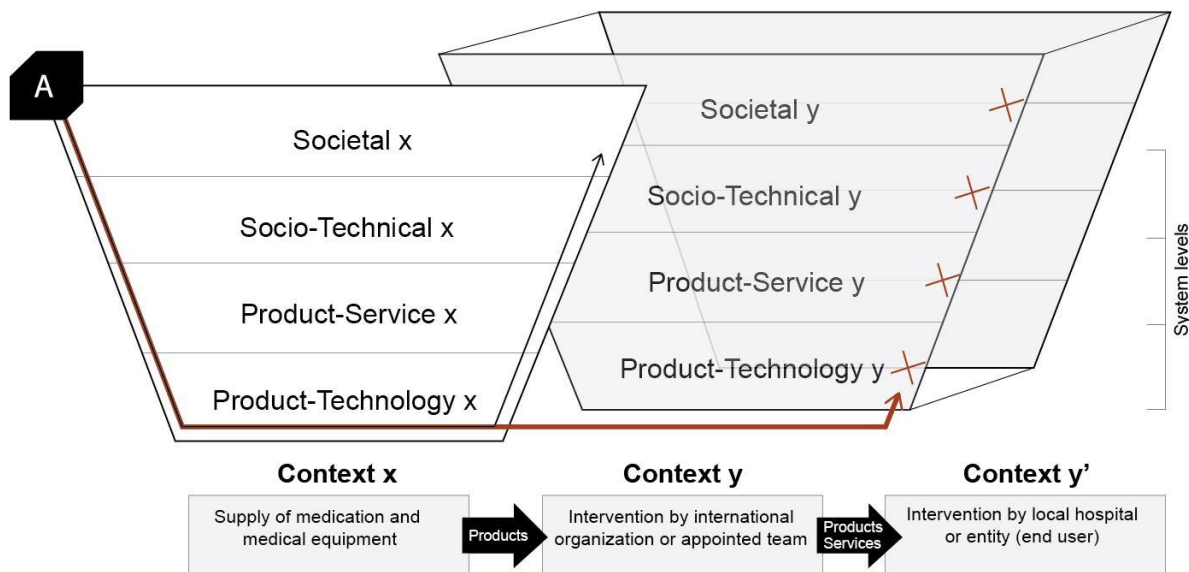
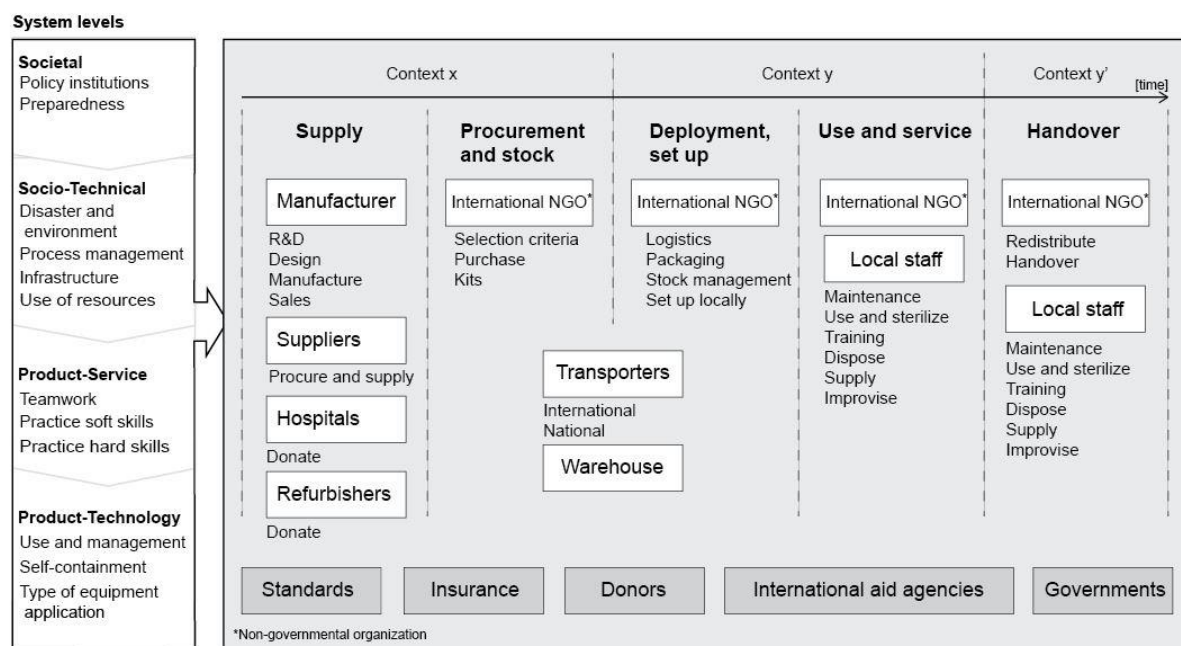


Figure 1: Transfer of product A between contexts x, y and y' [Adapted from (Joore, 2008)].

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 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 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 of Figure 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.



System levels	Common relation/cause	References validating context characteristics of surgical equipment in humanitarian emergencies
Societal	Policy institutions Preparedness	1,2,3,7,8,13,20,21,22 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 Process management Infrastructure Use of Resources	2,3,5,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,23,24 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,24 1,3,4,5,7,8,9,11,12,13,14,15,16,17,18,19,20, 21,23,24 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 Practice soft skills Practice hard skills	7,8,10,11,12,13,14,15,17,19,20,21,22,23,24 1,2,3,5,7,8,10,11,13,14,15,17,19,22,24 1,2,3,5,6,7,8,9,10,11,13,14,15,17,18,19,20,22,24
Product-Technology	Use and management Self-containment Type of equipment and application	2,6,7,13,14,16,17,18,19,22 2,3,5,7,14,15,8,18,21,22 3,4,5,7,11,13,14,15,17,18,19,20,21,22,24

Figure 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, Wiratmodjo, & Koeshartono, 2008 (15); Rajpura, Boutros, Khan, & Khan, 2010 (17); Redmond, O'Dempsey, & Taithe, 2011 (6); Rice et al., 2010 (14); Ryan, 2005 (8)).

### Two examples

The following factual examples were collected by means of interviews with experts from the international organization Médecins Sans Frontières (future publication) 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 1 and 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. 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 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 tends to malfunction and disrupt the nurses' workflow (product-service y) (Santos et al., 2013).

#### *X-Ray device*

An x-ray device (Figure 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). Technical support documents (created by the 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').



Figure 3 (a) Pulse oximetry in use with temporary fixing (source: ALR Santos); (b) Transport of x-ray device (source: Lizette van der Kamp).

### **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 (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; Tukker & Tischner, 2006). In a traditional business model, a manufacturing company sells a product (e.g. a medical device) to a well-defined customer (e.g. a 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 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 (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 (Karsh & Holden, 2007; 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 consideration of 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 a 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 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 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 1. Proposed characteristics for a Socio-Technical Systems Design orientation to humanitarian innovation.

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#### **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 (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 (Clarkson, 2009; 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; Clarkson et al., 2003; Mittermeyer et al., 2011; 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 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; Tukker & Tischner, 2006).

- Organizations use business logic to support effectiveness, market demand, sustainability and optimization (through innovating business models) (Ceschin, 2012; Gaziulusoy, 2011b; Mays, Racadio, & Gugerty, 2012).

Some of the expected barriers to the adoption of the characteristics of Socio-Technical Systems Design as described in Table 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 high 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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