Available online at www.sciencedirect.com
ScienceDirect
Procedia Computer Science 00 (2013) 000–000
Procedia Computer Science
www.elsevier.com/locate/procedia

Conference on Systems Engineering Research (CSER'13)
Eds.: C.J.J. Paredis, C. Bishop, D. Bodner, Georgia Institute of Technology, Atlanta, GA, March 19-22, 2013.

Requirements Analysis for Safer Ambulance Patient Compartments

Mehdi Dadfarnia, Y. Tina Lee, Deogratias Kibira, and Allison Barnard Feeney

National Institute of Standards & Technology, 100 Bureau Drive, Gaithersburg, MD 20899, USA

Abstract

Providing emergency care services in the confined space of the patient compartment of a moving ambulance has proven a hazardous activity. A National Institute of Standards & Technology (NIST)/Department of Homeland Security (DHS) project is applying systems engineering approaches to analyze requirements and develop design guidance that will improve Emergency Medical Services (EMS) workers' safety while optimizing patient care. The analysis of an ambulance's patient compartment requires multiple disciplines such as ergonomics and crashworthiness. Systems engineering tools provide a platform to perform the analysis by bridging these disciplines and bringing information sources together.

In the first phase of this project we compiled a number of requirements from the results of literature reviews, a nationwide web survey, workshops and focus group meetings. The next phase entails our process for reconciling potentially conflicting requirements from use case scenarios and then determining which constraints and metrics to be used for trade-off analysis and optimization in a human simulation modeling tool. The results of this analysis are being used to develop ambulance patient compartment design recommendations that will be provided as inputs to current and emerging ambulance design standards. In this paper we report on our efforts to provide science-based recommendations that may be used as a basis to revise and enhance current ambulance design standards and practices.

Keywords: Ambulance patient compartment; emergency medical services (EMS); safety; use cases; requirements analysis

1. Introduction

The Emergency Medical Services (EMS) community is united behind the need to improve safety and optimize EMS worker performance in the patient compartment of an ambulance. EMS workers face occupational fatality rates that are comparable to other emergency personnel and more than double that of the general population [1]. Yet there are no science-based standards that govern ambulance patient compartment design and safety. The General Services Administration's (GSA) KKK-A-1822F [3] specification has been the defacto ambulance design standard since the 1970s, and has been adopted as an ambulance procurement specification by the majority of states. However, the original GSA specification was developed to support Federal agency ambulance procurement; it was never intended to be a safety standard. The specification was built around EMS community and manufacturer consensus and lacks a sound scientific basis. The GSA has stated that they will not maintain the specification past 2013 [4].

To fill the void being left by GSA, and with an eye toward a future, rigorous safety standard, the National Fire Protection Association (NFPA) developed NFPA 1917, Standard for Automotive Ambulances [2]. The first edition of NFPA 1917 [2], released in September 2012, was intended to revise the GSA specification, and only incrementally address safety and worker performance issues. In this paper we report on our efforts to provide science-based recommendations that may be used as a basis to revise and enhance current ambulance design standards and practices.

In 2004, the National Registry of EMTs (NREMT) and the National Highway Traffic Safety Administration (NHTSA) conducted a study to identify safety issues related to the ambulance patient compartment [5]. The study showed that EMS workers and the equipment within the ambulance patient compartment must always be secured to keep patients and workers safe. The findings from this study show an increasing need to research better seating and equipment location and security, as well as mobile restraint systems [5]. Other studies have also been conducted to show that EMS personnel are more prone to accidental injuries and are in the need of better safety and layout design measures [7], [8], [1]. By far, the gravest area of concern has been the inability of EMS personnel to access equipment and to treat patients while remaining restrained [5].

The Department of Homeland Security's Science and Technology Directorate’s Human Factors and Behavioral Sciences Division (DHS) and First Responders Group is sponsoring a research project on ambulance patient compartment layout and design that will deliver science-based recommendations to the NFPA 1917 committee. The National Institute of Standards & Technology (NIST), BMT Designers & Planners, and the National Institute for Occupational Safety and Health (NIOSH) are working collaboratively to study worker and patient safety, human performance issues, and crashworthiness of the ambulance patient compartment [6]. This project will provide the foundation for a uniform standard for ambulance design and construction based on scientific data.

The project includes three major phases:

- Phase 1: Gathering requirements. In this phase we identified needs and requirements of future patient compartment design through structured and systematic approaches.
- Phase 2: Analyzing requirements. In this second phase we evaluated and verified requirements using a set of alternative design concepts and criteria. The design concept evaluation identified critical and important requirements that would improve patient care and safety.
- Phase 3: Conducting industry review & standard recommendation. In this third phase we will validate that the selected requirements satisfy community needs. The results of this validation will be candidate requirements to be presented to the NFPA for incorporation into the second edition of the NFPA 1917 standard.

This paper describes the first phase of this project and how it segues into the second phase. A systems engineering approach has been described to collect requirements to perform analysis. Section 2 of this paper describes systems engineering concepts that have been chosen for use in this project. Section 3 describes the process of collecting requirements for analysis. Section 4 of this paper describes applying the systems engineering principles discussed in section 2 onto the ambulance patient compartment project. Section 5 describes the challenges that came up in the systems engineering process and how they have been resolved. Section 6 lays out the conclusion and a summary of future work.

2. Systems Engineering Principles

Systems engineering is an interdisciplinary systematic approach to design, develop, or enhance a system. This systematic approach involves a development process that takes into account requirements engineering and analysis, system architecting and design, trade-off analysis, and system validation and verification.

The systems engineering V-Model development methodology [14] was chosen to meet the demands of this project. The V-Model encompasses the system’s requirements, including the behavioral and structural requirements. In this model, the requirements are first obtained at the highest-level of hierarchy. This highest level is the systems level, and is based on stakeholder needs. From there, the system-level requirements are decomposed into requirements that correspond to sub-systems of the whole system. This process of decomposition is continued down to the component-level requirements and specifications, which are used to optimize the system. Verifications are done at each level of the hierarchy to maximize quality and minimize risk by testing the compliance of the requirements with the system design. Validations are done to test the system against the stakeholders' needs. Once validation is completed, the V-Model system development methodology is concluded.

Various diagramming representations are employed in the V-Model development process. The diagramming representations provide functional descriptions of what the system does at each level, with respect to system structure, behavior, interfacing, and minimum levels of acceptable performance and maximum cost. They include, but are not limited to, use case diagrams, requirements diagrams, and activity diagrams.

Systems engineering tools allow us to bridge different information sources together, even if they appear to be interdisciplinary. These tools provide a platform to put together and analyze data from different fields of study. Systems engineering tools can capture structural requirements such as restraints, composition and interconnection of the system's architecture, behavioral requirements such as task-based and information-based functions, and allocations between behavioral and structural aspects of the system.

Our challenge, to identify design guidance that will lead to improved EMS worker and patient safety while optimizing worker performance in the ambulance patient compartment, is well-suited to a systems engineering analysis approach. The analysis involves information and requirements elicited through surveys, literature reviews, workshops, and foreign standards gap analyses, which can be bridged together through a systematic approach to capture structural requirements and behavioral requirements.

Furthermore, three characteristics of the ambulance patient compartment system design problem demand a systematic approach and analysis to arrive at the proper set of design requirements. These characteristics are:

- Complexity. The ambulance patient compartment can be seen as a system of systems. It encompasses many systems or objects within it, such as communications, controls, seating, and cabinetry; and also is situated to function along with other systems and external factors, such as the hospital or driving environments.
- Emergent system requirements. The requirements for a patient compartment emerge with usage of the ambulance. Obtaining emergent system requirements involves the need for a systematic approach with commitment from potential systems users. A lack of commitment from users means a lack of understanding of emergent requirements, which may lead to poor system performance once the project is complete.
- Need for evidence-based approach. To ensure a high level of quality, evidence is needed to analyze the quality priorities set forth from different stakeholders and users. Due to its utilization of scientific-based evidence, a systems approach has been identified to optimize safety in emergency vehicles [9].

These characteristics are well-matched to several principles for a successful systematic approach outlined in B. Boehm et al [10]. These principles include a need for the systems development to:

- Identify success-critical stakeholders of the system for consideration. By identifying these stakeholders, emergent requirements will be considered and higher quality assurance levels can be obtained.
- Provide a platform for the success-critical stakeholders to feel commitment to the system under development. Providing transparency of progress for the stakeholders during systems development will further encourage a high level of quality, enable incremental definition of the users' emergent requirements, and increase user acceptance.
- Back up any decisions about the system with evidence. The evidence supports the system to be interoperable with its intended environment and an increasingly complex, global system of systems.

In accordance with our first principle of a successful systematic approach, the V-Model of systems development requires identification of success-critical stakeholders up front. Requirements are first sought from project stakeholders such as patient compartment users or ambulance owners. Through this process, system-level requirements are derived from the stakeholder requirements. The system-level requirements are decomposed into subsystems, which are in turn decomposed further down until a requirement can be satisfied by a component. Throughout this decomposition, validation and verification measures are taken to assure that corrective actions and decisions are being taken. Validation looks back at making sure the stakeholder needs and system goals are met. For the ambulance patient compartment, validation is done through interactions with ambulance manufacturers, and EMS personnel. The validation process supported our other two mentioned systems engineering principles. It provided a platform for stakeholders to feel committed to the ambulance patient compartment guidance under development with transparency into project progress, and it enforced decisions about the patient compartment to be based on evidence.

3. Information Gathering & Requirements Capture

Several different initiatives were used to identify both requirements governing existing ambulance patient compartments as documented in literature and standards, and new requirements for future ambulance patient compartment design. Existing requirements were identified through literature reviews, standards and specifications gap analysis, practitioner interviews, site visits and ride-alongs. Requirements on future ambulance patient compartment design were gathered through focus groups, a nationwide web survey, and a workshop. The compilation of this list resulted in potential requirements insights that were useful in the process of developing requirements for future patient compartment standards. The approach encapsulated in the box in Figure 1 depicts the various approaches taken thus far to gather the requirements. This figure also shows the relationship of these requirement-gathering approaches to the next phase of analyzing requirements by using systems engineering methods and simulations.

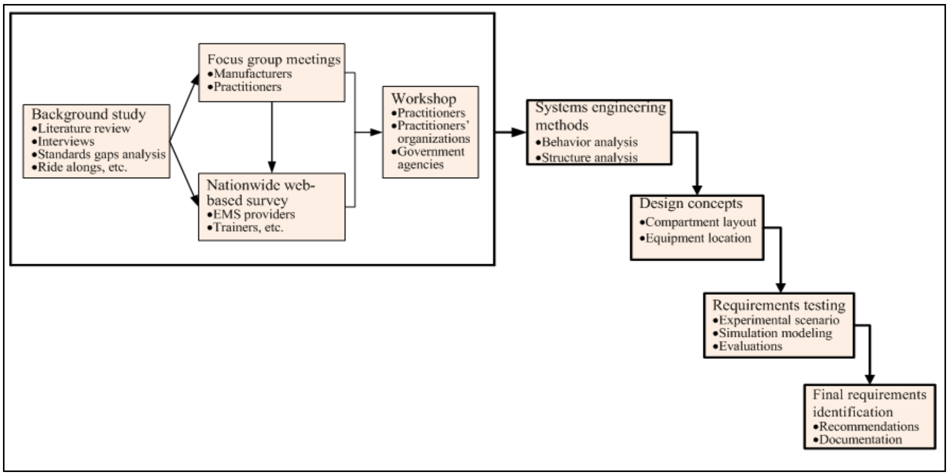

Fig 1. Information gathering process

The purpose of the literature review was to look at both academic literature and existing specifications and standards. The academic literature ranged from crash reports to ergonomic analysis of ambulance patient compartment workers. A collection of this literature was compiled as a bibliography in [6]. In addition to the academic literature, both foreign and American national standards pertaining to ambulance patient compartments were examined. A gap analysis systematically compared requirements between the foreign ambulance patient compartment standards and the current American standards, the KKK-A-1822F [3]. The result of this was a set of standards and specifications that were present in foreign standards, but not part of the American standards.

Practitioner observations and interviews were conducted to gather further requirements. We interviewed practitioners at two National EMS conferences. We conducted more than 20 EMS station site visits, observing EMS workers real-time patient care as well as simulated patient care routines for varied patient care scenarios. The greatest benefits of the ride-alongs and site visits were the ability to observe various patient care scenarios and to obtain feedback on requirements that aid in capturing emergent usage of the patient compartment system.

Facilitator-led focus groups of EMS practitioners and ambulance manufacturers were designed to arrive at an initial list of requirements that would serve as the basis for developing a nationwide web survey.

The nationwide web survey, conducted in December 2011, was broadly announced to the EMS community. The purpose of the nationwide web survey was to identify requirements for ambulance patient compartment design and to measure customer satisfaction with current designs, especially the patient compartment design interior layout and impact on patient care and EMS safety. Additionally, the frequency of different equipment use and importance of equipment use was gauged through this survey. The survey received 2537 responses, including over 300 pages of comments, needs, and recommendations. The results of this web survey, as well as the observations and interviews, drove the preliminary set of design needs.

Following the web survey, we held a workshop to validate the requirements collected to date, to determine if there is consensus on industrial needs and issues, and to prioritize those needs. A workshop was conducted at the EMS Today Conference & Expo in February 2012, and the topics covered included seating and restraint systems, communications, working environment, and patient care equipment and storage. EMS workers, representatives of EMS practitioner organizations, ambulance manufacturers, and government agencies participated and provided valuable feedback. In addition to the feedback, participation of these parties in the focus groups and workshops encouraged an incremental commitment in the process of analyzing these standards. Not only did this help to make more correct decisions for the patient compartment, it increased the chances of user acceptance to any changes that are made.

In this process, the hierarchy of the collected requirements were also accounted for. A sample of the requirements and their hierarchies that were collected are presented in Table 1. These requirements were compiled starting with higher-level "needs" and were put together with corresponding lower-level "criteria."

Table 1. Sample collection of requirements

Need	Requirement	Criteria
The EMS provider is able to provide safe and effective patient care from a seated position.	The EMS provider shall be able to reach the patient's body from head to knee while in a seated position.	Seating shall be designed such that a 5^{th} percentile female with a maximum functional reach of 26.7 inches (67.8cm) can reach a secured patient's body from the crown of the head to the kneecap to provide care for patients to 95^{th} percentile male stature.
		EMS provider should have access to both sides of the patient's body from a seated and restrained position

The information-gathering process resulted in two sets of requirements. The literature survey, foreign standards gap analysis, ride-alongs and interviews, yielded a set of existing patient compartment requirements from both the United States and foreign countries. The focus group meetings, the nationwide web survey and the workshop, captured a consensus of the needs and changes that the ambulance patient compartment stakeholders, namely the EMS workers and ambulance manufacturers, may seek in future ambulance designs.

4. Requirements Analysis Using Systems Engineering Analysis

Carrying out the V-Model development of needs, requirements, and specification of the ambulance patient compartment system at each level of hierarchy required appropriate diagramming representation. The V-Model starts with developing functional, behavioural diagrams from use cases and activity or sequence diagrams to derive high-level requirements from these representations to decompose into lower-level requirements. These requirements were allocated to the system's structure, and were refined with the use of verification matrices. The diagrams were developed in SysML, and a flowdown from SysML diagrams to requirements and verification matrices is depicted in Figure 2 (from [11]).

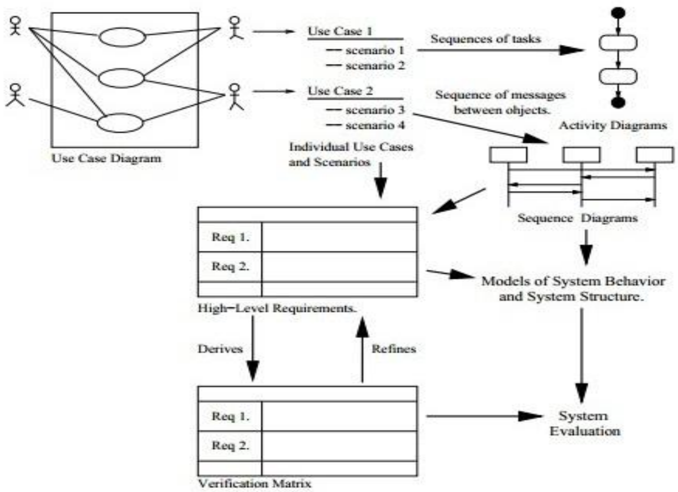

Fig. 2. Flowdown from SysML diagrams to requirements

The collected data from the information gathering and requirements capture efforts were used to develop five use-case diagrams to further identify patient compartment design requirements. These use cases depicted the different functional behaviors. These functional behaviors describe what the system, the patient compartment, must do. The five use cases that have been developed for the ambulance patient compartment system are:

- Facilitate communication mechanisms for information transfer
- Safely handle ingress and egress mechanisms
- Secure occupants restraint & seating system
- Maintain a safe, clutter-free workspace
- Grant equipment, device, and medication accommodation

These five use cases are depicted in the use-case diagram in Figure 3.

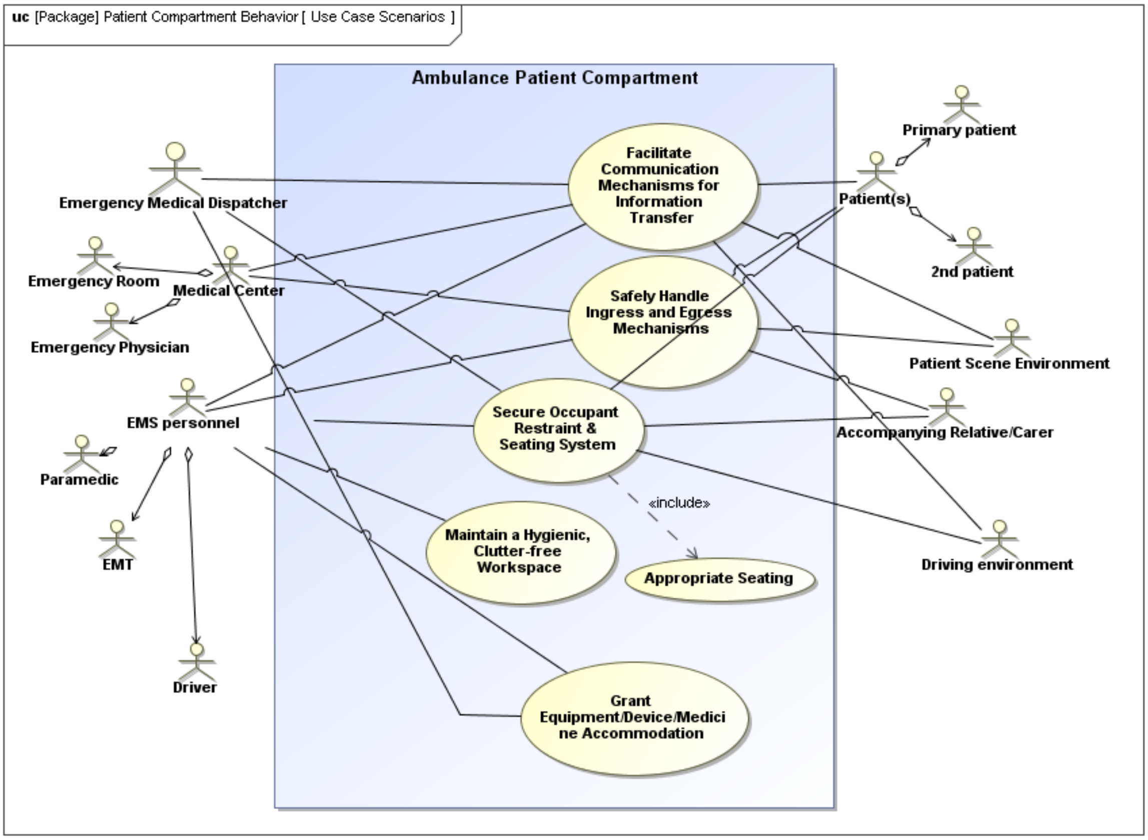

Fig 3. Use-case diagram for ambulance patient compartment system

The use-case descriptions include a title, the goals of the use case, primary actors, pre-conditions, primary flow of events, alternative flow of events, post-conditions, and derived requirements. The goals of each use case laid out the objectives that the ambulance patient compartment is expected to meet through the particular use case. Pre-conditions entailed the conditions that must hold for the use case to begin. Primary flow laid out the most frequent scenario or scenarios of the use case. Alternate flows of events listed the scenarios that are less frequent or off nominal [13]. They specified different patient scenarios that may occur in the patient compartment, including treatments for cardiac, respiratory, stroke, pregnancy, or burns. There can also be special cases of treating bariatric patients as opposed to normal-sized patients. Post-conditions took into account the conditions that hold once the flow of events has been completed [13]. Activity diagrams and sequence diagrams were used to assist the primary and alternate flows, as the 2 diagram types aid in the generation of behavioral and structural requirements and structure interface requirements, respectively. Examples of goals pertaining to one use case are as follows:

Use Case 1: Facilitate Communication Mechanisms for Information Transfer

Goal 1: Enhancing Communication Systems

1.1: Ability to communicate efficiently and effectively between the patient compartment, and the driver, the dispatcher, the hospital, and others.
1.2: Patient information is transferred through this communication system.
1.3: Driver awareness of activity in the patient compartment.
1.4: EMS provider awareness of driver actions.
1.5: Medical center is notified of incoming patient.

Requirements from surveys, literature reviews, and focus groups were allocated throughout the process of developing and analyzing each use case. Requirements were also derived throughout this process. To verify the requirements and needs pertaining to each use case, they were traced to the goals of the stakeholders that each use case initially defines. These requirements were also allocated to objects within the ambulance patient compartment structure, including equipment storage/mounts, seating, restraints, communications devices, and more. A table tracing the use case "Facilitate communication mechanisms for information transfer" down to its derived requirements and their corresponding associated objects is shown below.

Table 2. From use case to derived requirements and corresponding subsystem objects

Use Case	**Goal No.**	**Req. No.**	**Requirement**	**Object**
Facilitate Communication Mechanisms for Information Transfer	1.1, 1.3, 1.4, 1.5	1.1	3-way communications	Communications Device
	1.2	1.2	Method to write down patient assessment/priorities & other patient info (pen & paper, recording, laptop?)	Patient Information Recording Device/Method
	1.2	1.3	Easily transfer patient assessment/priorities & other patient info to the hospital/care center	Patient Information Recording Device/Method

Tracing down to a lower-level hierarchy, the object requirements were decomposed into sub-requirements. The sub-requirements in turn corresponded to components of each object. Components included more specific definitions of storage or mounting for specific equipment or devices, the composition of the seating & restraint parts, the composition of the communications devices, and more decomposed objects. Added to the description of each of these components were a function and an attribute. The attributes described the characteristics of the component, and include reachability, configuration, and interfacing, and security. The functions told us what the component does, based on the characteristics it has. The decomposition of some of the requirements depicted in Table 2 is shown in Table 3.

Table 3. Decomposing objects to components

Requirements	**Sub-requirements**	**Component**	**Attributes**	**Functions**
1.2: Method to record patient assessment/priorities & other patient info (pen & paper, recording, laptop)	**1.2.1:** Fast documentation of patient information	Information processing paradigm	Speed	Process the patient information quickly
	1.2.2: Easy Access to patient information recording device/method	Recording device's storage area	Reachable	Accommodate close proximity to EMS personnel
1.3: Easily transfer patient assessment/priorities & other patient info to the hospital/care center	**1.3.1:** Reliability of patient information transfer	Data transfer system (e.g. such as a bus or network)	Data transfer reliability	Process the patient information reliably
	1.3.2: Speed of patient information transfer	Data transfer system (e.g. such as a bus or network)	Data speed transfer (e.g. such as bit rates)	Transfer the patient information quickly

Thus, the goals of the stakeholders have been traced down to lower-level components and corresponding component requirements inside the ambulance patient compartment. These component requirements have then been used to derive specifications for the component and set constraints on the component design that are later to be used for optimization of the system and the trade-off analysis between different system (ambulance patient compartment) design alternatives.

5. Challenges in Resolving Potential Requirement Conflicts

The greatest challenge in the systems engineering V-Model development process for the ambulance patient compartment has been resolving the lower-level component requirements that are conflicting. These conflicts need to be resolved to have efficient ambulance standards. If two or more components share the same or similar attribute-function pairs, it is then necessary to observe them and see if they possess potentially conflicting requirements. Potentially conflicting sets of component requirements have been defined as those that desire the same attributes and functionalities for their components. Also, the simultaneous application of these requirements to corresponding components is not possible. Examples of four components that hold similar attributes and functions, and can potentially be conflicting, follow in Tables 4-7:

Table 4. Waste and sharps disposal attributes and functions

Sub-Requirements	**Component**	**Attributes**	**Functions**
4.5.1: Sharps and trash disposal containers shall be located such that a 5th percentile female with a maximum functional reach of 26.7 inches (67.8cm) can properly dispose of trash and sharps while seated and restrained from each working position	Disposal positioning	Reachability	Accommodate close proximity to EMS personnel

Table 5. Monitoring equipment storage attributes and functions

Sub-Requirements	**Component**	**Attributes**	**Functions**
5.2.1: Access to patient monitoring & defibrillation equipment does not strain EMS personnel from their patient care seating position	Storage/mounting for patient monitoring equipment	Reachability Storage/mounting configuration	Accommodate close proximity to EMS personnel

Table 6. Communication device storage attributes and functions

Sub-Requirements	**Component**	**Attributes**	**Functions**
1.1.7: Easy access to communications device	Communication device's storage area	Reachability	Accommodate close proximity to EMS personnel

Table 7. Cot location attributes and function

Sub-Requirements	**Component**	**Attributes**	**Functions**
2.2.1: Access to cot for patient healthcare shall not be made difficult by the location where the cot can be locked	Transfer mattress/carrying sheet	Reachability	Accommodate close proximity to EMS personnel

The potential conflicts have been observed in their attributes and functions, since they require an EMS worker to be able to reach all four components from the same seated position. In fact, it has been concerning that too many other components, such as the various equipment mounting and storage locations, have the attribute to be 'reachable' and the function to 'accommodate close proximity to the restrained EMS personnel.'

With sets of component requirements that have been determined to be potentially conflicting, the specifications and constraints corresponding to those components will be chosen for a trade-off analysis and optimization. Specifications are limits set on the component's designs to provide a mathematical basis for the component requirements. Constraints are performance limits that are selected to optimize the performance of each component. The assessment of resolving the conflicts will be based off of a set of metrics and constraints that the component specifications must adhere to. These metrics are used to optimize the system for the most important criteria (i.e., the criteria that determines how the requirement conflicts are resolved). The metrics should come from a solid mathematical foundation, as the component constraints and specifications also should. Thus far, the conflicting requirements in the ambulance patient compartment are based on whether or not the specific equipment storage location or mounting point are within the reach envelope of the EMS personnel. To resolve this conflict, it is necessary to maximize reachability and to define this as a metric with a mathematical basis. An important constraint already identified for resolving the conflicts is for the component to be reachable in accordance to the frequency of component (e.g., equipment storage) use and importance of the component use as indicated by the nationwide web survey. A degree of reachability compliance (mandatory, desired, and best reachability value) should be in each conflicting component's constraints. This will help determine the appropriate component's significance of reachability versus the maximizing reachability metric during trade-off analysis between different ambulance-patient-compartment-layout concepts.

Using simulations, numerical metrics and constraints will be evaluated. Furthermore, simulations will eliminate the need to construct expensive prototypes, and will also give the benefit of providing faster, cheaper evaluations. A human simulation modeling software has already been identified, which calculates the reach envelope for human heights ranging from 5th percentile females to 95th percentile males. A reach envelope for this height range can be measured and simulated for different postures (sitting up straight, leaning forward, etc.) and for both left-handed and right-handed seated individuals. Likewise, the visibility of the components will be taken into consideration. Using these capabilities, it will be possible to simulate the numerical metrics and constraints of the conflicting components' reach envelopes in the different ambulance patient compartment layouts. We will be able to observe which of the design alternatives provides a more optimized patient compartment that allows the EMS personnel to access and treat the patient while seated and restrained.

6. Conclusions and Future Work

This paper demonstrates how systems engineering principles can be applied to practical applications, such as ambulance-patient-compartment design. These principles include defining the system based on stakeholder input, providing a platform to feel commitment to the developing system, and backing up any decisions about the system through evidence. The application of the principles has been immensely useful in requirements analysis, as it has aided in designing and optimizing future patient compartments. As a result, the methodology has helped effectively break down system requirements to component requirements. Furthermore, it has also revealed potentially conflicting requirements at the component-level stage to be resolved through a trade-off analysis.

Future work includes using human simulation software to simulate the component reachability in the different patient-compartment layouts, to resolve any requirement conflicts, and to validate the requirements. For the requirement conflict resolution, a trade-off analysis will then take the simulation results and metric and constraint equations to optimize the entire ambulance patient-compartment system. With these experimental results, a final set of design requirements will be identified. The final set of requirements will be input for the next open comment period for the NFPA 1917 draft, tentatively scheduled for the spring of 2013 [12].

Acknowledgements

The U.S. Department of Homeland Security Science and Technology Directorate (DHS S&T) Human Factors/Behavioral Sciences Division and First Responders Group sponsored the production of this material under Interagency Agreement HSHQDC-11-X-00049 with the National Institute of Standards and Technology (NIST). The work described was funded by the United States Government and is not subject to copyright.

References

1. Maguire, B.J., K.L. Hunting, G.S. Smith, and N.R. Levick. "Occupational Fatalities in Emergency Medical Services: A Hidden Crisis. "Annals of Emergency Medicine, 2002, 40(6): pp 625-632.

2. National Fire Protection Association. NFPA 1917 Standard of Automotive Ambulances. NFPA1917, 2013.

3. U.S. General Services Administration. Federal Specification for the Star of Life Ambulance. KKK-A-1822F, 2007.

4. McCallion, Teresa. "Sneak Peek at NFPA 1917." Accessed 08/31/2012. http://www.jems.com/article/ems-insider/sneak-peek-nfpa-1917.

5. Proudfoot, S.L., P. Moore, and R. Levine. "Safety In Numbers: A Survey on Ambulance Patient Compartment Safety." Journal of Emergency Medical Services, March 2007, 32(3): pp 86-90.

6. Dadfarnia, M., Y.T. Lee, and D. Kibira. "A Bibliography of Ambulance Patient Compartments and Related Issues." National Institute of Standards & Technology Internal Report (NIST IR 7835), February 27, 2012.

7. Reichard, A.A., and L.L. Jackson. "Occupational Injuries Among Emergency Responders." American Journal of Industrial Medicine, 2009: pp 1-11.

8. Ferreira, J., and S. Hignett. "Reviewing ambulance design for clinical efficiency and paramedic safety." Applied Ergonomics, 2005, 36: pp 97-105.

9. Levick, N.R. "Emergency Medical Services: A Unique Transportation Safety Challenge." Paper presented at the Transportation Research Board's 87th Annual Meeting, Washington DC, 2008.

10. B. Boehm, S. Koolmanojwong, J.A. Lane, and R. Turner. "Principles for Successful Systems Engineering, Procedia Computer Science." Volume 8, 2012, Pages 297-302, ISSN 1877-0509, 10.1016/j.procs.2012.01.063.

11. Austin, M, and J. Baras. "Lecture Notes for ENES489P Special Topics in Engineering: Hands-On Systems Engineering Projects," College Park, Maryland, USA, Fall 2010.

12. D. Kibira, Y.T. Lee, and M. Dadfarnia. "Modeling for optimal ambulance patient compartment layout," 2012 Spring Simulation Multiconference, March 2012, Society for Modeling & Simulation International (SCS)

13. S. Friedenthal, A. Moore, and R. Steiner. "A Practical Guide to SysML: The Systems Modeling Language," Burlington, Massachusetts, USA, 2009; pp 275.

14. Patterson, F. "System Engineering Life Cycles: Life Cycles for Research, Development, Test, and Evaluation; Acquisition; and Planning and Marketing." Handbook of Systems Engineering and Management. Ed. A. Sage and Rouse. W. Wiley, 1999: 59-111.