Utility-Theoretic Training for Mass Casualty Incidents

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ABSTRACT

This paper describes an approach to training emergency responders for mass casualty incidents. The approach is derived from a methodology and supporting software system called Summit. The Summit approach uses an integration of scenarios, hierarchical task analysis, interaction modeling, and expected utility theory to represent how actors engage in complex tasks; here we model mass casualty incident (MCI) activities supported by interactive technologies. Our goal is to ground MCI training in realistic scenarios and to demonstrate required response capabilities through associated hierarchical task analyses (HTA). The terminal nodes in an HTA are interactions, that provide a fine-grained model of the actors, technologies, data, and methods involved in realizing the required capability. The components of an interaction may have associated *utility factors* (benefits, costs, and risks) that provide learners with a rationale-based resource for understanding how different technologies are used to support MCI response efforts. Assessment of the approach is underway within a local EMS organization.

Keywords

Mass casualty incidents, training for emergency response, scenario and task analysis, expected utility theory.

INTRODUCTION

Mass casualty incidents (MCIs) are among the most challenging scenarios that emergency response organizations must face. Training for these incidents is also challenging, not least because the scope and scale of an MCI makes creating realistic exercises and other training methods both time consuming and expensive. In this paper we describe an approach and supporting software application designed to provide responders, in particular, emergency medical services, with a computer-based trainer for MCI scenarios.

A mass casualty incident is, technically, any emergency where the effects of the incident are beyond the capabilities of available resources. For example, a motor vehicle accident with three injured people qualifies as a mass casualty incident when the available response resource is a single ambulance with a two-person crew. Normally, however, we think of MCIs as large-scale incidents or emergencies with at least tens, if not hundreds or even thousands of victims and other people affected. For the remainder of this paper we will assume this latter, less formal, but more widely-held understanding of an MCI.

Preparedness and training for mass casualty incidents is problematic not least because of their relatively low frequency. Thankfully, large-scale MCIs are rare. Most local emergency response districts will never need to operationalize their MCI plans, training, and equipment, except for occasional full-scale field training exercises and table-top simulations. Because of this relative lack of opportunities for actual practice, MCI preparedness may be considered a kind of organizational *vigilance task.* Vigilance tasks are those activities, such as managing a nuclear power plant failure, that require constant training, preparedness, and monitoring for occurrences that are relatively rare [1]. The theory underlying the idea of vigilance tasks posits that just because they are so rare, preparedness for MCI decays or *decrements* as a function of lack of practice. Some more recent work expands on the idea of a vigilance task to claim that learning and skill are functions of the evolution of declarative knowledge (knowing that) into procedural knowledge (knowing how), the latter being essential to effective practice in stressful and time-constrained domains [2].

Mass casualty incident full-scale field exercises and table-top simulations are useful to help identify faults in inter-organizational communication, situational awareness, and command and control. In the United States, organizational and individual role responsibilities are defined in the National Incident Management Systems (NIMS) and Incident Command System (ICS) [3]. What is less well understood, however, is what is required from a particular, individual responder, who must perform critical, but unfamiliar tasks effectively under stress and within the incident command and control framework. All emergencies are ultimately local, community events [4] and the concrete particulars of a local NIMS and ICS-based response are not as well defined or understood as they can appear to be for larger scale, more abstract, national-scale emergencies. In such local MCI emergencies, *the devil is in the details* and effective response requires training that accounts for local context.

This paper describes an approach to continuous, virtual training for MCI emergency response personnel within their local context. The next section describes the conceptual basis of the Summit approach and software system that implements these concepts. The section following that shows how Summit is being used to model MCIs. We then describe how these models are planned for use as training aids for MCI emergency response personnel, specifically, for emergency medical services. Finally, we describe our plans going forward and argue for a number of different ways that the approach can be used for other types of training scenarios and for real-time support in emergencies.

SUMMIT

Summit was developed as an approach to modeling large-scale systems of interactive technologies. It consists of both a methodology and a supporting software tool designed to capture and model elements of these large-scale systems. Summit has been used for both design and evaluation of 'real world' systems, and in an undergraduate human-computer course as a means for students to model class projects. The Summit conceptual model appears in Figure 1 and is described in detail below.

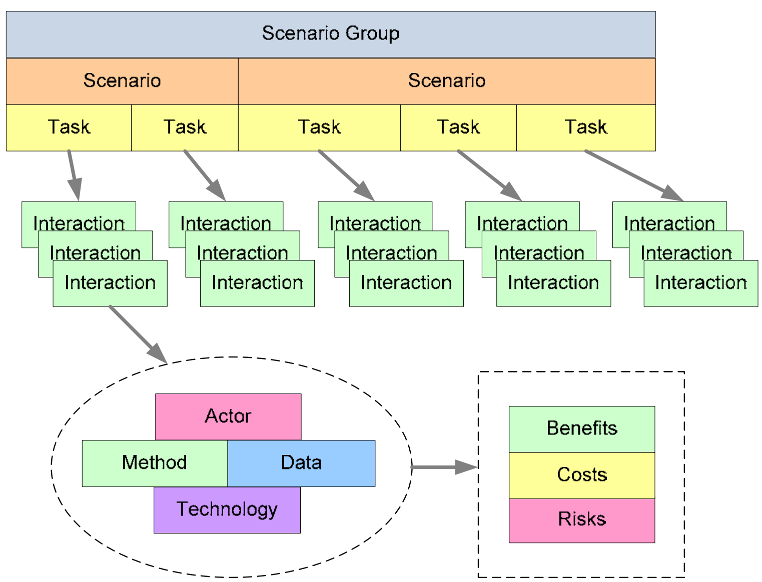

Figure 1 - The Summit Conceptual Model

As an approach to capturing and presenting training content, Summit includes some acknowledged practices, such as the use of scenarios and task analysis, as well as some novel elements, such as technology interaction modeling and utility analysis. We believe this approach compares favorably to more conventional forms of training, such as scenario analysis on its own, in that it support a multi-perspective view of the activities being modeled. Learners can navigate a model from the top down, from the bottom up, or from any point in between.

Though the data collection and modeling in Summit is designed to be non-linear to support opportunistic data gathering in the field (and often is non-linear), a notional step-by-step process would appear as follows.

1. Identify and create *scenarios* describing both typical and atypical (critical incidents) activities in the domain of interest.
2. Decompose and structure the elements scenarios through *hierarchical task analysis* breaking down scenarios into tasks, sub-tasks, and interactions.
3. Identify technology *interactions* at the lowest level of the task analyses. Interaction are the terminal nodes of the task analysis and include:
   a. The *actors* (people) involved in the interaction.
   b. The *technology* they are interacting with, actual or envisioned.
   c. The *data* they use or need for the interaction.
   d. The *method* (discrete process) that describes in detail the interaction activity.
4. Identify the *benefits, costs, and risks* (*utility factors*) associated with each technology interaction.
5. Analyze the completed model for opportunities to realize or increase benefits and manage down costs and risks through interventions such as training, process improvement, and introduction of new technologies.

The Summit data gathering and analysis process results in a model that explicitly relates elements of an *information ecology* to the actual and envisioned situations (scenarios) where those elements are needed and employed. For example, the model shows how a technology such as a computer-aided dispatch (CAD) system is part of an emergency response scenario, including who uses it for the different tasks and sub-tasks underlying the scenario and the potential benefits, costs, and risks associated with its use. One of the strengths of the Summit approach and supporting software system is that these relationships are made *explicit* and *navigable* in the model. Users of the tool can begin with a plausible and familiar (or unfamiliar) scenario, then navigate to the actor, tasks, technologies, data, etc. that are planned for the envisioned response to the scenario. Conversely, they can start with a lower level model element such as a specific technology or data element, and then examine the kinds of scenarios and tasks the technology or data are intended to support.

One unique and valuable aspect of the Summit approach is that it explicitly incorporates utility-theoretic ideas in the way the approach links utility factors (benefits, costs, and risks) to technology interactions that may involve one or more actors collaborating to perform a low-level, discrete task. Utility factors may be modeled as categorical data, or as categories with either actual or relative values (measured in money, time, or some other constrained resource) depending on the availability of such data. Utility factors are central to the Summit approach and to the training proposition presented here. The use of utility factors enhances task and technology training because they provide information on why a particular task is performed in a particular way (the benefits), the resource constraints attending task performance (the costs), and what might go wrong in the process of completing the task (the risks).

UTILITY-THEORETIC TRAINING

The Summit approach to activity modeling places task analyses between the scenarios in which tasks occur, and the specific, low-level interactions between people and technology that take place in the course of completing a task in response to a recognized goal. Task analyses are essentially abstract decompositions of some holistic activity intended to show how the activity is conducted as a series of discrete, atomic task elements arranged hierarchically and in sequence. Anchoring task analyses to plausible scenarios in which the task is conducted helps achieve completeness and coverage by forcing the modeler to consider the effects of minute confounding details such as the environmental conditions in which the activity occurs. Herman Kahn, one of the originators of the scenario analysis method, argues that scenarios are essential to modeling complex situations because:

> *"They force the analyst to deal with details and dynamics that he might easily avoid treating if he restricted himself to abstract considerations."* [5]

The approach used for capturing scenarios for Summit analysis draws from the format proposed by Carroll [7] and includes the following elements.

- Scenario Title – short description of the scenario.
- Actor – the person or role performing the scenario.

- Setting – a description of the context in which the scenario takes place.
- Scenario Goal – the objective of the interaction with the technology being designed.
- Scenario Narrative – a detailed account of how the scenario actor will interact with the technology to achieve the scenario goal.
- Claims Analysis (in Summit, Utility Analysis) – in Carroll's conception, claims are statements about envisioned pros and cons of technology support for the scenario, along with the design trade-offs to be considered. In Summit, claims follow a particular taxonomy to include statements about the benefits, costs, and risks associated with technology support for the scenario.

While scenarios provide the top-down perspective showing tasks occurring within a realistic narrative, Summit's utility factors are used to augment abstract task and technology interaction descriptions with the rationale for why it is important to carry out a particular task in a particular way, or why it is important to complete the task at all. By modeling the terminal nodes of a task hierarchy as interactions between actors, technology, and information each potentially 'tagged' with the benefits, costs, and risks associated with the interaction, Summit goes beyond the 'what' and 'how' of conventional task analysis to provide a rationale for the task model taking a particular form. Summit's *benefits* give evidence for the value gained by carrying out a task in a particular way. Capturing *costs* provides a measure of this upside potential relative to the actual or implied costs of the activity. Considering an interaction's benefits minus its costs gives a rough, order-of-magnitude measure of the *return* that results when a task is completed as planned and without error. Summit's *risk* utility factor is included to help identify how a task might fail or be completed in some sub-optimal way because of factors associated with people, technology, and information interacting in the task.

Taken together the benefits, costs, and risks associated with completing a task element resolve to an intentionally simplistic version of an expected utility function as given below.

$$U = (\sum b - \sum c)\ (1 - \sum r)$$

U – expected utility

b – benefits derived from an interaction

c – costs of supporting the interaction

r – risks associated with the interaction

In other words, the expected utility (U) derived from conducting a task in a particular way may be computed as the sum of the associated benefits minus the sum of the associated costs times the aggregate probability that associated risks will obtain during the task. This perspective on expected utility is intentionally simplistic because in modeling 'real-world' activity we take the view that a more holistic, but necessarily more 'messy' model is more useful than one of higher fidelity with terms that are extremely expensive if not impossible to capture in practice. In addition, utility factors can be captured using a true ratio scale (usually monetary, but also possibly time), an integral scale where benefits and costs are given relative values, and a categorical scale, where benefits, costs, and risks are all assigned a value of 1. This flexibility allows for a model to evolve from a 'quick and dirty' version to one with more rigorously defined factors.

Modeling task elements as interactions with associated utility factors provides the learner with a rich model of how completion of a task might be complicated by both the characteristics of the task itself and of the environment in which the task normally occurs. Another advantage to the Summit modeling approach is that it provides an explicit, shared representation of how a group or organization views the elements of an important reference task. This representation allows for grounded communication between group members and acts as a baseline for quality improvement.

MODELING MASS CASUALTY INCIDENTS WITH SUMMIT

The first of our Summit training models analyzes EMS response to a mass casualty incident. As discussed in the Introduction, MCIs are critical events where EMS personnel play a central role, but (thankfully) most EMTs and paramedics rarely if ever have an opportunity to practice and learn through experience on actual MCI incidents. In standard approaches to MCI training, the scenarios that are given often generic, designed to be used as the basis for training in almost any locale. Because they are designed for general applicability, they necessarily fail to account for the particular context of an actual MCI, including the local topography, traffic patterns, demographics, culture, and emergency response infrastructure, among other factors. These particulars play an important role in shaping an emergency response as it unfolds around an incident and, we argue, should be incorporated into the training that is provided to response personnel.

MCI training often involves full-scale simulated field exercises, which are costly and manpower intensive to plan and execute. Even so-called *functional exercises*, which only involve anticipated command staff, can take weeks or months to plan and execute [6]. Also, some aspects of an MCI cannot be safely recreated in mock exercises, which forces some tasks to be entirely simulated and thus do not allow the entire process to be exercised. On much less expensive tabletop exercises many such aspects of an MCI are simulated, leading to assumptions that may mask significant problems that might arise when these low frequency events do occur. Summit allows an entire event to be modeled more quickly and cost-effectively, which in turn allows a wider range of events to be examined and exercised in training.

In our first MCI Summit training model we developed a scenario involving a major bus accident in our area. A national "superbus" company runs a service between a local pickup location and mid-town Manhattan. The vehicles the company uses are large, double-decker tour buses that can carry as many as eighty passengers. In our area the bus route includes mountainous terrain and the potential for severe weather. Accidents with tour buses do occur. For example, a recent bus crash in the United States, in Oregon, resulted in nine deaths and over 20 passengers injured. Even a relatively small-scale MCI such as this would challenge the emergency response system of our and most other local emergency medical response organizations.

Our bus crash scenario is based on a plausible event with a scenario narrative synopsis given below.

> *A SuperBus Corp. double-decker passenger bus is traveling northbound on Interstate 99 in central Pennsylvania. The bus is carrying 62 passengers including 14 children, and a driver. It is January and the weather conditions include just below freezing temperatures, snow, and freezing rain. While passing a long line of vehicles at 72 miles per hour the bus hits a patch of black ice causing it to spin out of control, strike the median guardrail, and rebound across both northbound lanes striking the outer guardrail, flipping onto its side before sliding down an embankment into a wooded area. Passengers in other northbound vehicles observe the crash and there are four separate 911 calls to report the accident.*
>
> *The accident results in 51 of the 63 passengers sustaining injuries including broken bones, blunt force and penetrating trauma, and head injuries. Three of the injured passengers die almost immediately at the scene.*

Modeling this scenario in Summit results in a high-level arrangement of tasks and interactions as shown in the figure below.

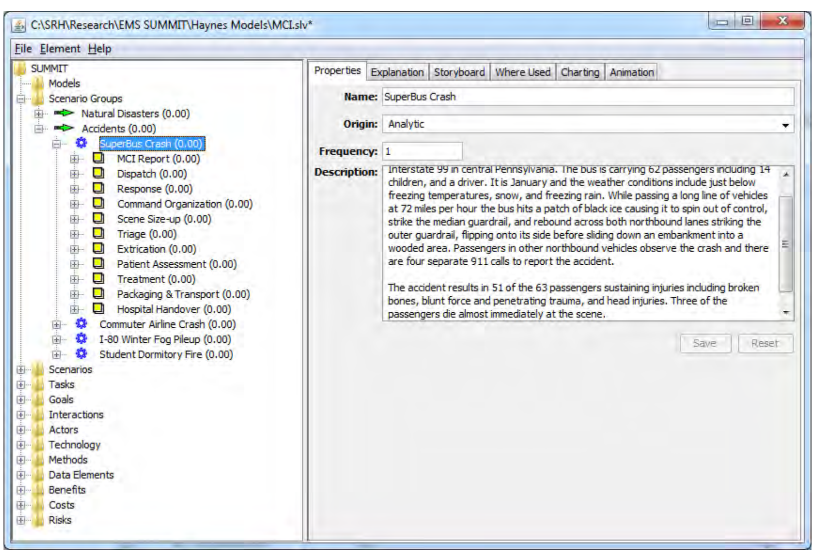

Figure 2 – MCI Scenario and Top-level Tasks in Summit

The Summit data view in Figure 2 shows how scenarios are represented in the software system with task hierarchies providing the detailed task elements, or in this case, high-level task phases, that occur over the course of the scenario. In this way Summit provides the learner with the context in which lower-level, more detailed activities are conducted. Contrast this view with Figure 3, which models the critical MCI task of patient triage.

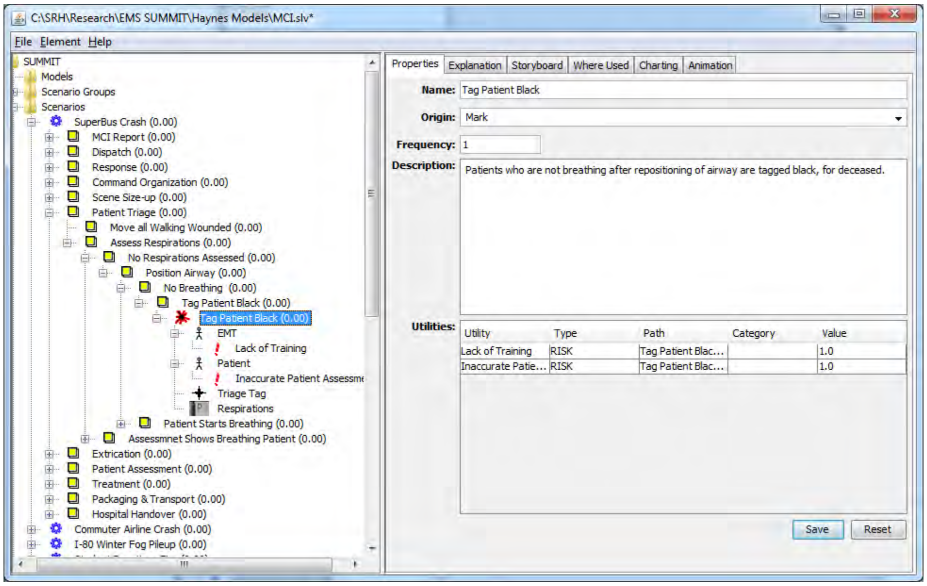

Figure 3 – MCI Triage Task Model in Summit

The data view in Figure 3 shows how the critical MCI task of patient triage is modeled in Summit. This view gives a perspective on the task hierarchy, and provides learners with instructions for how patients are prioritized (triaged) on MCIs in the state of Pennsylvania in the United States.

The example data view above provides an overview of Summit's general user interface implementation, navigational scheme, and feature set. The example includes a Summit interaction, indicated by a red 'splat' icon labeled *Tag Patient Black*. In the example this interaction is the only activity element of a Summit task with the mirror label *Tag Patient Black* (the yellow, square icon). Tasks may have one or many interactions as components. In this case the single interaction designates the task as the terminal node of a task analysis branch, which in turn is part of a sequence of tasks that are expected to be performed in the event of the SuperBus Crash scenario (the blue gear-shaped icon). Moving down the hierarchy shows that the actors expected to be included in the *Tag Patient Black* task are the Patient and the EMT. The EMT actor uses a Triage Tag technology (albeit a low-tech technology) as part of the interaction underlying task performance. It is important to note that representations such as this one provide a basis for analysis of alternative technologies available, such as using RFID tags and hand-held readers for patient triage.

An important feature of the Summit approach is the tagging of interaction elements with utility factors, the benefits, costs, and risks. The abbreviated example above shows two such utility factors. The EMT 'carries' inadequate training as an associated risk and the patient is at risk of an inaccurate patient assessment. The benefits, costs, and risks associated with interaction elements are designed to convey contextual information to the learner, information that goes beyond the more simplistic declarative content to include *why* the interaction takes the form that it does (the benefits) as well as the various constraints involved (costs, risks). These utility factors provide rich information content that can be used to expose the design rationale that underlying the design of the interaction thereby enhancing both technology use and general task performance by the actors.

Figure 4 shows an important task that is done within an MCI scenario where the potential for severe head and neck trauma dictates that providers consider spinal immobilization for all patients [16].

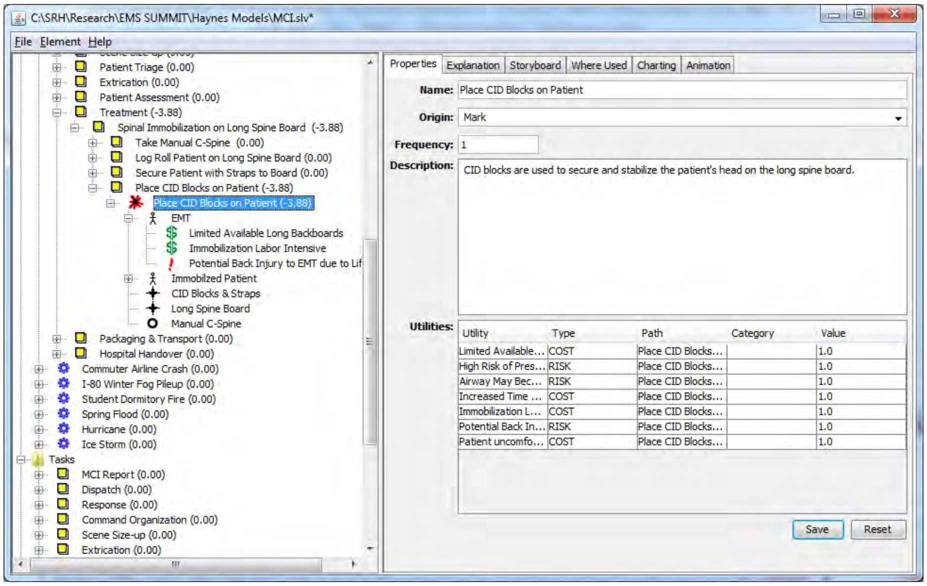

Figure 4 – Spinal Immobilization Interaction Model

In this part of the model, the utility-theoretic ideas of cost benefit and risk are clearly displayed for the user. In Summit the utility factors, the benefits, costs, and risks are tagged under the interactions. One example is that the use of full spinal immobilization is associated increased on scene time as well as increased patient discomfort. The benefits, costs, and risks associated with interaction elements are designed to convey contextual information to the learner, information that goes beyond the more simplistic declarative content to include *why* the interaction takes the form that it does, the benefits that accrue when it occurs, as well as the various constraints involved in its completion including costs and risks.

SUMMIT AS A TRAINING DEVICE

The Summit approach and tool represents a unique integration of several different theories related to learning and practice in the emergency response domain. First, the use of 'real world' scenarios and scenario-based problem solving are widely used in medical education and training and so are familiar to any practitioner with EMT or higher certifications. Scenarios have long been employed as a means to comprehend complex situations by teasing out the particulars of a situation and showing how these particulars can impact the actors involved [5]. More recent work shows how important scenarios are in helping to understand and communicate the role of interactive technologies in both individual and collaborative human activity [7]. Scenarios have been employed as a means to evaluate very large-scale integrated systems [8]. In Emergency Medical Services, providing personnel with scenario-based training has been shown to increase survival rates for out-of-hospital cardiac arrest victims [9]. Scenario-based training can be particularly effective as a means to ground practice in the specific details of local events. Scenarios are concrete narratives, realistic stories that are designed to avoid the abstractions and generalizations that, while sometimes both necessary and useful, can serve to mask factors that determine the effectiveness of a *particular* response in a *particular* context.

Task analysis is a widely used method for developing training and other educational content [10]. One of the underlying tenets of task analysis for instruction is that complex tasks may be best learned by decomposing them into successively simpler components that can be more easily learned. Graphical displays of task analyses as inverted trees or outlines serve to retain the position and role of an atomic task element within the context and flow of the more complex whole. A completely elaborated task analysis also shows how output from one task may serve as an input into other tasks downstream within an activity. The hierarchical structure of a task analysis supports both top-down and bottom-up learning and in this way can support a wide range of learning styles. Protocols used to guide emergency response in the United States are essentially task analyses, they detail the normative sequence of activities a responder must follow in a given category of event and are a key element of most state-specific EMS training programs. In Summit a loosely structured but detailed scenario can be decomposed into a task analysis that accounts for important local determinants of emergency response success.

Our approach to modeling the terminal nodes in a task analysis as technology interactions is, as far as we know, a novel approach to increasing the depth of information communicated within a task specification. Of particular importance is that it allows the modeler to represent the use of technology and information as part of a task, and also to make explicit the role of technology and information in collaborative activities. Because technology and information are increasingly central to so many human activities, including those carried out by EMS, we believe this approach this fills a significant gap in current approaches to instructional design using hierarchical representations of tasks, which commonly focus on the human activity only without accounting for the role of technology and information in successful task execution.

The use of utility factors (benefits, costs, and risks) is another unique aspect of the Summit approach to training and learning. Utility theoretic ideas are one of the central components in structured and formalized approaches to decision making [11, 12], but their use as resources for learning is not, as far as we know, a topic that has been explored for its potential applicability in training. Making utility factors explicit in training content helps ground instruction in the context in which skills, knowledge, and technology will be used. Making explicit the benefits of a given approach helps explain why actors are encouraged or required to use methods, technology, and data in a certain way within certain contexts. Costs and risks make plain the downsides of a particular approach, and communicate areas of concern that task performers should be aware of to complete tasks safely. This awareness enables them to make better decisions based on actual or probable costs, risks, and benefits, not just long standing assumptions about what might be true.

A central pedagogical idea underlying this approach is that a Summit model shows the relationship between a familiar scenario narrative, which may be chaotic, and the more abstract and structured tasks that are involved in providing patient care as part of the scenario. Scenarios have the important attribute of helping to make complex situations familiar by grounding them in local particulars [5]. The Summit model also shows how technologies are designed to fit into the task flow, as well as the information (data) required for each task element as either input from an earlier task or output to a task downstream in the flow. Because emergency medical services are often the entry point into the continuum of care that makes up the overall healthcare system, it is important to understand and manage these information flows to optimize clinical decision making throughout the continuum.

We are also investigating the Summit model can show how important collaborations occur in EMS tasks and how information is communicated between actors collaborating in a task sequence. In this way Summit may act as an important explicit, external, and durable representation of local task coordination strategies. External representations such as these are important coordination mechanisms for the many healthcare professionals who might contribute to a single patient's assessment and treatment. Shared representations can act as the catalyst for emergence of communities of practice within a given domain [13], such as EMS or healthcare more generally. They are also useful as a means to promote *reflective practice* in healthcare education [14], because they provide both a "case base" and commentary about what may have gone right (benefits) and what could be managed differently (costs, risks) on a given case.

The scope and scale of a Summit model varies according to the relative size of the scenario and tasks being modeled. The size of a Summit model can also depend on the resources available to capture model data, and the fidelity that is required to support a particular training objective. Our emergency medical services models range from approximately 60 to over 300 elements, but Summit models for other domains have been as large as 5,500 elements [8].

LESSONS LEARNED

Our work so far on evaluating Summit modeling for MCI training has taken place in cooperation with a local emergency medical service and has consisted primarily of informal walkthroughs and modeling exercises. This work has helped to reveal a number of issues with the approach and will be used to inform subsequent designs of both the approach and supporting software system. In this section we provide a brief discussion of these lessons learned.

First, while we have found that EMS practitioners without specialized training can easily comprehend a Summit model once it is built, we have encountered some difficulty in attempting to carry out participatory model building with their active involvement. The task analysis formalization, in particular, appears to be difficult for those unaccustomed to decomposing activity into discrete tasks within a structured hierarchy. In some ways this result is not surprising; the challenges that arise from asking information system users to act as self-reflective "knowledge engineers" were well-documented in some very early work on medical informatics [15].

A second area of difficulty has been in identifying and especially *quantifying* the benefits, costs, and risks associated with discrete task steps, the terminal nodes or *interactions* in the Summit modeling framework. We have found that interaction benefits are especially problematic. Though in many cases people are able to acknowledge the positive aspect of some task, technology, or information, quantifying these benefits even on an ordinal or relative scale has proven difficult. To a degree this difficulty appears to stem from the fact that the benefits that accrue to patients often take the form of decreased discomfort or distress, which are evident but essentially impossible to assign values on any meaningful numeric scale.

One aspect of Summit task analysis that has proven to be a challenge is modeling task flows that are determined by conditional logic. We have found that incorporating conditional logic into the Summit approach is necessary to account for task flows that branch in response to the specific circumstances found in a scenario. An example would be when a particular positive assessment finding on a patient causes the EMT to perform a specific treatment, versus a negative result that would lead to further assessment. Emergency medical service personnel's response to MCI events, as with most emergency situations, is dynamic and reactive that leads to conditionals playing an important role in accurate modeling of the tasks that are performed. We have attempted to overcome this challenge through the use of a represenation of conditional tasks that produce a task flow matrix, similar to a flow chart, to provide visual representation of the condition-based branching and merging that can occur on a complex ambulance call. Future versions of Summit will be enhanced to include these visualizations.

During the development of the MCI model one of the individual tasks modeled, spinal immobilization was isolated to show the possible use of this training for EMS providers. It has been shown that EMS providers have poor compliance with the selective spinal immobilization protocol [16]. Providers have shown an only 64 percent compliance rate with this protocol at one local service. Using Summit we have develop a task analysis model of this individual task, within the larger MCI scenario. The model of the task of spinal immobilization, shown in Figure 4, produced a scenario based model that shows how all the tasks of spinal immobilization fall into the whole. The utility factors also demonstrate the adverse effects some tasks can produce to the user of the model. It is hypothesized that using this task model in education of the providers will increase adherence to the protocol. Using the Summit approach to training on high frequency events, such as spinal immobilization, will help to engender a familiarity with Summit possibly improving its effectiveness when used to train for vigilance tasks such as MCIs.

MOVING FORWARD

Emergency medical services personnel train for the use of MCI-related methods, technologies, and information, but the Summit model makes clear and explicit how they might be used within a particular scenario designed to represent an actual situation that a local EMS responder might encounter in practice. Many of the claims made in this paper are so-far theoretical conjectures, and a priority moving forward is on validating the approach and obtaining evidence of its relative effectiveness as a resource for learning. The initiative to use Summit as a training device emerged from feedback received from local EMS personnel during walkthroughs of models created to support technology selection decisions. We are developing a series of Summit models as training aids for EMS personnel, for MCIs, as reported here, and also for more common scenarios such as cardiac arrests, drug and alcohol overdoses, and motor vehicle accidents. Our current plan is evaluate the approach through, in the first instance, guided walkthroughs with practicing emergency medical technicians (EMTs) and paramedics working within a local EMS service. Our hope is to deploy Summit models as evolving resources that EMS personnel can use in interactive reviews of those emergency scenarios deemed most important for ongoing training and continuous quality improvement. Early, informal walkthroughs of the approach have shown promise and we have been encouraged by practitioners to further develop the models.

ACKNOWLEDGMENTS

The authors would like to acknowledge the support of Centre LifeLink EMS (www.centrelifelink.com) and the United States Office for Naval Research (ONR) through Charles River Analytics (N00014-10-C-0281 / N091-086/P10008).

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