Final Report

Mine Emergency Decision Making

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1. General Introduction

This report summarizes the work performed at the Dynamic Decision Making Laboratory (www.cmu.edu/ddmlab) together with NIOSH. The goal of this work was to perform a critical evaluation of two simulations that will be used to train miners. In this report we present first, a summary of existing research on using interactive simulations to train individuals in complex and dynamically changing environments. Next, we summarize and interpret our findings from a critical evaluation of the two NIOSH simulations designed to train miners to navigate underground mines and to respond to unexpected, dangerous events. Finally, we will outline some research ideas to improve the use of these tools in training miners as well as for testing the effectiveness of these simulations in learning and testing experiments.

2. Synthesis of Literature Review

This review will focus on two main issues. The first section will examine what factors affect human response to emergency situations. The second section will address current research in the use of games and simulations to train people to solve problems in complex, real-world situations with rapidly-changing conditions. The primary goal is to consider the application of high-fidelity simulations to training mine workers, both in basic skills as well as in crisis situations.

Factors Affecting Human Behavior in Complex Systems

People’s cognitive abilities are inherently limited, and in addition to those limits, there are standard biases of reasoning that lead to errors. For example, people often underestimate cumulative effects of interactions between elements in a situation and consequently often fail to compensate for them (Cronin, Gonzalez, & Sterman, 2008). Skill level is related to ability to overcome inherent difficulties, but it also depends highly on how much training a person has had, how recently the person was engaged in that training, and the quality of the training program.

Some factors discussed in Chiles (2002) are related to the features of systems and just how complex they really are. Some systems lead to greater division of attention and higher stress levels. Bad design concepts may make some critical elements, such as status monitors and warning systems, less visible or comprehensible. Similarly, features
of the environment can compound these difficulties, with distractions further decreasing the likelihood of registering important information and too much noise interfering with lines of communication. Finally, humans are social organisms, such that social factors cannot be ignored. As Chiles (2002) notes, the influence of social factors is often related to the level of sophistication that an organization has achieved over time.

Simulations of Complex Systems

In designing simulations and tools for testing human behavior, the capabilities and limitations of human learners must be taken into account. The design of simulations and games for training is common and goes back to the beginning of computers, where researchers attempted to develop simulations that reproduce real-world situations. These tools, called *microworlds*, were first used by Turkle (1984) and were later on expanded by other researchers to conduct psychological experiments in a wide variety of domains. For example, Brehmer and Dorner (1993) identify several different ways that simulations can be used from a research or evaluation standpoint. Users’ activities in a simulated environment can be used to characterize individual differences between users, to predict a particular user’s future performance on the task, and to identify aspects of the task that are particularly demanding. Brehmer and Dorner also showed that comparisons of performance can reveal standard errors made within the simulated environment, such that additional steps can be taken to help trainees avoid those errors in the real world. Joslyn and Hunt (1998) used simulations in a series of experiments to determine which participants were especially skilled at making quick decisions under time pressure, and found that real-world performance was predictable based on performance in the simulations.

DiFonzo, Hantula, and Bordia (1998) also point out that there are two levels of realism that need to be considered when experimenting with microworlds; the degree to which the experiment is realistic to participants and the degree to which it is realistic to the situation. If the simulated task does not seem real to the person performing it, the person is less likely to take the training seriously and any experimental data collected from the process will be questionable. At the same time, if the simulated task does not match what would be experienced in the real world, the training will be ineffective for the participant and the data will not be generalizable.
There is a fuzzy line between using simulations to collect data for pure research studies and collecting data for the purposes of performance evaluation. However, the remainder of this review will be devoted to the educational applications, of which there are many. Simulations can be used to assist training in a wide range of tasks, including basic communication and math skills (Griffiths, 2002), science and technology problem-solving (Foss & Eikaas, 2006), medical skills (Bradley, 2006), financial decision-making (DiFonzo et al., 1998), air traffic control (Joslyn & Hunt, 1998), submarine defense (Ehret, Gray, & Kirschenbaum, 2000), and diplomatic negotiations (Kelle, 2008).

One issue in using simulations for training purposes is that not all of them are created equal. Simulations fall on a continuum with respect to their faithfulness to the real world task (Bradley, 2006; DiFonzo et al., 1998). A static model of a system, or part of a system, is as much a simulation as a virtual space that renders a dynamically changing representation of the system. Any interaction with either of these types of simulations will improve a person’s knowledge of the system, just in different ways.

One question to be asked when considering the use of simulations is what type of system interaction training is required (Bradley, 2006). The goal may be to train operators to perform a set of procedures as quickly and efficiently as possible, in which case a part-task trainer would be the best simulation. Alternatively, people who have already been trained to do procedures may also need to get a sense of the kind of environment in which they will be performing them and the various types of situations they may encounter in the environment. For this goal, a simulated environment or an integrated simulator would be more appropriate (Bradley, 2006). An advantage of computerized simulations is that they are very flexible with respect to modifying features, so a simulation of a specific task can have more general application by simply altering the subject matter of the task (Omodei & Wearing, 1995).

Many of the areas in which simulations are used for training are those in which it is very expensive or potentially dangerous to test systems or train operators in the real world, such as flying large airplanes for the first time or prescribing drugs to patients. At the same time, sometimes building a simulation with the appropriate level of fidelity is more expensive than the payoff that will be gained from using it, as in the “Sim One” simulation of a human medical patient (Bradley, 2006). In a study by Lerch, Ballau, &
Harter (1997), it was known that a proposed new automation system for the US postal service would be expensive to develop. As such, a simpler simulation was used to study the decision-making of those who would be using the system and to determine the system requirements. They found that different requirements would have to be met in order for the system to be effective for both expert and novice users. Thus, simulations can be useful for reducing costs in both system and human resources. Furthermore, presumably the better designed system would be easier for the users to learn once in place.

Whatever the specific educational goals are, the primary advantage of simulations for training is that they actively engage the user. As noted by Brehmer and Dorner (1993), computerized microworlds present the user with multiple problems at once, rather than one simplified task. Interacting with this complexity has several components. The user must continually monitor the goals of the task, must learn how to navigate the simulated task space, must use his or her own knowledge to diagnose current states and predict future events, must form and update strategies, and finally, must keep all of these activities connected in a coherent problem-solving process.

The potential of simulations for training becomes clearer when we consider that these are the same activities that a person must engage in to complete real-world tasks as well. Prior research on situation awareness has shown that good situation awareness requires perception of important elements in the environment, comprehension of their meaning, projection of future situation states based on current states (Endsley, 1995), as well as “the perception of reactions to a set of changing events” (Klein, 2000). As such, when a person has good situation awareness while engaged in a simulation, they are more likely to have it in a real-world setting; a likelihood that ought to increase as the simulation becomes more life-like.

Even so, learning from simulations requires some activities beyond those identified by Brehmer and Dorner (1993), including committing knowledge gained during simulation interaction to long-term memory and generalizing knowledge beyond the particular stimuli presented in one run of the simulation (Lane, 1995). Considering the educational value of simulations from the generative learning point of view, Zantow, Knowlton, and Sharp (2005) observe that information must be properly organized,
integrated, and elaborated upon by the trainee in all phases of the simulation in order for high quality products to be generated.

*Simulations vs. Games*

Not all simulations are games and not all games simulate real phenomena (Lane, 1995). A simulation can be constructed of the fluctuations in the stock-market or the functioning of a human heart, and much can be learned from interacting with such simulations, but they are not games. Games generally have objectives, a set of allowable actions and possibly objects to act upon, and criteria for success. Microworlds constructed to simulate control systems (Brehmer & Dörner, 1993; Ehret et al., 2000; Gonzalez, Vanyukov, & Martin, 2005) are good examples of simulations that can be used as games. The control task itself involves a goal, the interface contains allowable actions, and the feedback from the system can be used to gauge success. Similarly, the stock-market simulation can be integrated into a game if it can be made to respond to investment actions taken by a user.

Utilizing games for educational purposes is partly a matter of selecting the appropriate game type and tailoring it to the task at hand. It is also important to present feedback in the appropriate way. Foss and Eikaas (2006) suggest providing several types of feedback in conjunction, including rapidly-returned dynamic feedback as the game is being played, periodic short tests to help provide a sense of progress (e.g. quizzes), and a general evaluation upon completion of the task. Based on subjective feedback from several courses in which games were used as part of the curriculum, Foss and Eikaas found that students rated their experiences with the games highly and preferred some diversity in the learning resources available to them. As valuable as feedback can be, however, it has also been shown that people often misperceive feedback and fail to consider time delays and non-linear behaviors of complex, dynamic systems (Paich & Sterman, 1993; Sterman, 1994). Feedback also suffers from the complexity problem and information that is too complex can create a gap between possible and observed performance.

*Making Simulation Games Effective for Learning*

Inasmuch as a simulation captures the complexity of the real world in an artificial environment, part of the advantage of using simulations for training is that some of the
complexity that is not relevant to the task or skills being trained can be left out of the simulation for the sake of making the task-relevant elements more salient and the task more manageable (Gonzalez, Vanyukov et al., 2005). An example is the Ned simulation (Ehret et al., 2000), which was designed to train submarine approach officers by reproducing their workstation in greater detail and diminishing the potentially distracting details of the larger environment.

Chandler & Sweller (1991; Sweller & Chandler, 1994) emphasize the importance of other cognitive resources (those not immediately engaged in the task) to ease the burden of processing (e.g. background knowledge from long term memory). A number of such strategies for lowering the level of extraneous load in task situations are described by Sweller, van Merrienboer, & Paas (1998). Some strategies are general, such as minimizing redundancy of information across distinct sources and combining several sources of information that only provide a portion of what is needed into single, consolidated sources. Other strategies depend on the specific features of the decision situation. Fully worked out examples may be referred to as precedents for what can be done in a specific situation. Also, incompletely solved problems may be used in training to promote learning to accuracy or creative thinking.

Although some research has found little relationship between intelligence measures and performance in microworld simulations (Rigas, Carling, & Brehmer, 2002), other research has found a significant relationship between fluid intelligence tests as well as working memory and the performance in complex, dynamic tasks (Gonzalez, 2004; Gonzalez, Thomas, & Vanyukov, 2005). Thus, it is important to consider the administration of tests that measure the cognitive abilities of participants in microworld studies.

Summary

Based on this literature review, it would appear that the primary predictors of response to real-world situations are the complexity of the task and the information presented while doing it, the degree of cognitive workload that results from the complexity, and the cognitive abilities and expertise possessed by an operator with which to compensate for the workload and make good decisions in the face of uncertainty.
3. Critical Review of NIOSH Training Simulations

In this section, we present evaluations of two simulations being developed in the NIOSH Pittsburgh Research Lab. Because they were designed to train people on different tasks, each evaluation was first done relative to the specific purpose of the simulation, which will be summarized at the beginning of each section. Because both simulations are being developed for training purposes, however, both evaluations also focus on identifying places where complexity, and consequently cognitive workload, can be reduced.

3.1 NIOSH Mining Online Training

The Mining Online Training program, designed and developed at the Pittsburgh Research Laboratory of NIOSH consists of two key components. The “Map Reading Basics” (MRB) exercise is a browser-based tutorial designed to familiarize new mining employees with key terminology regularly used for mine navigation. Users complete a series of modules that explain important concepts and are cumulative, such that users will be able to give and understand directions within the mine environment.

Users who complete the MRB exercise are then able to take the “Mine Navigation Challenge” (MNC), which is a simulated virtual world modeled after first-person perspective games. Users walk through the passages of a mine environment in order to complete tasks given to them by characters in the simulation and must use their new knowledge of mine terminology to navigate to their destination. A “Scavenger Hunt” provides additional practice at locating objects in the virtual mine.

The “Instructor’s Manual” identifies several “knowledge objectives” for this program that outline the material that users should have mastered after completing the exercises. Users should understand how to enter a mine and identify mine systems, how to recognize mine passageways, how to follow directions and to select travel routes from one location to another. Teacher’s too, must have prior knowledge of mine terminology, principles of mine ventilation, and emergency evacuation requirements in order to administer training. It should be noted, however, that in the current version, users are not required to resolve emergency scenarios or other scenarios requiring complex decision
making. Users are evaluated with respect to the number of errors they make and their ability to resolve those errors without assistance.

We used a cognitive walkthrough of the program to perform the evaluation. Every component of the interface was examined from top to bottom of the main browser menu and in sequence within each area. Comments, questions, and problems were recorded with respect to the central question; how does this feature help/hurt the user’s understanding of mine navigation. All feedback was based upon the information available to the first author and his background knowledge at the time of evaluation. For the sake of easily referencing the objects of feedback, this evaluation will be organized using the same organizational structure of the training browser. Comments are written in first person narrative format and labeled with the headings from the modules and components of the system that they refer to. A general summary of the feedback will be provided at the end of this section.

3.1.1 Map Reading Basics

Pretest

The pretest was relatively straightforward and contained about the right amount of detail for that stage of training. When viewed again after having completed the training modules, it was also clear that all of the information tested by it was covered in the training material. I got a perfect score on the pre-test. I attribute this partly to having done some reading about mines prior to the evaluation, and also partly to the fact that some of the legend objects make intuitive sense even to a novice in the subject matter, which was very good. At the same time, it should be noted that the letters on some of the map objects help one use the process of elimination to assign the proper labels, so that good performance on the part of a user might reflect deductive responses rather than understanding.

Entering a mine

Knowing the different types of mine entrances is important. Assuming that different types of mines can only be accessed with one of these types of portals, one question raised by this section is whether the different types of portals indicated anything about the way the mine is navigated once inside. In other words, do they represent
radically different mine types that will be mapped differently? Also, does a single mine ever have more than one portal?

*A Look Underground* and *Mine Passages*

These two sections do a fine job of introducing the most basic elements of navigation inside of the mine, and it is especially important for the user to master these terms at this point. Additional notes could be added here about what types of signage are available to help the user know how to orient when he or she is not near a face or a crosscut with a numbered mine door. The distinction between a regulator and a mine door is also important, and it should be emphasized that regulators should not be used as doors because they help control air flow. At the same time, it seems intuitive that they could be used as doors in an emergency, but then users must be given information to help them understand the conditions under which it is allowable to do so. Regulators can keep smoke from spreading, but for a person caught in smoke, the fresh air on the other side might be life-saving. The knowledge check for “Mine Passages” was quite good. It could be expanded to give the user even more practice with these basics before moving on.

*Directions*

This section introduces the terms for relative locations within the mine. Although the terms “inby” and “outby” are clearly established standard jargon within the mining industry, they are also unique terms that are not used outside of the industry. As such, they are very unfamiliar to the novice who is encountering them for the first time and have no general meaning to help the novice link them to other navigating experiences. Of the concepts encountered up to this point, this one requires the most practice to master and more examples would be helpful. One might ask, if the entries and crosscuts are numbered in the mine, why can’t absolute coordinates be used to locate people or objects more precisely and use these terms only when the object is in motion (i.e. He is at entry 5, crosscut 8, heading inby.). Presumably, someone or something that is in one of the passages around that intersection and not moving would be visible when you get to that intersection. Also, if entries can begin on either the left or the right, and are not physically numbered in the mine, how can a miner determine his/her location?

Two other elements of this section require comment. The fact that air intake is marked with single arrows on the map and air return is marked with double arrows could
be emphasized a little more if it is helpful to miners for navigating; perhaps by making that text bolder in the description. Are there indicators in the mine as to whether a person is in an in-flow or out-flow passage? Would a person ever be assigned to work in a return air section and would that not be a health risk?

Similarly, this section introduces the “survey station,” but there is not enough information given about it for the novice to know why he or she needs to know about it. What exactly is a survey station? What is its purpose/function? What is the system for how survey stations are numbered and can the numbers be used to track progress through the mine? On the picture in this sub-section you can see 154 and 155 in proximity to each other, adjacent in one direction, and you can see 175 to 177 in sequence going another direction. Where are the intermediate stations and how does one know which direction he/she is going when following survey stations?

As it is, the knowledge check on this section is too thin given the importance of the material covered in this section. The survey station question (“A survey station is a good place to get mine maps? True/False) cannot be answered based on the information given. It is purely a guess. The second question (Which is most healthy to breathe? Return/Intake Air) raises the issue of health risks in different passages, and makes the trainee wonder what conditions would require him/her to be in a return air passage where the air is unhealthy.

The third question is difficult for a novice to infer the answer to, because he or she may still be assimilating the definitions of the terms “inby” and “outby,” and the fact that they describe relative location only. More examples of location descriptions in the main “Directions” portion are needed to make these distinctions clear. Perhaps have three “people” (P1, P2, and P3) marked on the map so that when the trainee clicks on them, a location description in both absolute (entry*crosscut) terms and relative terms (e.g. P2 is inby P1, but outby P3) is shown. The knowledge check could then include one or two more questions that have the user select the correct location description for a person in question. In sum, this section is one of the most critical to the goals of the overall program and should be enhanced.

Travel Routes
This section is also very important to the goals of the system. One overall comment is that the main headings in the sub-sections (Evacuation, Emergency Oxygen, and Communication) do not match the labels on the main section menu. The labels on the main menu should be the boldest headings on the sub-section windows.

In the “Escapeway” section, it should be made explicit that the black arrows in the primary and secondary escapeways point the opposite of the way out of the mine. On the map segment shown, my first thought was that they pointed the way out. Then I saw the edge of the double-headed arrow on the left and remembered that they are the airflow arrows. If fresh air is coming in through the escapeways, people need to go against the arrows to get out of the mine. This point should be re-emphasized here. Another important issue with this sub-section is that it does not tell the trainee how to determine whether an escapeway is viable or not. Are there cues that a miner can use to tell whether the primary escapeway is clear or whether to proceed to the secondary escapeway for better chance of escape? Finally, a minor detail is that there is a blue patch on the map in this sub-section that looks like a water puddle, but it is not explicitly described as such. Is it typical for water spots to be marked on mine maps?

The sub-section “SCSR Cache” also raises some issues. First, on the map section shown here, there are several more items that had not been defined yet, including “B”, “SP”, and “DH.” The phone symbol is intuitive. With respect to the SCSR caches, presumably there is other training for how to use them, so the discussion of them in this sub-section should only pertain to how they are a consideration in choosing travel routes within the mine. Trainees should be told how caches are distributed in the mine; how many there are, and how frequently they can be found. Particularly for choosing an escape route from the mine, it should be made more bold and emphatic that the SCSR is only good for one hour of air and miners should be able to check the viability of a unit to ensure that it is filled to capacity. The material does not make clear how many units are in a cache. If there is an emergency, how will I know the likelihood that there will be a unit left in the cache nearest to my workstation? Finally, if SCSR caches can be on equipment, does that mean they can be mobile? Are these in addition to fixed location caches or do I need to know where all the equipment is to know that I can get to a unit?
Why is there a “Mine Phone” sub-section in “Travel Routes?” This does not seem relevant unless the phones are used to communicate the viability of routes. If so, emphasize this point. In that respect, why are they not always marked on the map? There is also very little description of the functionality of the phone here. Suppose, for example, that a route you choose is cut off, can the phone be used to dial a nearby section to determine whether that alternative is an option? How reliable are phones as a communication system in times of emergency?

I would suggest having the “Travel Routes” section right after the “Mine Passages” section. Both of them refer to visible objects and landmarks within the mine that can be used for navigation. By the same token, I would move discussion of survey stations to the “Mine Passages” section, because that is not given any more significance in this training than that of a landmark. The knowledge check in the “Travel Routes” section is extremely thin and does not really test the knowledge gained in the section. The first question does not ask about the SCSR cache, it only uses it as a landmark. The second question is out of place here, since Inby and Outby directions are discussed in the “Directions” section and the belt tailpiece is not discussed until the “Mine Systems” section. As such, rather than having this knowledge check here, it may be more effective to add these questions to the knowledge check for the “Directions” section (along with others) and really use that as a major intermediate test of navigational skill.

Mine Systems

The topics in this section are also only indirectly related to navigating in the mine. “Roof & Rib Control” and “Water” refer to important safety considerations. The “Haulage” sub-section says “the belt ends at the tailpiece,” but it does not tell how to recognize the tailpiece on a map. Again, this information is needed before that earlier question can be answered and a map segment would be helpful here. It would also be helpful to have a picture of the man-trip and track here to distinguish how coal and people are hauled differently.

For both “Electrical” and “Water,” how can the power and water lines be used as landmarks if there is no signage to refer to one’s current location and to the direction inby and outby? Will they always lead to a portal that a person can get through? What if there are water puddles and power lines in the same vicinity? What can a person do to check
the safety of the situation and/or warn others of possible danger? Also, this simulation is primarily about map reading and this section does not even show how these systems are marked on a map. Overall, the knowledge check on this section is sufficient, but I would suggest moving this section earlier as well, since the material is more about familiarizing the trainee with general mine knowledge and does not teach navigation directly.

A Larger Area

This section does not provide enough examples or connection to earlier sections to really provide good training. There are too many questions left unanswered. What tells you whether you are in a main or a section? How do you know when you cross the boundary between a main and a section? Are there signs? Also, do coordinates in sections follow the same conventions as for mains? In other words, are there numbered entries and numbered crosscuts within sections that run perpendicular to those in the mains? For example, would a person in 3 left section, be at entry 4, crosscut 3 within that section or do people have to know that 3 left section is an extension of, for example, main crosscuts 16-21.

There is also a gap between the training material and the test material in the knowledge check for this section. The extremely simplified mine map segments used in the sub-sections to illustrate mains, sections, and area names do not correspond well to the map segment shown on the section splash-screen and used in the knowledge check. Under the “Main Entry” sub-section, the main entry shown runs vertically, but in the test map it runs horizontally. None of the training maps in the sub-sections include the escapeway, belt, ventilation, and survey point symbols, which were the only cues I had to deduce where the main section and portal were. It took bad performance in the knowledge and much examination to infer that my “left” was the bottom of the map and that 1 Left Section would be on the left hand side of the map only if the map were rotated 90 degrees counter clockwise.

Also in the test map, there is no amount of un-mined (solid) ground separating the three sections like there was in the training map, so that the only cue that you have of a change in section is that some are deeper (i.e. extend further) than others. If this is the way that mines really grow, how do you know when you go from one “section” to another? Could it not be that the whole portion of the mine that Arrow A is pointing at is
one big Left section? What does it mean when pillars are red arrows? That has not been encountered before now. Also, to refer to the mains as “South East” is meaningless on this map, because there is no compass on the map.

Re-Test

On one hand, it is good for the re-test to match the pre-test. On the other hand, after the training, a person who has really mastered the material ought to be able to answer more challenging integrative questions. One approach that would lend more of a game-like quality would be to have three post-tests of increasing difficult (e.g. Easy, Medium, Hard), that trainees can take. Feedback could be given with respect to errors by referring to sections of the map reading basics that should be reviewed to correct misunderstandings. When one test can be completed without error, the next harder one would be unlocked for the user to attempt.

Taking Map Reading to the Next Level

The only ambiguous aspect of this section is the “Regulations” sub-section. What do trainees need this for? Is there any detail in these resources that they will need to know, and if so, shouldn’t it be in this training? How will they know whether they need to access these materials or not? Are these regulations for how to make mine maps properly? Otherwise, it is clear that the other sub-sections are places one can go for more information about the material covered.

3.1.2 Printable Exercise Map

The only feedback comment I have about this feature is that the legend sometimes gets mixed up with and obscured by the map. This feature did, however, spark a question to consider about the potential of the application. That is, can this software be used to train for specific mines? How easy is it to implement a new mine layout in this and to update it as the mine grows? Can maps be normalized so that they can be scanned for easier rendering in this system? Such features, if possible, would make this system even more valuable as a training tool.

3.1.3 Navigation Challenge

There should be a reminder of the controls when you first load up the simulation. Aside from that, the first major difficulty I experienced in this section was maintaining a sense of where I was located in the mine. It is very difficult to find your own location on
the map. David told me to wiggle my mouse a little to see the helmet light move, and I was able to see the light movement, but it was still very subtle and difficult to see. Depending on whether you want to give trainees their own position on the map and the direction they are facing when they access the map, you could test different methods of providing that information to them. This is discussed further below. Also, is it possible to zoom in on the map? That might help trainees maintain their bearing as well.

The navigation challenge also made it clear how difficult map directions (east, west, etc.) are to maintain in an underground environment, even after the map reading basics have been completed. I attributed this to having had too little practice at integrating the basics before stepping into the navigation challenge. The basics give you all the key terms in nicely categorized sets, and having the post-test be identical to the pre-test is good for making sure people understand the terms. However, there is a large gap between the knowledge needed to define terms and the knowledge needed to comprehend the mantrip operator when he starts rattling off instructions both on what to do and where to find the boss.

To reiterate earlier comments somewhat, the effectiveness of this simulation could be greatly improved by adding some additional post-test material that forces people to put the pieces together through mixed question types. These might include direct pointing on a map (e.g. Click on the intersection of entry 4, crosscut 10), short answer or multiple choice declarative knowledge questions (e.g. If you were to make your way toward that point from where you are now, would you be going inby or outby?; What is the term for what is located at that intersection?), and perhaps some procedural knowledge questions using an interactive map (e.g. Trace the shortest path from where you are to 2 Right Section Entry 4).

Also with respect to the instructions, is there any way to print or to get the mantrip operator to repeat the description of the location of the boss who needs the tools? He talked really fast and it was hard to keep all that information in working memory. I had to exit the simulation and re-start it a couple of times in order to hear everything he said and write it down. I did learn, in the second task, that pulling back from the boss and then re-approaching made him repeat the instructions, but again, I did need to have it
repeated a couple of times to catch all the details. I was unable to use the pull-back and re-approach strategy for the mantrip operator.

Finally, the real-time speed of movement in the simulation is really frustrating to a novice who must keep a great deal in memory anyway. It may be good for advanced training scenarios, where you want the time it takes to do something in the simulation to match what a person would experience in the real world. For learning the basics of navigation, however, the relevant challenge is just to figure out where you are going, and people would get better training on that aspect by being able to move more rapidly to where they are going and get more practice by doing more navigation scenarios.

3.1.4 Scavenger Hunt Introduction

Could the “Items” and “Directions” be combined, since the latter does not use the space to the right? Perhaps there could be links for each item at the top of the text window, such that mousing over them would give you picture and instructions, and clicking on them would give you more information. The “Starting Up” tab could be permanent text at the top of the window, always visible, and the tab could be eliminated.

Also, under directions, the reference is made to “Spad.” It seemed familiar after having gone through the basics section, but I could not remember what it was because it was off to the side and did not seem important then. I assume it is a term for survey station, but it was not clear in the basics section or here. This should be clarified.

3.1.5 Scavenger Hunt

There are three main recommendations for this section. First, the search is generally very blind and requires the user to spend time wandering around randomly. There are no cues on where to look for things, the mine is a big place, and because the real-time setting does not allow you to move very fast, it can get very monotonous.

The second issue is that there is very little feedback, particularly of cumulative progress. When you find something, you are told you found it, but you can’t pick it up so you don’t know that you won’t find the same thing twice. To clarify, I was unable to figure out how to pick something up. It would be helpful to have a checklist that you can toggle on and off (like the map) that indicates what has and has not been found up to that point.
Thirdly, in terms of freedom of movement, when walking along the belt, you cannot walk between the fire hose barrels and the belt, which is inefficient (since you have to backtrack and loop around a pillar to get back on track). It is also somewhat annoying because it looks like there is enough space to fit through, which raises the question of whether that constraint matches reality or not. It is also an important problem that there are no keyboard controls (at least none that I could find) for turning left or right. You have to use the mouse for that even if you are using the keyboard otherwise, which is frustrating.

Finally, with respect to the control panel for both the Navigation Challenge and the Scavenger Hunt, will trainees be able to, or for that matter need to, adjust anything on the control panel? If not, it may be best to hide the control panel from users. It is also not clear what HUD is. And, although this may be a matter of limited functionality in the prototype, I was unable to speak to any of the other avatars in the simulation. When will users be required to say something and how does one go about doing so?

3.2 Computer-Based Training (CBT) for Choice to Use Refuge Chamber

Because “refuge chambers” are a relatively new technology for promoting the safety of miners, one of the first things to teach mine workers is how to know when to use them. To this end, a decision-making assessment tool is under development that presents various conditions to users and tracks their tendencies with respect to using a refuge chamber use over a series of successive choices. Because this simulation is still in the early stages of development, the evaluation was done on the basis of a conceptual outline of the task structured as a decision-tree. Its current form is a rapid prototype created using Microsoft PowerPoint.

To begin with, it is assumed that the trainees who would be using this simulation will be aware that the primary decision they need to make is whether to try to get to the refuge chamber or try to get out of the mine when there is an emergency. If this is the case, the simulation should include some description of the features of the refuge chamber as part of the introductory material. It is also important to consider that if this simulation is to be used for training purposes, there will need to be a theory driven
decision rule set for the conditions under which miners should use refuge chambers and when they should attempt to get out of the mine.

This simulation also assumes that trainees have enough general mining expertise to know the contingencies between the presented options. For example, the trainees must know that main haulage is where the mantrip is located (in the majority of mines) and that the primary escapeway is a separate passage. More importantly, the trainees must know the conditions under which the mantrip is unlikely to work, such that walking is a better option. As another example, when deciding whether to put on the SCSR, the trainees must know that, although it will allow them to breathe in harsh conditions, because one cannot be heard clearly while wearing the unit, it will limit one’s ability to communicate with others.

The order of cues is important in this simulation. One of the first decisions to be made is whether or not to answer the phone. The ring of the phone itself does not necessarily signal an emergency, so the choice is offered again with the added cue that smoke has been observed. Presumably, the choice sequence would be altered if the trainee were to see smoke before noticing the phone ringing. The likelihood of preference should therefore be evaluated under all the different cue orders. Also, with respect to cues that support decision making, the developers’ notes indicate that “distances are important,” but it is not clear how distance information will be provided in the current version of the simulation.

Finally, an important cue in this simulation is the responses of the other miners to the events that are occurring. When given information about this, the trainee is faced with the more implicit and generic choice of whether to follow the group or whether to follow his or her own preference for what to do. For example, if the trainee chooses to go to the refuge chamber, he or she is told that, “No one else is at the refuge chamber” and must then choose whether to continue following the refuge chamber course of action. Similarly, the trainee is also asked directly on multiple occasions to decide between taking action on his or her own behalf and seeing to the welfare of the others (e.g. Option: “Find and warn miners on the section.”). Consequently, social influence is such a major factor in this simulation that the trainees may be more concerned about making socially acceptable choices than they are about objectively assessing the information.
provided by all of the cues. If these cues are to remain as they are in the simulation, some consideration should be given as to how to separate the influences of social pressure and direct information processing on choice.

3.3 General Summary

The primary strength of the Mining Online Training program is that it allows the user to visualize the challenges of navigating in a mine without having to actually be in a mine. The rendering of the mine environment is high quality and the current version of the simulation already includes all of the elements that are needed to train new employees how to navigate the mine. The most important step to take for improving this simulation is to expand the testing and feedback materials in order to help users deepen their knowledge of the conceptual material and be able to utilize that knowledge to solve novel navigational problems. Some suggestions have been made with respect to particular sections. Some additional possibilities may emerge through empirical tests of the simulation, which will be outlined in the next section.

The strength of the computer-based training for choosing whether to use the refuge chamber is that it models a very well-defined problem and provides the trainee with clearer and more detailed alternatives to choose from. There is also an element of risk that is not present in the navigation challenge. The current limitation of the refuge chamber simulation, however, is that the task is de-contextualized. The cues are described verbally rather than being rendered in the virtual mine environment. We suggest that the ideal computer-based training suite will implement tasks like the refuge chamber choice task in the virtual space with visible versions of the cues (e.g. smoke, people running, etc.) for trainees to respond to. A synthesis of the simulations would capitalize on the strengths and compensate for the weaknesses in both.

4. Research Design for Testing Simulation Effectiveness

In this section, we present several possible designs for testing these simulations. They are organized by which simulation they would be applied to.

4.1 Information-Seeking Tendencies of Trainees
In both simulations, it would be possible to give users more information than what is currently presented; about the details of the situation, about their status in the game, etc. As such, one object of study could be the degree to which users access additional information. In the refuge chamber CBT, there is currently no information given about the distances between things or about the probability that a given option will be successful (i.e. will save your life). The interface could include links or buttons that can be selected in order to obtain the desired information and the users’ use of these resources could be measured. In the Mining Online Training suite, it is already possible to access an overhead view map using “Ctrl-M.” In addition, as the game progresses, the path traversed by the player is marked on this map. As with the suggested links in CBT, the number of times the map is accessed and the amount of time spent viewing the map could both be recorded as measures of processing of additional information.

An additional dimension of this proposal is that, in the real world, there is often some cost to acquiring information. In the games, information costs could be assessed as direct reductions of performance scores (e.g. every time you access the map, it costs you five points). Alternatively, if time limits were placed on tasks within the game, information costs would be fully integrated in that the time spent accessing information would mean that much less time is available for action.

4.2 Adherence to Optimal Route

Particularly in the mine navigation simulation, the availability of path traces is an opportunity for data collection. The navigation challenge gives players a specific location to go to and a goal to accomplish when they get there. As such, in this simulation, success can be measured both in terms of the completion of the goal and the efficiency with which they reach the destination. The complexity of the instructions could also be manipulated to give players multiple goals to accomplish at once, and a dependent variable in the study would be their prioritization of the goals and their sequence of goal completion relative to the most direct route between the required locations.

Another potential dependent variable is whether players use their own path trace for planning and for navigational error correction. Do they even notice that it is there? Are they able to re-trace their steps with it and see their own errors? How much hit-and-
miss is there in their first few minutes before they are able to set themselves to a more deliberate path. As a specific example, while working on the first task in the navigation challenge (i.e. to take the tools to the foreman), after picking up the tools, going over the nearest belt crossover, and going through the first available door, I made my way directly toward entry 2 and started down it in the direction of crosscut 13. When I got there, it was blocked off from that direction, and I had to cut back to entry 3 and loop around to get to him. It would be interesting to see if others make the same mistake.

4.3 Methods of Maintaining Awareness of Current Location

As noted earlier, one of the difficulties in the map navigation challenge is seeing where you are at within the mine. The current method of using the mouse to see movement of headlamp light is inefficient. Perhaps other methods could be tested, such as a blinking arrow that shows both the position one is at and the direction one is facing, to determine which leads to the best performance in route selection and error correction.

4.4 Risk Perception in Emergency Situation

In the refuge chamber CBT, an alternative to providing risk information is to elicit from players their perceived probability of success under conditions at each decision point. This could be implemented as a rating of current level of risk after each decision has been made, and because a particular choice is often presented as a result of several different prior choices, the traces of decision sequences and risk ratings could be compared to see how risk perception is related to different chains of prior choices.

4.5 Decision Framing Effects in Refuge Chamber Use Patterns

Assuming that use of a refuge chamber is objectively preferable in some situations and not preferable in others, another approach to measuring what people will choose is to present participants with different cover stories that emphasize particular contingencies regarding the chamber. All of the information would be true, but one condition would emphasize the advantages of using the chamber or of trying to get out of the mine and the other condition would emphasize the risks of using the chamber and the risks of trying to get out of the mine.

5. General Summary
Factors that are known to affect human behavior in complex systems include factors inherent to humans and factors related to the task. In relationship to human factors, people’s cognitive abilities, fluid intelligence in particular, are a major factor known to influence performance in complex tasks. In addition factors related to the task include workload, time constraints, and the actual design of systems.

The work that NIOSH is doing in using simulations and games for training of novice miners is remarkable. The tools developed will keep the learner engaged, producing an improved learning result compared to traditional, less interactive classroom settings. We summarized some of the recommendations we have in order to improve the tools used for training. What we proposed are relatively simple changes in the tools. We believe the tools are already accomplishing the major learning objectives.

We also proposed some ideas to conduct some experiments and studies that should lead to interesting findings and new discoveries of ways we can improve learning in this contexts. We would be happy to continue a collaboration in order to test some of these ideas.

6. References


