

Improving the Emergency Manager's Hurricane Evacuation Decision Making Through Serious Gaming

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ABSTRACT

Making an evacuation decision in response to a hurricane is a high-impact event that directly affects public safety on a large-scale. Despite being extremely critical events, the frequency of hurricanes is low, and as a result emergency managers are rarely afforded the opportunity to engage in the evacuation decision making process, real or simulated. Emergency managers are currently offered in-person courses or webinars to gain an introductory understanding of the meteorological and evacuation clearance time information and the associated tools available to make these critical decisions. Additionally, the offering of these training opportunities is infrequent, limited in capacity and the current training techniques, whether in-person or by webinar, do not allow emergency managers to practice critical decision making, or measure an emergency manager's ability to learn the information correctly and then transfer it to an actual evacuation event.

Through this work, a web-based, 'serious gaming' approach was used to develop hurricane evacuation decision training for the emergency manager. This paper describes the iterative design approach to developing a training game and collect initial feedback from emergency managers on the prototype capability. Instructional goals were identified in conjunction with the Department of Homeland Security Science and Technology Directorate as well as the Federal Emergency Management Agency (FEMA) and the National Hurricane Center (NHC), who jointly conduct the current hurricane evacuation decision training on an annual basis. The game platform was integrated with the recently re-designed hurricane evacuation decision support tool (HVX) and has the advantage of reaching many more state and local emergency managers without time or funds to attend the in-person training. Furthermore, the embedded analytical capabilities enable emergency managers to identify difficult concepts and allow them to further practice these concepts within simulated hurricane scenarios until a performance criterion is achieved.

ABOUT THE AUTHORS

Hayley J. Davison Reynolds has been a technical staff member at MIT Lincoln Laboratory since 2009. Her expertise is in human-systems integration and systems engineering. She has worked extensively on aviation decision support systems, and she has expertise in biosurveillance systems and emergency management systems as well. She received a Ph.D. in Aeronautical Systems and Applied Psychology and a S.M. in Aeronautics and Astronautics from the Massachusetts Institute of Technology and a B.S. in Psychology from the University of Illinois at Urbana-Champaign.

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INTRODUCTION

Hurricanes can be devastating events. Rappaport (2014) published that over 2500 deaths were due to Atlantic tropical cyclones over the past 50 years. One of the key ways that deaths are prevented in hurricanes is removing those who would be affected through the evacuation process. The responsibility for evaluating the need for a hurricane evacuation falls to the state and local emergency managers. Depending on the locality, emergency managers may call for the evacuation themselves or advise the local elected official to do so.

The evacuation decision is not a simple decision, and it is fraught with uncertainty. A major source of uncertainty is the weather forecasts. At three days from an impending hurricane, the forecast uncertainty can mean the difference between no impacts on the community or complete devastation. Another evacuation consideration is how long an area takes to evacuate, which can be determined by elements such as geography, road structure, and population density. Over the last 25 years, emergency managers have had the hurricane evacuation tool, more commonly known as HURREVAC, to help them determine the appropriate time to evacuate, according to the weather forecasts and evacuation requirements.

Development and maintenance of the HURREVAC tool is supported by the National Hurricane Program (NHP), which is a joint effort between the Federal Emergency Management Agency (FEMA), the National Hurricane Center (NHC) and the Army Corps of Engineers. In addition to support for the tool itself, NHP also trains emergency managers on how to use HURREVAC and hurricane preparation and response decision making as well.

In 2014, the Department of Homeland Security in coordination with FEMA conducted a study of the HURREVAC tool with respect to modernizing the technology (MITLL/SNL, 2014). In this study, over 50 emergency managers from across the United States were interviewed to identify the critical needs of the emergency managers for hurricane decision making. Specific investigation of the state of the HURREVAC tool was conducted, including a software architecture evaluation and emergency manager needs gap assessment. One result of this study determined that a software update of the HURREVAC tool was necessary and additional emergency manager decision support tools were desired. The study also revealed a need for more emergency manager training opportunities in hurricane evacuation decision making and associated training tools. This HURREVAC update is currently in the process of development, and the updated tool is called HVX (HURREVAC-extended). HVX will address the shortcomings of the HURREVAC tool and also provide integrated training opportunities.

National Hurricane Program Training Assessment

The current training available from the National Hurricane Program are live instructor courses, webinars, and HURREVAC help text. The live instructor courses are offered in a one and five day format. The five-day hurricane decision making course (FEMA L-324) covers four days of education on the National Hurricane Center weather products and one day of HURREVAC training. On the HURREVAC day, one or two hurricane scenarios are presented to approximately 20 students and they are walked through example decision making using the simulated storm. This interaction is conducted with each of the students loading the simulated storm into their laptop's HURREVAC tool and following along as a group with the instructor as he creates specific reports and particular visualizations. The one day course consolidates the information from the five-day course into a single day.

The webinars explain the features of HURREVAC and demonstrate how to access features using video-guided scenarios that answer specific questions relevant to emergency managers.

The HURREVAC help text is an exhaustive description of each feature in HURREVAC with supporting information on how to best use this information and when NOT to use it as well.

During the NHP Technology Modernization study, expansion of training opportunities was one of the primary suggestions provided by emergency managers. One issue that emergency managers have is that the live instruction classes are a limited offering and only allow a handful of emergency managers to be trained in a year. These classes are often full, especially the five-day course. At the same time, travel budgets for emergency managers are limited, and the travel required for the live courses results in an emergency manager receiving the training only once or twice in his or her career, when ideally there should be extended initial training and then seasonal refresher training. Because of the seasonal and infrequent nature of the hurricane threat, often the training becomes “stale” in the mind of emergency managers at the start of the season or when a hurricane is imminent. This could result in inappropriate use of information for hurricane evacuation decisions or confusion when the hurricane threat arises. Another issue that was identified by the Technology Modernization analysis team was that the current training contains limited assessment techniques to determine whether the emergency managers have actually learned and can apply the information provided in the training.

NHP Training Needs

The research showed that emergency managers are in need of training from NHP in three key areas: how to access the features in HVX (e.g., the “buttonology”), initial training of hurricane evacuation decision making for new/unfamiliar emergency managers, and refresher training of decision making for emergency managers at the beginning of a season or hurricane event.

The NHP should provide remote training opportunities to accommodate emergency managers with minimal budgets. This training should be within the HVX tool itself so that there is not a different system or download required. The training should be relevant to the emergency management environment, more specifically, the training questions should use actual or simulated storms with questions that an emergency manager would ask (Mautone, et al., 2008). There should also be a means to assess whether the emergency managers are learning the training materials.

Another requirement was to pursue the most engaging training possible, and the means chosen to achieve this engagement is the serious gaming method. Evidence has suggested that gaming is an effective means of conveying the training objectives with high levels of engagement (Garris, et al., 2002).

For the remainder of this paper, an Instructional System Design method was used to convey the information on design, development and assessment of the NHP training system prototype (Merrill, et al., 1996).

DESIGNING AN EVACUATION DECISION MAKING TRAINING MODULE

The design of the evacuation decision making training module was completed with the aid of the current NHP training team from FEMA, NHC, and Army Corps of Engineers. The group held several multi-hour sessions to discuss and agree upon the content of the module. The content was also presented to and agreed upon with the greater membership of the NHP.

Instructional Goal

The instructional goal agreed upon for the training module was, “Understanding which NHC products are used for which decision making timeframe.”

Instructional Objectives

To identify the objectives required to achieve the instructional goal, a matrix of the decision-making timeframes and the emergency management tasks was generated, as shown in Figure 1 below.

	Before storm formation	Early storm awareness	Pre-watch/warning storm awareness	Watch/Warning phase	Monitor storm during impact & initial recovery phase
Storm situation awareness		<ul style="list-style-type: none"> • Which products are available • How to access those products 			
Impact/risk assessment		<ul style="list-style-type: none"> • Which products used together can answer emergency management questions 			
Evacuation decision making		<ul style="list-style-type: none"> • Avoid common missteps 			

Figure 1: Instructional objectives matrix for the NHP training module.

The five decision making timeframes were: 1) Before storm formation, 2) Early storm awareness (Five+ days until storm impacts), 3) Pre-watch/warning storm awareness (two to five days until storm impacts), 4) Watch/warning phase (0-48 hours until storm impacts), and 5) Monitor storm during impact & initial recovery phase (after storm impacts have begun). The three emergency management tasks the training module would focus on are storm situation awareness, impact/risk assessment, and evacuation decision making. For each of the cells of tasks and decision making timeframes, the training team identified which products were available/applicable, how to access these products, which products used together can answer the emergency manager’s questions, and how to avoid common missteps.

Instructional Strategies

The strategies that the training team identified to accomplish these objectives were a tutorial and assessment questions. Tutorials led emergency managers through how to access the NHC products and what information these products offered. Then scenario-based assessment questions that were provided required the emergency managers to know when to access these products, how to interpret them, and what the limitations of the products are. “Level 1” assessment questions were simple, straightforward questions designed to build confidence of emergency managers who read and understood the information provided in the tutorials. “Level 2” assessment questions were then provided to determine whether the emergency manager understood the subtleties of the information. These questions are “trickier” and built to identify the common misuse of the products.

Evaluation Methods

The evaluation method identified was specific to the application of the NHC products in a given context. The training team wanted to ensure that the focus of the training was not on whether the evacuation decision was “correct” or “incorrect,” but rather whether the NHC products used to make those decisions were used at the correct timeframe in the correct context. Therefore, while feedback on the evacuation decision could be provided (e.g., 40 percent of emergency managers who took this training chose to evacuate +18 hours until the arrival of tropical storm force winds, 30 percent chose to evacuate +19 hours.), feedback on the use of specific products was provided using the following ratings—appropriate, inappropriate, or provides no information.

Types of Training Materials

Once the specific training objectives were identified, the training team then identified past storms that would provide interesting contexts for each of the decision timeframes. The specific information in the tutorials and the specific wording of assessment questions were also identified.

Media Selection (Serious Game)

As previously discussed, the media for training delivery was a serious game method. The age range of the emergency managers to be trained was anywhere from 20-70, and many of the emergency managers with decision-making responsibility were in the older age ranges. The serious game method is challenged because there is a portion of the emergency manager population that is not comfortable with using computers and may not be interested in games as a training method. Efforts must be made during development to evaluate the usability of the training once it is developed to ensure it is feasible across the emergency manager community.

Design Document

For the game development, the information about the products, objectives, storms, and questions were input into a spreadsheet to allow the developers to produce a gamed approach to the training.

DEVELOPMENT OF A SERIOUS GAME INFRASTRUCTURE FOR TRAINING

This section describes the concept of use for the NHP training game. The game itself is currently mid-development, thus some functionality is not yet fully developed. The currently developed prototype is described in the next section.

There was a requirement by the emergency managers that they would not have to go to a different website or download different software to accomplish the training tasks. Thus, the implementation of the training itself is a mode within the overall HVX tool.

Training mode in HVX is accessed through the selection of a “Training” tab at the top left of the HVX tool. To enter the HVX tool, the emergency manager is required to login to his or her specific profile. This user profile not only saves the emergency manager’s individual configuration settings and favorite locations for the HVX tool, but it also contains their training data. This data includes what modules have been completed and when, what their performance was, and what HVX features were accessed to answer each question. Ultimately, this data can be viewed by the trainee as well as their trainers with the appropriate permissions.

Developing Course Materials

The learning goals, specific learning objectives, and example storms were identified in conjunction with the NHP training team, described in the previous section. These goals, objectives, and storms were inserted into the matrix shown in Figure 1 as the game objectives matrix. For each cell in the matrix, a tutorial walkthrough or specific question was generated to accomplish the objective. The final state of the course materials resulted in a series of scripted tutorials followed by learning assessments for each HVX module.

Evaluation Instruments

There are several means to evaluate the emergency manager trainee within the training. One means of assessing the trainee are the answers to the gaming assessments. These “answers” can be tagged as “correct” or “incorrect.” Alternatively, some questions asked in the gaming have no “right” answer. The evacuation decision is an example of this type of question. Depending on the local standard operating procedures and each emergency manager’s tolerance for risk, the ultimate evacuation decision can be personal and is too complex to be determined “correct” or “incorrect” in an absolute sense. The trainee’s answer for this type of question is presented back to them with reference to all of the answers that other trainees have provided (e.g., 40 percent answered +18 hours and 60 percent answered +19 hours). For this type of question, the assessed element would be HOW the trainee got to that answer. In this case, the “correct” answer would be that the trainee used a particular feature of HVX. (For example, “correct” in a question could be that they accessed the wind radii features, and “incorrect” could be that they accessed the wind swath for that question.)

Assessments are conducted after each question, as described above, and they are also provided at the end of the module. Performance for a module is provided by giving percentage of “correct” and “incorrect” answers, but also how many times a particular HVX feature was used “correctly” or “incorrectly.”

Game Infrastructure

The NHP training game was created using a game engine written in JavaScript. It uses an HTML5 canvas layered on top of the HVX interface in order to display the state of the game. The state of the game is described using two sets: a set of entities and a set of components. An entity is something that can be acted upon and has a set of properties. Components are a single behavior, such as the drawing of an entity on the screen or the parsing of player input, which act according to the properties of the entity using the component. These two first-order types are used to construct a table, mapping entities to the components they use. Once an initial game state is constructed, every frame, 1/60th of a second, the game state is updated. The game state is updated by executing the behavior of each component on all entities in the game state using the component. During the course of play, any entity may be marked as using or not using any component and any entity can be removed from the game state at any time a new game state is created.

PROTOTYPE GAME IMPLEMENTATION AND EVALUATION

To evaluate the game training concept with emergency managers before extensive training modules and capabilities were designed and implemented, a prototype training game was developed. In this prototype, three features of HVX were chosen, and tutorials and assessment scenarios were written. The prototype training module was implemented within HVX, and the assessment questions within HVX were simplified to “correct” or “incorrect” answers. After answering a question, the trainee received feedback about whether their answer was “correct” or “incorrect,” and at the end of the prototype module, an overall score was provided.

The purpose of this prototype module was to implement initial capabilities for the entirety of a training capability, and then use this prototype to gain feedback from emergency managers both in a conceptual sense and a usability sense. The usability portion is important because of the issue of technological discomfort within the emergency manager population and the remote-use nature of the training game. As this program is mid-development, an assessment of both the training concept and the usability could provide valuable feedback to the remainder of the development period and aid in prioritizing development of the training capabilities.

Prototype Game

The initial screen of the training prototype is shown in Figure 2 below. When the training mode tab is clicked from HVX (red box), the introductory information box appears.

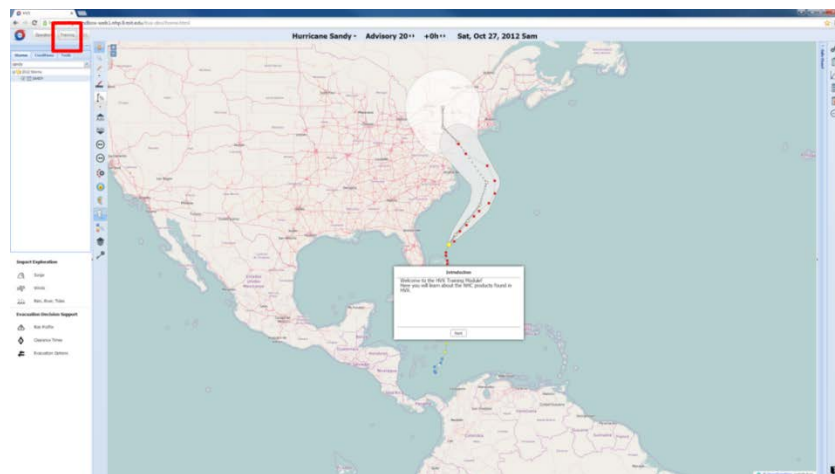


Figure 2: Introductory screen to the NHP training game prototype.

In the tutorial segments following the introductory information box, trainees are guided through the process of selecting an archived storm, choosing an advisory for the storm, and accessing the HVX feature (the error cone as the first example). To aid the trainees in navigating the key buttons, a “hint” functionality was implemented. An information box asks the trainee to access the feature (e.g., “Click on the Error Cone.”) and it also provides a “Hint” button at the bottom. If the trainee clicks on the hint button, a spotlight zooms in on the button, lowlighting all other information so that it is easily identified.

Once a feature is accessed, key information about that feature is conveyed to the trainee about what that feature is for, how it should be used, and errors that are commonly made with that feature. Instead of a series of information boxes to convey this information, trainees are asked to click on different parts of the map to show that they know what part of that feature the tutorial is describing. This enables a high level of interactivity instead of blindly clicking “Next” through an endless series of information boxes.

After the information is conveyed about the feature, simple scenario-based questions using this information are asked. These Level 1 questions are simple and designed to reinforce the information previously presented. Figure 3 shows an example Level 1 question for the wind radii feature. The question in the information box states, “Based upon this advisory, progress the forecast hour to the hour when tropical storm force winds are likely to begin to impact the state of North Carolina.”

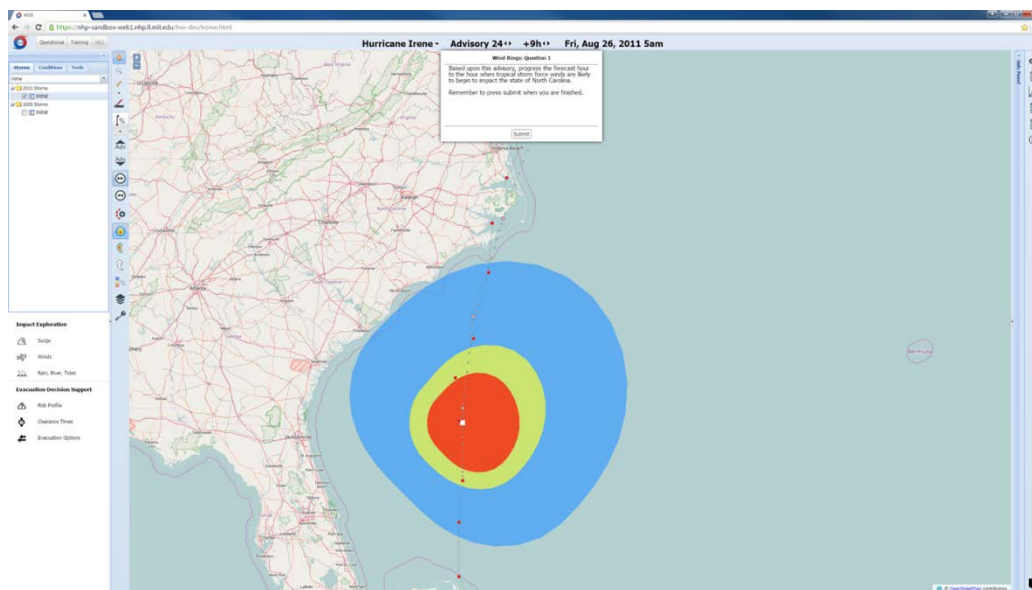


Figure 3: Level 1 training scenario-based training question for the wind radii feature.

The answer for game-based training is generally not provided in a multiple choice format, but rather through interacting with the features in the tool. In this case, the answer is provided by clicking the “next forecast hour” button until the hour in which the tropical storm force winds enter North Carolina and then the trainee presses submit when satisfied.

Once the trainee completes the tutorials in the prototype, the trainee is prompted with a set of Level 2 assessment questions. In this prototype, three questions are provided, each of which covers a different training feature. The Level 2 questions are slightly more challenging than the Level 1 simple questions, and they are not preceded by a tutorial of the feature. Thus, the trainee must decide which feature is appropriate, and then answer a challenging question about it. Figure 4 shows an example of a Level 2 question. The question states, “In your discussion with Virginia’s governor during Advisory #26, he asks if any cities have a low probability of experiencing wind impacts. Which of these Virginia cities has a less than 30 percent probability of experiencing tropical storm force winds over the next five days? Select the applicable location denoted by pins and submit your answer.” The trainee can then click the pin of the answer and press the “Submit” button.

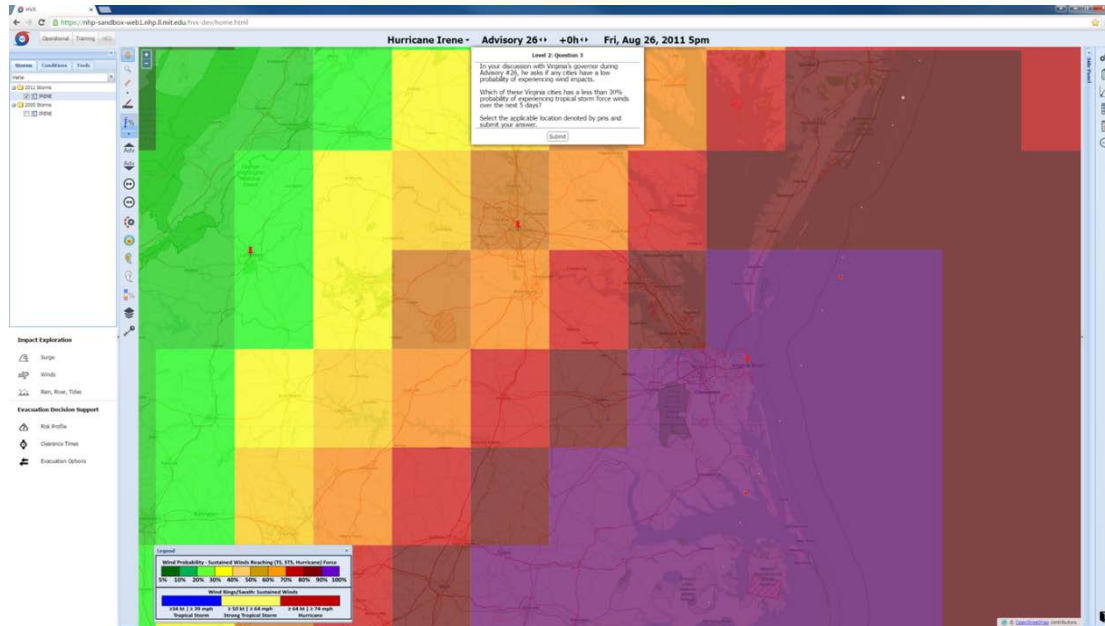


Figure 4: Level 2 assessment scenario question for the wind probability graphic.

Training Evaluation of Prototype Game

An initial training evaluation was conducted at the Florida Governor’s Hurricane Conference, a venue at which many emergency managers receive training and share information about hurricane weather products and procedures. This evaluation had three purposes: 1) to allow emergency managers to experience the training concept in a hands-on format, 2) to evaluate the concept of the remote training platform in its current instantiation, and 3) to gain insight into any outstanding usability issues that might hinder the training process.

Four Florida emergency managers from different counties volunteered their time to participate in the evaluation during the conference. The average experience of the emergency managers with HURREVAC was 8.75 years (two years minimum, 17 years maximum). While four data points would not provide statistically significant results, the qualitative outcomes met the goals of the evaluation.

The emergency manager volunteers were briefly introduced to HVX and the purpose of the training, and then they were asked to complete the prototype training module, which took approximately 15 minutes to complete. During the training module, two researchers observed their interactions and took note of their comments. At the end of the training module, they were asked to complete a short survey about the training prototype and the training concept as a whole.

In the surveys, a question was asked and then a Likert rating scale was provided from 1 (not at all) to 7 (very). The following questions were asked in the survey about the current implementation of the training prototype:

Question	Average rating	Minimum/Maximum rating
How useful would the style of training demonstrated in the prototype be to emergency managers who use HVX?	6.25	5/7
How engaging was the training demonstrated in the prototype?	6	4/7
How useful was the HVX feature tutorial?	5.75	4/7
How useful were the scenario-based questions that followed the tutorials?	6.75	6/7

For the instantiation of the NHP training game in the prototype, overall, the average usefulness and engagement scores were high. The feature tutorial and the engagement level were the items that appeared to need the most work. The emergency manager volunteers saw value in the style of training and the scenario-based questions. The write-in comments on this section of the survey had suggestions to improve engagement such as adding humor into the delivery of the materials and using as many real-world scenarios as possible. Verbally, one volunteer suggested that this training could follow the Red Cross CPR online training, which he thought was very engaging and effective.

The survey also asked questions about the training game concept in general:

Question	Average rating	Minimum/Maximum rating
How useful would a web-based training capability be?	6.75	6/7
How useful would a training capability that is within HVX and using HVX be?	7	7/7
How likely are you to recommend a web-based training that teaches the HVX buttons and features to new emergency managers?	6.75	6/7
How likely are you to recommend a web-based training that teaches emergency managers techniques for effective use of the National Hurricane Center products for decision making?	6.25	4/7
How useful would it be to see the consequences of various evacuation decisions to different stakeholders (e.g., elected officials, local tourism business) in a training capability?	6.5	5/7

There appeared to be positive feedback about a web-based training capability in general. There was consensus that web training covering the HVX features—the “buttonology”—would be valuable. However, one emergency manager thought that the decision making use and the stakeholder feedback concept were “good ideas, but beyond HVX scope.”

During the observation of the training module completion, several usability issues were observed. The information boxes in which the training information was conveyed were not movable and only white. Two volunteers tried to move these boxes to other locations, and one volunteer suggested that the color of the box relate to what type of action was expected (e.g., push “next” button, select a forecast hour, click a pin). Some map features required several clicks to register as “selected,” which was unacceptable and confusing to several volunteers. Two volunteers also found that the clickable pin area was too small to be adequately usable.

The training performance was also assessed. For the Level 1 questions that followed each tutorial, the four volunteers scored 100 percent correct. This was as expected with the way the module was designed, because Level 1 was expected to be simple and straightforward. The Level 2 questions were designed to be more difficult. 75 percent of the volunteers got the error cone question incorrect. 50 percent got the wind radii question incorrect. 25 percent got the wind probability graphic question incorrect. The expectation for the trainee is that they would then review the tutorial portion on the features for the questions that were answered incorrectly to gain insight into how they could improve their performance. The responses aligned well with the intended design for the questions, even if there were only four volunteers for the evaluation.

DISCUSSION AND NEXT STEPS

Overall the NHP training game prototype was well-received by the limited volunteers in the training evaluation. Informally, the concept has been presented to the larger HVX users group consisting of 20+ emergency managers, FEMA representatives, NHC representatives and other interested parties. Positive feedback has been received at these meetings and has corroborated the findings within this report.

The next step in NHP training game development is expanding the prototype training module to a full, complete module with many more features and decision timeframe questions. One major developmental focus will be improving the engagement quality of the game. Ideas for how to do this were presented at the most recent user group meeting. One idea involved including stakeholder advisors who would provide their input on a trainee's decisions. The input could be provided in a casual manner, possibly improving the humor in the game as well. The other developmental priority is improving the usability of the training game. Because of the trainee audience, ensuring that the training system is easy to use and not confusing is a critical component to the success of the training game.

ACKNOWLEDGEMENTS

The researchers would like to thank the volunteer emergency managers who participated in this training evaluation as well as the participants in the HVX user group, who have provided many valuable design suggestions to ensure HVX training game will result in success. We would like to thank the National Hurricane Program for their continued support of HVX and training development. The researchers would also like to thank the greater HVX team at MIT Lincoln Laboratory for all of their hard work for making such a great prototype system in a short amount of time.

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