HARRY'S HAZARDOUS DAY DESIGN EXHIBIT

Michael G. Peltier & Leonard D. Brown

Lowell Institute for Mineral Resources
University of Arizona

Harry’s Hazardous Day: Design Exhibit

1. Game Overview

Harry's Hazardous Day (*HHD*) is a story-driven synthetic learning environment (serious game) which emphasizes multi-player teamwork and the consequences of learner decision-making. *HHD* improves worker health and safety in three ways: 1) it reminds leaners to remain vigilant on the worksite by maintaining situational awareness; 2) it augments skills for workplace examinations, particularly around hazards recognition and mitigation; 3) and it enhances competency on standard operating procedures (SOPs) in the workplace. *HHD* incorporates a modular scenario design that can be used in a variety of instructional settings, from teaching hazards as part of an annual refresher module to full post-session assessment of learner health and safety competency. To date, three photorealistic storytelling environments have been developed (Sec. 5), and the game now incorporates an evaluation framework to analyze SOP competency (Sec. 6). *HHD* is being developed and tested in conjunction with several industry partners.

HHD is part of a larger suite of serious games, called *Learn with Harry*, that is being developed with the University of Arizona's Dynamic Safety gaming platform to address specific deficiencies in mine safety training. The gaming suite incorporates numerous C.F.R. training topics and provides key capabilities, discussed below, that have been identified through needs assessments (Brown, 2015). At present, the *Learn with Harry* suite is composed of three full-featured games: *Harry's Hard Choices,* which was developed in part with prior Brookwood-Sago awards, as well as *Harry's Fatalgram Simulator* and *Harry's Hazardous Day*. *Harry's Hard Choices* has been successfully deployed in our 40-hour new miner and 8-hour annual refresher training programs and has been used to train more than

1,000 miners to date. Table 1 provides an overview and comparison of gaming capabilities and training topics addressed by each serious game. In this technical exhibit, we illustrate the versatility of *Harry's Hazardous Day* as a vehicle for hazards recognition and situational

Table 1: The *Learn with Harry* suite of serious games.

Title	*Harry's Hard Choices*	*Harry's Fatalgram Simulator*	*Harry's Hazardous Day*
Major Safety Topics	Emergency Response; Self-escape; Leadership skills	Fatalgrams; Recent accident trends; Potential near misses	Hazards Recognition; Situational awareness; Rights & responsibilities; Communications
Training Focus	New miner; Annual refresher	Annual refresher; Tailgate training	New miner; Annual refresher; Tailgate training
Mining Sector(s)	Underground Coal (Part 46)	All Sectors	Non-Metal: Stone, Sand, & Gravel (Part 48 B)
Typical Play Time	40-60 min	10-15 min	15 min to several hrs
Concurrent Users	Single Player (1)	Multiplayer (1-3)	High Capacity Multiplayer (3-10+)
Tasks	Self Escape; Self-rescue equipment usage	Accident reconstruction; Use of best practices	Workplace examination; Various job activities (Roleplay dependent)
World Design	Single level, Open World	Multi-level, Limited World	Multi-level, Open World, Persistent
Hazards and Traps	Up to 16	1-4 (scenario dependent)	Unlimited (64+ typical)
Customization	No	Yes (site, scenario)	Yes (site, scenario, SOP)
Evaluation Instrumentation	Yes	Yes	Yes
Simulated Crew Dynamics	Limited	No	Robust
Consequences & Outcomes	Yes	Yes	Yes
Hardware	PC (Single & multi-display)	PC, Console, Phone, Tablet, VR	PC, Console, Phone, Tablet, VR

awareness training. The exhibit outlines key training capabilities (Sec. 2), game design (Sec. 3), hazards types (Sec. 4), current worksite examples (Sec. 5), evaluation tools (Sec. 6), and preliminary usability studies (Sec. 7).

2. Key Capabilities

As part of a three-year needs assessment, we conducted a series of field studies (Courage & Baxter, 2005, p. 565) examining current teaching media and methods used in mine safety training. We then performed a detailed analysis based on a usability engineering approach called Contextual Inquiry and Design (Beyer & Holtzblatt, 1998). Our objectives were two-fold: First, we wanted to gain a holistic view of the training process -- how the individual parts of the training regimen came together to shape the miners' understanding of safety & health; second, we wanted to examine the protocols, data sets, and information flows that miners experienced while covering important training topics. A detailed discussion of these findings was reported in Brown (2015). In summary, our field studies identified several areas for improvement in current training methods and media, which we have addressed through the following capabilities:

Dynamic context. Our field studies and trainer interviews suggested a need for better hazards recognition and situational awareness *in context* (Brown, 2015). In particular, trainers have provided supporting comments that include "'Tunnel vision' is common -- focusing on some aspects of work but not others", "A real mine is constantly changing", and "I want to evaluate users in real situations, not highly controlled ones." In one company's approach to hazards training, learners were shown photographs of a worksite, taken from different angles or at different times, and asked to pick out the subtle differences in the scene.

As training tools, static media are intrinsically limited in their versatility and are difficult to generate for a wide variety of potential hazard conditions. In contrast, serious games immerse users in a realistic context with all of the dynamic sights, sounds, distractions, and monotony of the real workplace, forcing users to think critically about their choices and surroundings (Brown, 2015; Garris, Ahlers, & Driskell, 2002). A strength of *HHD* is that it incorporates two important types of training in one application (Brown, Peltier, & Poulton, 2017). Users are required to recognize hazards and maintain awareness while performing a series of complicated domain tasks, as detailed in Sec. 3.

Communities of practice. Our field studies suggested a need for a stronger training emphasis on team activities, where users actively participate in "communities of practice," learning through social interactions and experiences such as those garnered from apprenticeship (Brown, 2015; Lave & Wenger, 1991; Wenger, 2000). Toward this end, *HHD* has a strong multiplayer focus and is, to our knowledge, the first serious game for safety training that features high-capacity multiplayer online capabilities. By adapting this approach, *HHD* can support a large number of concurrent users filling different job roles -- including users from the same crew or across multiple crews or worksites. Time is simulated in-game, allowing for the progression of a work shift and evolution of the mining workplace and critical controls. In gaming parlance, the virtual world is persistent (i.e. non-resetting). Multiplayer allows *HHD* to emphasize situational awareness skills, worker rights and responsibilities, and communications issues in the chain of command, using more believable dynamics than have been feasible in prior iterations of serious games.

Modular training media. Studies suggest that training media must be accessible to the target audience and designed around adult learning principles (Brown, 2015; Kowalski & Vaught, 2002). Toward this end, trainers have expressed a need for training media that are more modular and toolbox oriented -- they desire training media that could be customized to current training audiences, tasks, and work environments. Leveraging the rapid prototyping capabilities of our Dynamic Safety platform, multiple scenarios and hazards can be dropped into the game arbitrarily. Through a creation toolkit, which includes a growing library of game assets and models, we can also migrate new worksites as well as equipment into existing games and use those new assets as a focus for hazards recognition activities. Furthermore, we can also build customized mine environments for specific industry partners. Our current development time for new environments (of similar complexity to our existing models) is less than six weeks, and this development cycle is decreasing as our workflow matures. A discussion of the hazard types and environments featured in *HHD* may be found in Sec. 4 and Sec. 5 of this attachment, respectively. Through the modularity of *HHD*, game environments, hazards, and workplace tasks can be mixed and matched by the trainer to achieve specific results in the classroom.

High worker engagement. The work of Garris, Ahlers, & Driskell, (2002), Gee (2004), Hays (2005), and Lutz *et al* (2016) suggest user motivation and engagement play major factors in training efficacy. We have undertaken a series of usability studies to examine user acceptance of the *Learn with Harry* game series (Brown, 2015). The studies considered a representative sample of mine workers. In total, over 100 miners participated at four test sites throughout the United States. Users' skill levels ranged from novice to expert in the practices of mine safety, and their ages covered the full spectrum of mining industry professionals. Feedback was highly positive, with a high degree of user engagement and willingness to replay among both experts and novices. Furthermore, there were only minimal differences in preference across age groups.

3. Game Design

The fundamental approach of *HHD* is to embed hazards in a realistic simulation of the mining workplace. Our first scenario, entitled "The Big Pour," requires a team of learners to work together to meet the production demands of a large road project. As the story unfolds, unexpected events (e.g. weather and/or unscheduled maintenance) leads to delays that impact quotas and stress personnel. Learners are tasked with cooperating in specialized roles (e.g. loader operator, haul truck driver, crusher manager, foreman, drill operator, etc) to safely complete the production scenario as these unexpected events unfold. The game evolves through three phases, or acts, which can take 30-90 minutes (as needed):

Act 1: Planning the job. In Act 1, users participate in a daily tailgate to plan out the day's job activities and then perform a pre-shift inspection of the workplace to identify, flag, and report or fix hazards. Act 1 is complete and has been tested by industry trainers (see Sec. 7 of this attachment).

Act 2: Executing the job. In Act 2, users progress through normal shift activities where they are expected to mine materials in accordance with standard operating procedures (SOPs) under various production pressures. Users are required to demonstrate teamwork in realistic tasks. During the shift, unexpected hazards may be introduced into the workplace, either based on random chance or as a result of user activities. Notably, user choices lead to persistent consequences which will still be present in the environment the next time the game is played. Act 2 beta testing began usability testing in Q1, 2020.

Act 3: Returning to the Job. Act 3 illustrates the ever-changing state of the workplace. There has been a work stoppage and lapse of time on the job site due to a mechanical failure, weather condition, or even a lunch break. In the interim, the workplace may have changed, and there may be temporary or permanent changes in the site's operating procedures or a reassignment of job tasks. For example, equipment may be out of service, or other maintenance activities may be on-going. The team must resume work and deal with these unknowns as well as the new, often subtle hazards that have been introduced. Act 3 will begin testing in Q2, 2020.

HHD is designed to represent a continuing story of mining activities in a dynamic, evolving workplace with realistic task designs and SOPs. In developing game tasks and SOPs, we conducted a survey of mining industry health and safety professionals, regarding the types of job activities that they would like to see simulated in a hazards recognition exercise (Brown, Peltier, & Poulton, 2017). Respondents indicated typical but problematic job activities, such as Lock Out-Tag Out (LOTO), spillage cleanup around conveyors and pulleys, maintenance of equipment (e.g. conveyors, shakers, and collectors), and distracting tasks such as use of phones and highly repetitive chores. Respondents also suggested incorporating unusual situations and circumstances, such as supervisors filling-in on jobs for which they were qualified but performed rarely in practice, executing a familiar job in an unfamiliar area or on a different worksite, working solo while attempting to maintain contact, and implementing dynamic changes in traffic patterns or travelways.

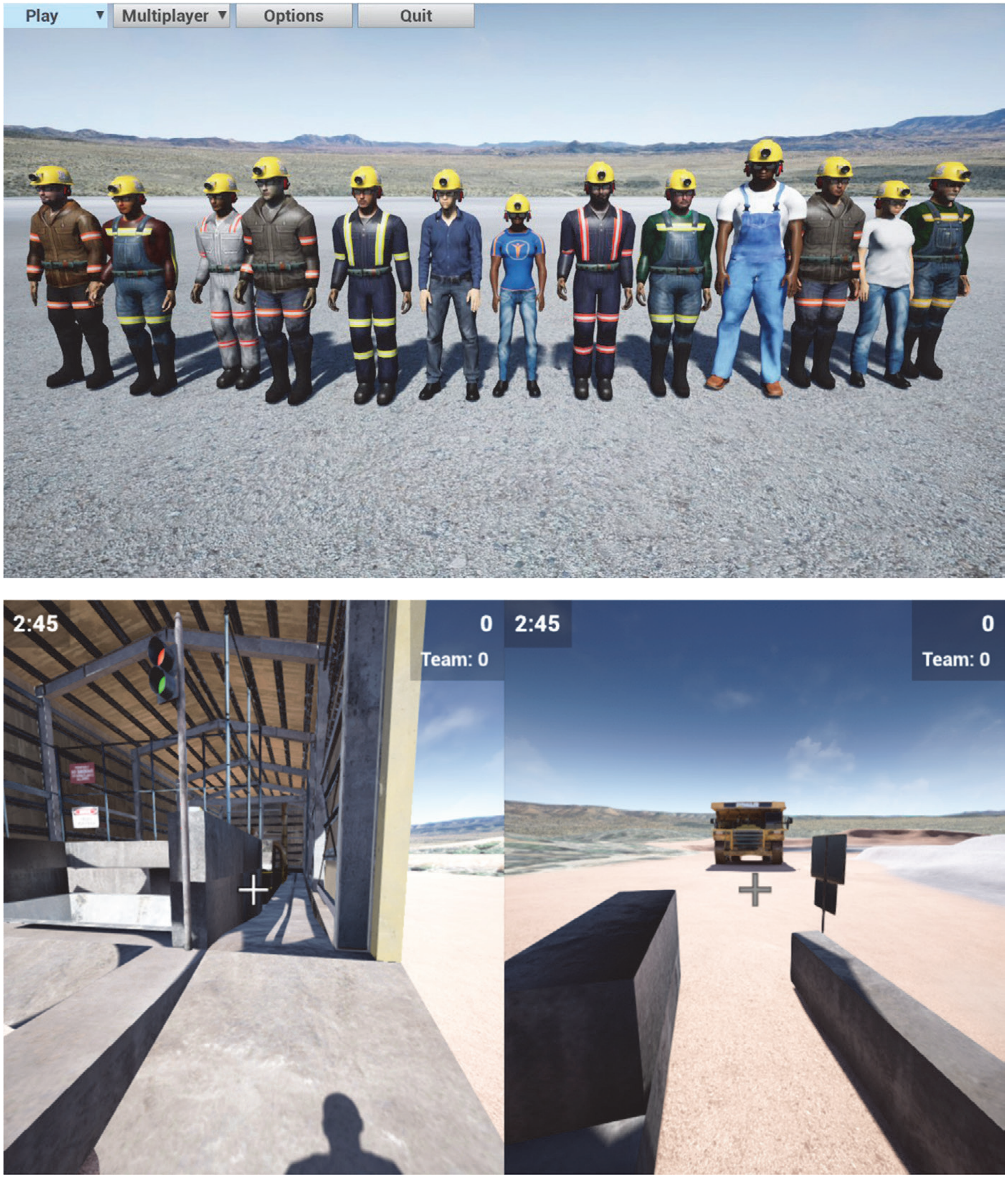


Figure 2. Multi-player gaming in *Harry's Hazardous Day.* Top: The game supports an arbitrary number of concurrent users in a persistent gaming world. Bottom: A split-screen multiplayer mode is available for use on larger video displays.

Algorithmically, a task sequence can be constructed at run time by assembling one or more primitive story elements. Elements may include travel in the workplace, area inspections, maintenance, communications, instrument readings, LOTO, safety equipment usage, and other job-specific tasks. An example task sequence would proceed as follows:

1. Receive orders from supervisor: "Go location X_i to do task Y_i."
2. Navigate to location X_i, using the shortest safe route.
3. At location X_i, perform domain task Y_i as instructed.
4. Randomly inject a mine hazard event at X_j
5. Based on user response, execute consequences at location X_j
6. Repeat Steps 1 through 5 N times.

This technical design emphasizes a non-linear story with emergent game properties in three ways. First, the user can go anywhere within the virtual environment and interact with most of the equipment, even if it is unnecessary to the current task objective. The user maintains freedom of choice to select the next action. Second, nearly every element of the game is randomized – the task order, the locations of tasks, and the hazards. From a technical perspective, a sequence of generic task elements is then composed pseudo-randomly at run time, creating an emergent story. There are presently 16 locations within each virtual environment where tasks can occur. Possible locations are set via an initialization file (INI) and locations are selected at random as the story sequence is built at run time. However, there are certain restrictions on this design, as some tasks are predicated on the completion of other tasks to advance the story. For example, one cannot use a piece of equipment without first retrieving it. Such requirements are easy to enforce programmatically. The third and final component of our non-linear game design involves hazards, which are injected randomly into the environment as discussed in Sec. 4.

To enable *communities of practice* (Wenger, 2000) in mine safety, *HHD* supports group-based cooperative learning, which is made possible by the Unreal Engine's multiplayer capabilities (Figure 2). Four multi-player features are currently implemented:

1. Mixed Multiplayer: The game environment uses a persistent world – meaning the simulation does not "end" simply because a user exits the game. The persistent state allows a user to join or leave at leisure; artificial intelligence (i.e. a "bot") can subsequently take over for that user's avatar to perform the job role when needed.

2. Communication Channels: Users of the virtual environment may communicate in a variety of ways, using the in-game text features and avatar signals, or via secondary voice chat app such as Zoom. In co-located settings (i.e. in the same classroom), users may also communicate with teammates directly.

3. Split-screen Modes: Multiple users can play on the same computer. In this mode, the video display is divided into several viewports representing the point of view of each user's avatar. Up to four users are supported on large displays. The split screen mode allows a class to observe gameplay for several users at a time.

4. Spectator Mode: A privileged "spectator" mode is available for training supervisors. In spectator mode, the supervisor can discretely observe user activities from any angle or perspective (including bird's eye views), without interfering in the game play. The supervisor mode requires special permissions to access.

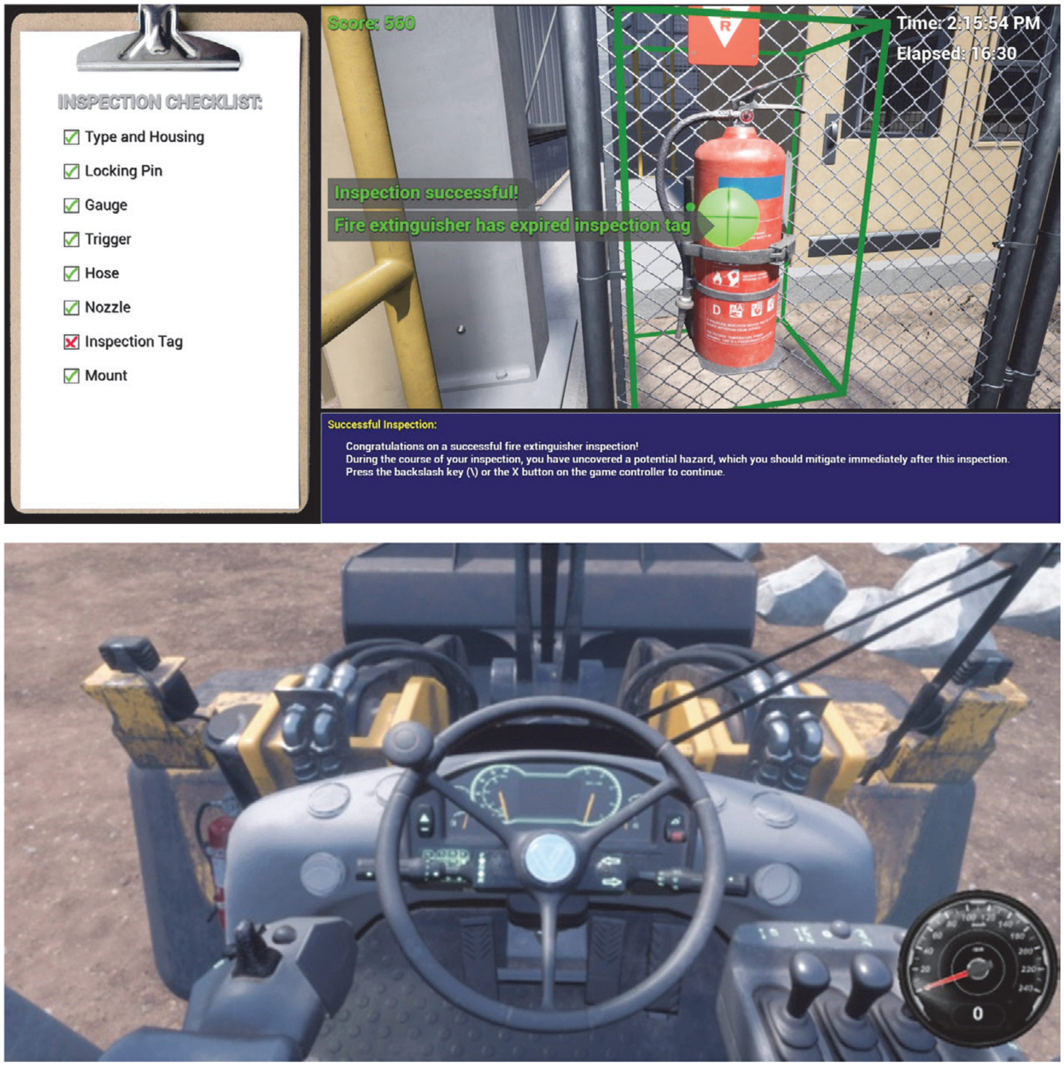


Figure 3. An adaptive user interface supports numerous tasks in the workplace. Top: Inspection interface for workplace exams; Bottom: Operating interface for moving equipment (e.g. loader).

The game features a user interface with a "Heads Up Display" (HUD) design pattern featured frequently in First Person Shooter-type games. As such, our usability testing indicates that the interface design has high acceptance and high usability among users, regardless of domain knowledge, gaming experience, or age (Brown, 2015). The HUD interface is shown in Figure 3. Note that each decision and action in the game is scored, positively or negatively, and the game also provides an interactive log of feedback. A user gains or loses points based on choices and behaviors. Furthermore, we have introduced a team score for collaborative activities in which the individual scores of all team members is aggregated. Users may also operate a variety of equipment in the game using authentic cabs visuals paired with either a gamepad or steering wheel interface. Studies indicate that such game mechanics are highly desirable to both trainers and trainees, as they serve as effective tools for user engagement and stealth evaluation (Brown, 2015; Yusoff, 2010).

4. Hazards Training

In *HHD*, hazards recognition and situational awareness represent half of the game effort, while the remainder of the game centers on completing a series of distracting job tasks, as discussed in Section 3. With industry collaborators, including Dave Brown of Mine Safety Assistance, LLC, and Mike Brnich of NIOSH, we are focusing on constructing hazards around MSHA's top 10 citations for each mining sector. For instance, in the sand and gravel sector, the top 10 citations for 2015 included the following (as per MSHA.gov):

1. Guarding of moving machine parts
2. Inadequate or damaged electricals
3. Haulage safety defects
4. Reporting (quarterly)
5. Audible warnings (haulage horns/backup alarms)
6. Guarding in place while operating
7. Safe travelways to all work areas
8. Berms & guardrails around drop-offs
9. Cover plates on electrical equipment
10. Housekeeping: Orderly work, passage, and storage areas

Figure 4. Example hazards in *HHD*. Left: Berms and guardrails; Center: Housekeeping; Right: Guarding of moving machine parts. (Photos courtesy D. Brown, Mine Safety Assistance, LLC.)

From a mine safety standpoint, the most cited standards bare great similarity across all mining sectors. From a technical standpoint, the workflow to implement hazards in our game is identical for all mining sectors. These facts greatly increase the modularity of both the code and assets. At present, we have developed eight classes of hazards, which include ground control, stumbling and falling, electricals and grounding, machinery, safe travelways, explosions and fire, errant ventilation, and housekeeping. Each hazard has a different visual representation and behavior modeled on real-life examples provided by our partners (for examples, see Figure 4). Furthermore, multiple examples may be developed for each hazard class, with a different appearance and/or operational deficiencies. Table 5 provides a list of the hazards that have been realized for *HHD* to date.

The hazards types and placements are also randomized. Specific hazards are determined at run time, while specific instances are created from a list of all possible hazards. Each hazard is accompanied by constraints that define how many of that hazard should appear in the game (minimum and maximum). The hazard list and constraints are defined in an INI file and loaded at run time. Note that, in addition to type and location, hazards may also be randomized in *time*; some hazards may be pre-placed at game start-up (latent

Table 5. Notable hazards appearing in game prototype.

Hazard Class	Examples in Game
Ground control	Bad ground control: Cracks in ceiling, debris hanging down, roof bolt dislodged; Rib sloughed off; Timber support damage: Cross pieces buckled; back bulging downward; Top has obvious cracking, debris fall
Stumbling, falling	Open/Broken/missing door on ore pass; Broken ladder: rung missing or cracked; Multiple ground fall events in decline; Ore pass door is open/missing; Ground clutter; Lower stope not properly blocked off; missing landings in shaft
Electrical, grounding	Damaged/scorched electrical panel/box; Electrical harness along wall is frayed through insulation; Bulb in light broken, sparking; Broken water pipe above light; sparking electrical wires; smoke emanating from electrical box
Machinery	Steel (drill bit) jammed in rib, sticking out; Broken rail in blind curve; Damaged, derailed ore car; fan guards missing
Travelways	Escapeway signage incorrect; Escapeway and cache signage missing; Broken bulkhead door latches; flickering lights in escape way; escapeway taped off
Explosion, Fire	Blasting caps laying in crew rest area; Pack of cigarettes and lighter at working face; Open/unlocked door to explosive cache; Open whiskey bottle near lunch pail; Miscellaneous bore holes, w/ blasting cap protruding
Ventilation	Open/Broken/Missing door on bulkhead; Bulkhead door is jammed shut; Check curtain partially pulled down; Inoperative ventilation fans; Gas multi-meter alarms in certain areas
Housekeeping	Equipment obstructing escapeway; Pile of timber obstructing escapeway line; Overburden debris; Scattered tools; Safety cache blocked by timbers

hazards), while others subtly "appear" when the user is not looking (dynamic hazards). Dynamic hazards are a very real danger in the workplace; they represent the unintended consequences of other, concurrent work activities --potentially due to the negligence of another user or bot. Dynamic hazards represent an emphasis for our workplace awareness training, since they are difficult to illustrate in most other media. Depending on training needs, the game may be set up with a pre-scripted hazards configuration (via INI) or with completely randomized hazards based on a difficulty level.

5. Worksites and Data Sets

Using the Dynamic Safety framework, we can coordinate many different types of data which are necessary in game tasks. Supporting realistic workplace examinations and other worksite activities requires a virtual environment that must be believable and realistic in both appearance and activity, with a sufficient levels of granularity to support hazards. For example, the granularity is too low, users may disregard hazards as a limitation of the game environment; similarly, users may also misinterpret the coarseness of the environment as an unintentional hazard.

We have developed several virtual worksites that are suitable to different storytelling scenarios. At present, we are using three virtual worksites on this platform, which are discussed here to illustrate the versatility of the game engine:

Limestone quarry. A limestone quarry (Figure 6) was developed from high resolution imaging and topographic data provided by an industry partner in northern Arizona. The quarry occupies one square kilometer and features multiple shelves and working faces, as well as overburden piles, access roads, and berms. Central to the world are a crusher and conveyors. Ultra-class and articulated haul trucks have been developed, as well as loaders and a track drill. All models are fully functional, supporting both vehicle inspection and operating SOPs.

Figure 6. Limestone quarry. Virtual environment features high-detail working faces, travelways, and berms, with user-playable equipment including haulage and loaders.

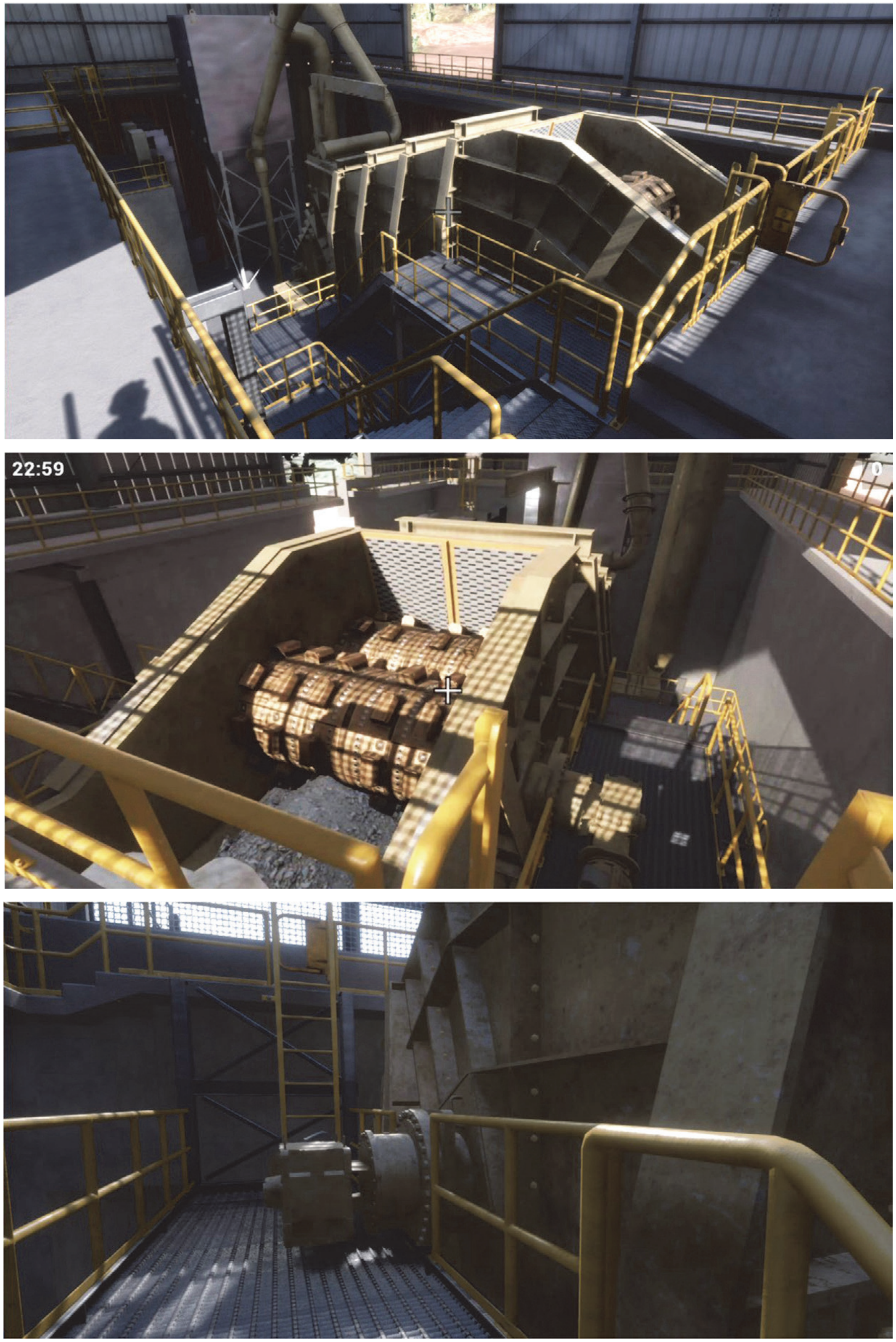


Figure 7. Crusher facility for stone quarry. Virtual environment features a functional three-story model based on Arizona prototype and includes 100-meter conveyor line.

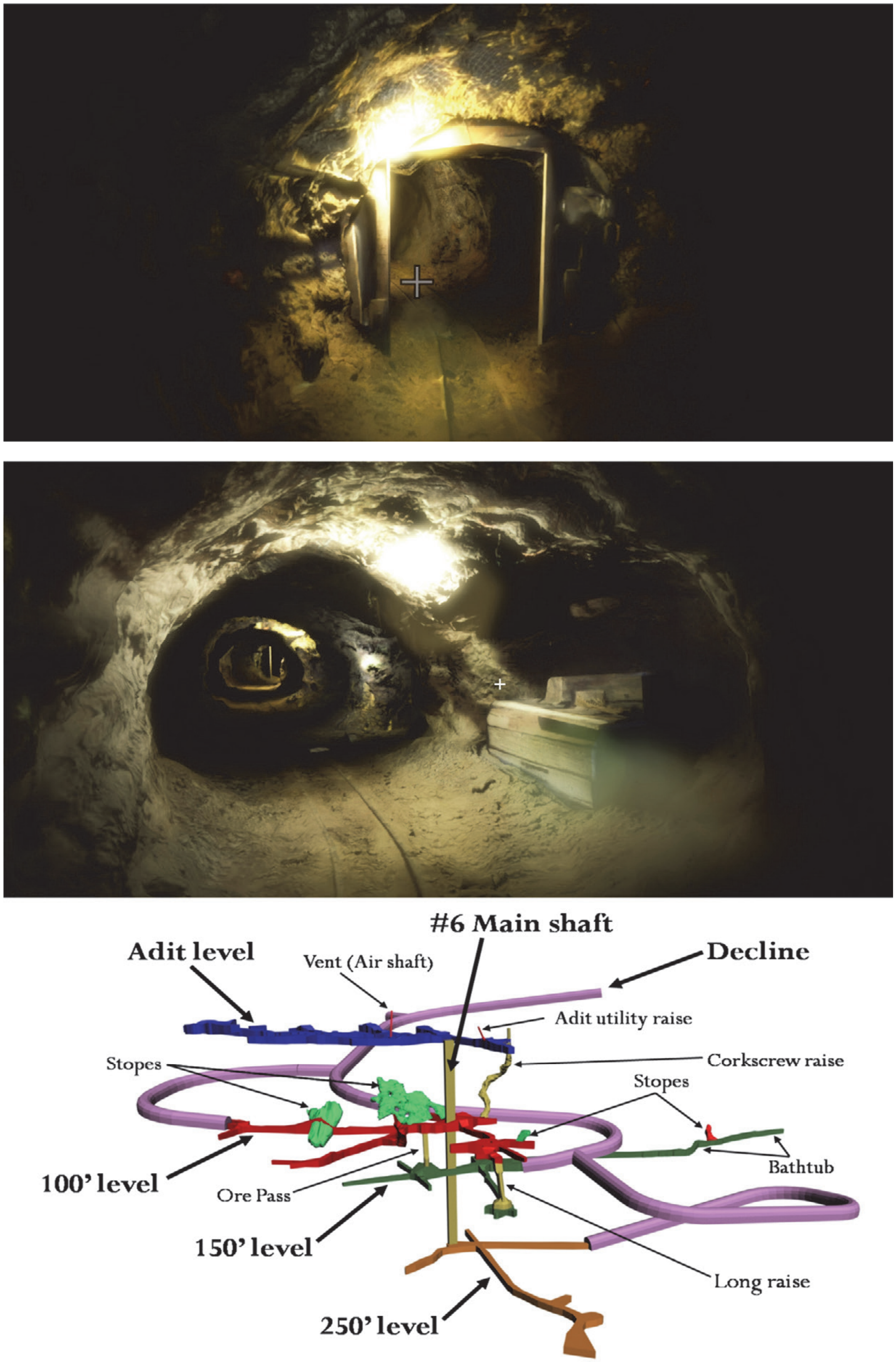


Figure 8. San Xavier Underground Mining Laboratory. Virtual environment was derived from photogrammetry of real site and is used for workplace examination tasks in *HHD*.

Crusher facility with conveyances. A virtual crusher facility (Figure 7, previous page) has been developed from photographs and schematics provided by an industry partner in Arizona. The facility features a variety of task-specific structures, including operating feeder, hydraulics, and other mechanical components. Travel ways, railings, guards, and other areas are faithfully represented in scale with the prototype. A 100-meter conveyor assembly with head and tail drive also connects to the crusher facility.

Underground metal mine. Run by the University of Arizona, the San Xavier (SX) Mining Laboratory is the only multi-level mine used for education and research in the United States. The mine is used for a variety of safety and health activities, including self rescue and mine rescue training, as well as vocational education in mining techniques. The SX dataset (Figure 8, previous page) is based on photogrammetric imaging and features a 4-level shaft with overhead stopes and numerous raises.

In addition to the 3D virtual environments, each data set incorporates a collection of maps, schematics, equipment, and instrument readings that have been collected in mine surveys, creating a robust data set for simulation of mine operations and emergency scenarios (Table 9). For example, mine maps may be are correlated with the virtual environment to provide effective navigational aids and other objective-specific scaffolding. Each virtual environment includes at least two map representations. In addition to the traditional 2D maps, which are similar to the printed maps used in a real mine, a 3D posable map provides an overview perspective of the worksite that can better illustrate travel ways and connectivity. Our mapping technique is derived from a proven 3D user interface tool called the World-in-Miniature, or WIM, which is used frequently in Virtual Reality applications (Stoakley, Conway, & Pausch, 1995).

Table 9. Data types used in our serious games.

Data Type	Description
1. 3D map	A 3D virtual model of the mine environment. All levels are represented at the same time in a pose-selectable 3D model.
2. 2D maps	A set of 2D maps showing the mine, one per level. Users can flip through the maps to locate objects or plan a route.
3. Cheat sheets	Text arranged into pages. Includes a list of task objectives and a table of vocabulary and map symbols.
4. Photographs	A collection of photographs taken during a site survey. Photographs are associated with specific, marked locations in the virtual environment.
5. Schematics	Equipment diagrams that are used for task-specific purposes. May contain exploded-view diagrams or usage instructions.
6. Multi-meter	The multi-meter indicates gas levels in the vicinity for oxygen (O_2), carbon monoxide (CO), hydrogen sulfide (H_2S), and methane (CH_4).
7. Overlays	Shows airflow patterns, escape ways, and safety cache information. Overlays may be projected into the virtual environment and onto the maps.

6. Evaluation Framework

To enhance the trainer's capabilities for post-session debriefing and evaluation, we have created a framework to track and evaluate learners' behaviors and activities in serious games. Data mining constructs allow analysis of results at the cohort, crew, or organizational level. A conceptual overview of this framework is given in Figure 10. The framework consists of three major components: The *HHD* serious game client with logging instrumentation, a cloud-based logging server and database cluster, and a web-based dashboard for viewing and breaking down performance trends on each type of SOP. Several types of SOPs have been developed which include workplace area examinations, fire extinguisher monthly inspections, crusher inspections, hazards mitigation procedures, haulage inspections, haulage startup procedures, and loader inspection operations.

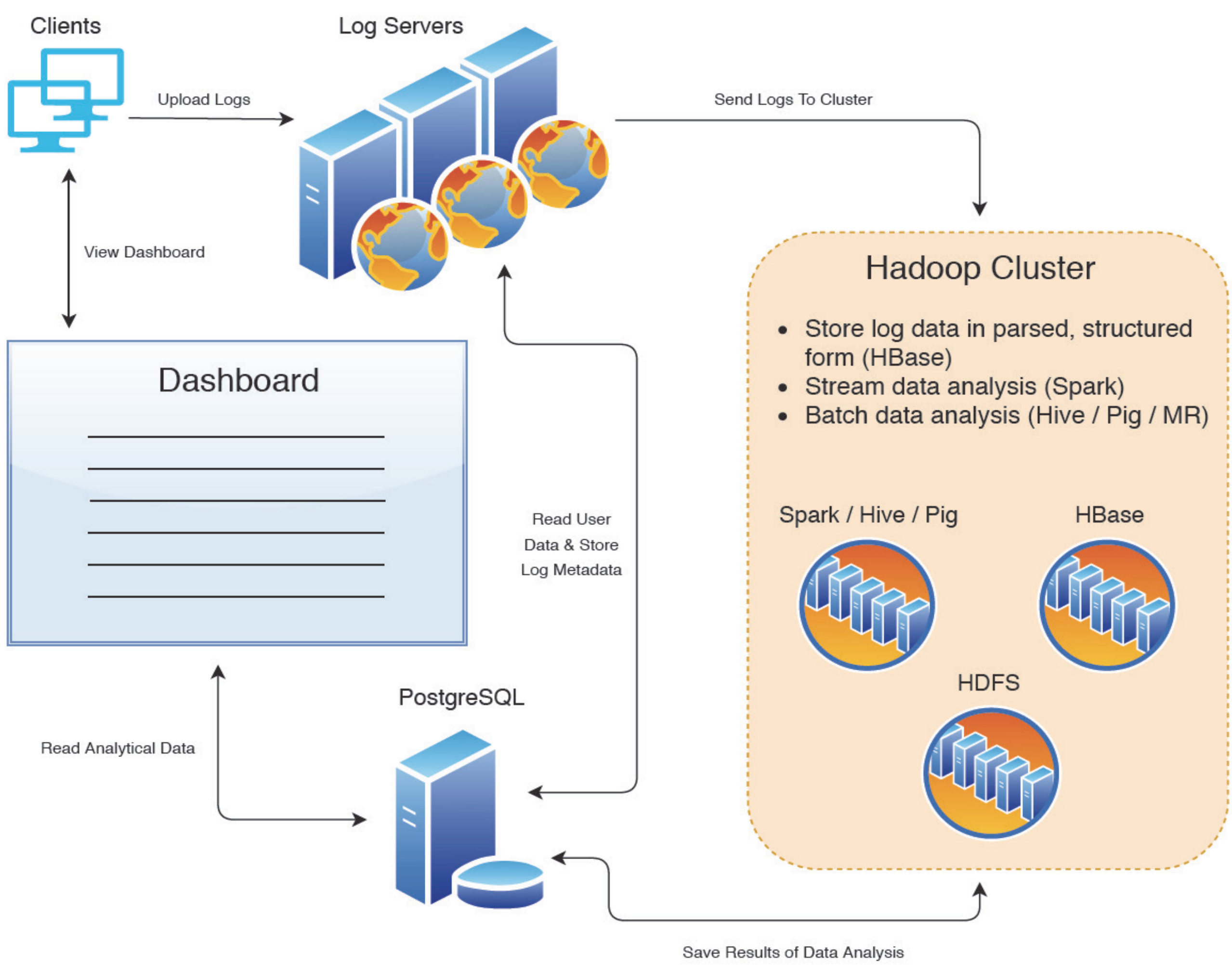
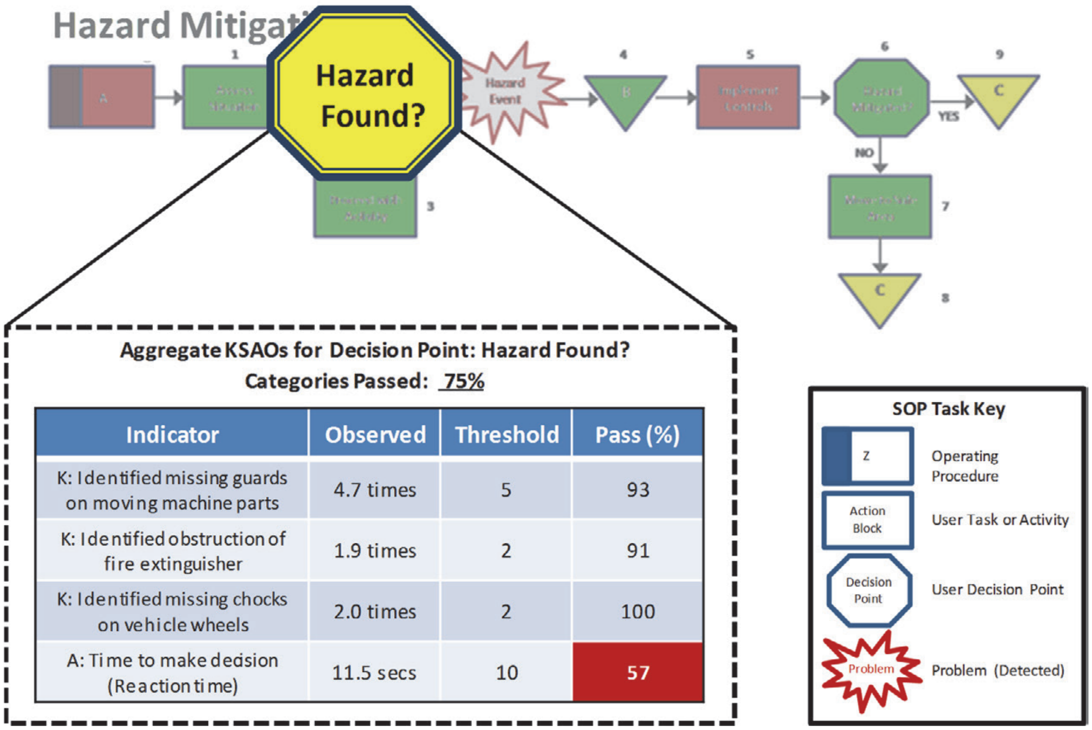


Figure 10: Conceptual overview of the Dynamic Safety evaluation framework.

Serious Game Clients. A significant strength of the Dynamic Safety platform is that it allows custom instrumentation and logging in each game client (e.g. *HHD*). Low and high-level metrics allow the trainer to reconstruct nearly all aspects of a learners' gameplay for post-session debriefing and evaluation. For example, the logging system can track disaster events that are keyed to recognizable hazards ("traps"), user behaviors such as navigational strategies, online crew interactions, and decision-making speed, and scenario outcomes such as crew health and morale. The logging endpoints can be remapped to illustrate various core competencies, allowing games to be re-purposed for different training activities.

Log Server / Cluster. The Dynamic Safety platform includes an AWS-hosted logging server and database cluster to aggregate and process game session data. The server may reside on either the internet or on the local area network, in cases where the test site does not support internet access. The database has two parts: A game log repository stores the individual game sessions as text blobs and a collection of tables contains performance statistics. A corresponding data analytics module is used to interpret the raw game logs and populate the tables based on core competencies. Furthermore, the data analytics module can be hot-swapped and the competencies remapped in real-time, thus allowing substantial versatility in setting up the evaluation and performance thresholds. Through the evaluation server, data on game performance may be aggregated and coordinated across teams of learners or over time. The server architecture is compatible with all Dynamic Safety games, including *HHD* and HHC, and may be used for leaderboards and other online reporting instruments currently in development.



Indicator	Observed	Threshold	Pass (%)
K: Identified missing guards on moving machine parts	4.7 times	5	93
K: Identified obstruction of fire extinguisher	1.9 times	2	91
K: Identified missing chocks on vehicle wheels	2.0 times	2	100
A: Time to make decision (Reaction time)	11.5 secs	10	57

Figure 11: SOP analysis using the Dynamic Safety Evaluation Dashboard.

Evaluation Dashboard. A client-side Evaluation Dashboard allows for reporting and debriefing. Game activities may be visually inspected by overlaying events onto a 2D map of the mine site and coordinated with 3D snapshots of the virtual world. The evaluation dashboard is shown in Figure 11. In particular, the dashboard visualizes critical decision points and user interactions. Travel paths are illustrated by various line colors for both walking and driving of haulage, with major game events indicated by specific symbols. A notable strength of the evaluation dashboard is that it allows the trainer to step forward and backward through time, observing sequences of events leading to injuries or accidents. Furthermore, the Evaluation Dashboard also provides a reporting system to generate handouts. At present, the handout options include Job Action Sheets for individual learners and team Improvement Plans. The Job Action Sheet compiles the list of core competencies and provides an itemized accounting of user activities in the game, including a score and completion time for each safety task, whereas the Improvement Plan illustrates the top problems encountered by each team, with associated expert feedback for reflection. Expert feedback is being developed in collaboration with NIOSH.

7. Usability Studies

We have conducted a formative assessment on an early iteration of the *Harry's Hazardous Day* game (pre-alpha). Feedback was solicited from domain users at the Western Region Mine Safety & Health Conference in Reno, NV. For these tests, we used a consumer Head-Mounted Display (HMD), the Oculus Rift DK2, as it offered a much higher level of immersion than was possible with traditional desktop setups. The HMD offered a nominal field of view of 110°, with a resolution of 960 x 1080 at 75 Hz per eye. The display also featured an integrated hybrid tracking system (i.e. inertial/infrared) to track head pose within a small volume (+/- 1.0m in our setup). An Xbox 360 gamepad was used for gaze-directed travel, to allow the virtual viewpoint to be moved over longer virtual distances in the scale of the mine environment. The gaze-directed travel technique is common in virtual environments; details of the technique may be found in Bowman *et al*. (2004, p. 200).

Eight subjects participated in this study. All eight users were safety trainers or members of management at mine sites in the western United States. Each user played the game for up to 20 minutes, completing several of the domain tasks while also searching for the various hazards. A questionnaire was used to collect comments after users completed the play-through. In particular, the questionnaire focused on the enhanced level of immersion, the user interface, and the hazards emphasis of the game. A list of questions and select feedback is given in Table 12.

Table 12. Sample user feedback for game prototype.

What did you like most?
So realistic.
Have to think about the hazards.
The 1st person view.
Turning my head to see.
The immersion.
Like the randomness.
Feels like I'm really in a mine.
Graphics are top notch.
Best fake mine I've seen.

What did you dislike most?
Dislike nausea over long time.
Nauseous.
Lack of gaming experience.
Dizziness.
Need clear purpose for game.
Limited interaction with environment.
Useful for training but not very fun.
Some hazards too simple.
Not difficult enough.

What did you think of the display?
3D is nothing like I've ever seen.
Huge fan of the VR.
Good VR integration w/ mining.
3D was comfortable.
Really neat, made more realistic.
Like to see in 360 degrees
Like turning my head to see.
More real.
Loved the 3D.

What did you think of the gamepad?
Navigation with gamepad was easy.
Not bad to navigate...for a non-gamer.
Decent, using controller, but not a 'gamer'
Easy, kind of -- but I fell down a shaft.
The map controls are inconvenient.
Some parts were confusing.
Hard to use the extra data sheets.
Focused on navigation, missed hazards.
Suffered from operator error.

What does *HHD* need for training?
Need a purpose, a goal.
Need reason to be there.
Need more signage, utilities, equipment.
Drilling, blasting, hauling, scaling.
Daily work activities.
More interaction, scenarios, objectives.
Multiple people.
Need a reason to be in mine, a purpose.
Not enough task distractions.

What would make *HHD* more interesting?
Tally for hazards or scores
Make it a survival game, add gamer mode.
Roof falls, confined spaces, low oxygen.
When run into hazards, have consequences.
Work in dangerous areas.
Balance between simulation and game.
Falling rock, key MSHA issues
Ability to customize hazards to site.
Make it day at work or disaster inspection.

We found that the virtual environment's level of detail and realism were very well received. Users commented that it was the most realistic "fake" mine they had ever seen and that the presentation was comparable to production games for entertainment. The level of immersion provided by the Oculus Rift was also praised. Users liked the ability to move their heads, indicating that it was helpful for navigation and awareness tasks. However, more than half of the users also mentioned that the HMD made them feel nauseous or dizzy. This is concerning, since the game session lasted only 20 minutes. Future work will need to identify and reduce the causes of nausea, which could be due to any number of factors, such as graphical latency, mismatches in physical and virtual motion, exaggerated stereoscopic disparity, or other inaccurate depth cues; a more detailed treatment of these factors may be found in Buker, Vincenzi, & Deaton (2013) and Sharples, Burnett, & Cobb (2014).

Some aspects of the user interface were more mixed. In general, users liked the gamepad due to its familiarity, and the gaze-directed travel mechanic was found to be satisfactory. However, interaction with supplementary data was considerably more cumbersome. Due to the heterogeneous nature of the data set, each piece of data had differing interaction requirements. Although mode switching is generally discouraged in user interfaces, it was not possible to create a 1:1 mapping between the gamepad controls and all of the necessary types of manipulation. For instance, 2D maps required methods to switch levels, pan, and zoom, while 3D maps required methods to rotate, pan, and zoom. In addition, there were three separate types of symbol overlays for each map that could be turned on and off. There simply were not enough degrees of freedom on the gamepad to enable all of the functions at the same time. One user commented specifically that "the map controls are inconvenient." Furthermore, the semantics of interaction differed among the data types -- 3D maps required rotations, while 2D maps did not; the gas meter had controls to take readings and calibrate, while photos did not. Manipulating all of these data types in an intuitive way, within the constraints of the input device, remains an open challenge which may be resolved through hand and gesture-based techniques (Brown, 2015).

In terms of the game tasks and story, users liked the hazards concept, particularly its randomized aspects, but felt that the virtual environment was too stagnant to represent a real situation. Three users specifically commented on the need for more people and more work activity. Another user commented that the game would be more fun if it provided a way to tally "score" for the hazards that were discovered. Users also wanted the hazards to have tangible consequences, such as a roof collapsing due to bad ground control or a blast that was sparked by a buildup of flammable gas. Another suggested that it needed to be more like a "survival game" or to have a "gamer mode" to increase its play value. Indeed, the game would likely benefit from the inclusion of game mechanics such as traps and consequences, which were not been tested in this prototype. The problems discovered in our pilot study influenced our current game design, particularly for Acts 2 and 3. Full classroom deployment with our industry partners is expected in early 2020.

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