



Facilitating task based noise exposure assessments utilizing PDAs.

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Abstract

The difficulties inherent in hand recording, editing, and coding observational data can limit both its utility and effectiveness as a tool in exposure assessments. Recently these limitations were noted during a noise exposure assessment of drill rig operators working at surface mines, where rapid changes in drilling operations and rig operator behaviors occurred simultaneously or in quick succession. In response to these limitations, researchers conducted a feasibility study employing a method of collecting observational data which uses a hand-held personal digital assistant (PDA) and an observational software system originally developed to record animal behaviors. Field observations were captured using the observational software system and basic PDA operation. These field observations were then merged with personal noise dosimetry readings and the combined data were graphed to quickly assess the associations between observational events and variations in exposure levels. Once these associations were verified, exposure values could be computed for combinations of rig operations and operator activities.

The use of PDAs to record workplace observations allows for greater ease, speed, and accuracy when capturing workplace behaviors and events as compared to traditional methods. Furthermore, PDAs provide greater detail during exposure analysis. Limitations of the process will also be discussed.

Key words: occupational noise, exposure assessment, workplace observation.



Introduction

The collection and analysis of workplace observational data has become an increasingly integral part of occupational health and safety research programs, particularly in the area of exposure assessments. Time-activity or time-motion studies can be powerful tools for identifying task- and behavior-related determinants of exposure. However, the process of recording, transcribing, editing, and coding observational data and relating that data to exposure readings can be tedious and time-consuming. In particular, dynamic work settings for which both exposure and the determinants of that exposure are highly variable pose the greatest challenge to effectively implementing a time-activity study.

An exposure assessment is often initiated to determine compliance with regulatory standards. A time-activity study may then be required to examine the factors contributing to overexposure in dynamic work environments. In noise exposure research, the documentation of a worker's job activities through the time-activity collection method is combined with personal dosimetry data to produce a more thorough noise exposure assessment. The time-activity data collection method typically includes hand- or computer-written notes documenting a subject's work tasks. This process has revealed numerous limitations in the field, including lack of consistency in observed data recorded by field observers, slight inaccuracies between the actual time a task is performed and the time recorded in the field notes, and a propensity to exclude tasks of short duration. Our research examining the noise exposure of surface drill-rig operators revealed that a worker's noise exposure was significantly impacted by events of short duration associated with the worker's behavior and location. Collecting this information required a recording of not only the details of the current rig operation but the worker's behaviors and location.

To facilitate the acquisition of these observations, researchers from the National Institute for Occupational Safety and Health (NIOSH) conducted a feasibility study to investigate the utility of recording observational events using pre-programmed personal digital assistants (PDAs) for noise exposure assessment research. PDAs have been utilized for data collection in other research fields including medicine and ergonomics (Drury, 1987; Weber and



Roberts, 2000; Koop and Mosges, 2002). Commercially available software, designed specifically to capture observational data in realtime, allows users to digitally record a pre-defined set of observations and download the resultant data file into a spreadsheet. The potential advantages of such an approach include the ability to capture a larger number of observations more rapidly and accurately, greater consistency in the set of observations collected, and a reduction in the delay between recording and analyzing observations by eliminating the need to transcribe results (Fletcher et al., 2003).

The feasibility study included recording workplace observations using a PDA while simultaneously measuring the personal noise exposure of an air-rotary drill rig operator working at a surface stone mine. The primary task of this rig operator involves drilling a predetermined pattern of blasting holes that will be loaded with explosives for the purpose of breaking up hard rock in preparation for removal. Historically, drill-rig operators have been identified as having a heightened and highly variable risk of exposure to both dust and noise. According to exposure surveys conducted by the Mine Safety and Health Administration (MSHA) at metal and nonmetal mines over the three-year period from 2000 to 2002, fifty-one percent of air rotary rig drill operators were exposed to noise levels that exceeded the Permissible Exposure Limit (PEL).¹ Although most of these rigs are equipped with enclosed cabs (see Figure 1), their effectiveness is often compromised when the rig operator leaves one or both cab doors open for varying lengths of time, or conducts activities outside the cab during active rig operations. By accurately tracking the rig operator's activities concurrent with drill rig operations (e.g., tramming, drilling, and adding or removing drill rod), we hoped to identify the combinations of rig operations and worker activities most responsible for the operator's over-exposure to noise.

Implementation

The process of utilizing PDA software to conduct a time-activity study can be divided into three main steps. First, identify subjects and behaviors to be observed (configuration). Second, collect observations (acquisition). Third, analyze results. However, as part of an exposure assessment strategy, this process was expanded to involve the six major components listed below:

¹ NOTE: MSHA issues citations only when samples are equal to or greater than 132% (or 32% above the PEL).



- (1) Define subjects and behaviors for configuring PDA software.
- (2) Establish exposure monitoring procedures.
- (3) Acquire simultaneous observations and exposure data in the field.
- (4) Integrate observational data and exposure data.
- (5) Create detailed activity and exposure time history graphs for reviewing and editing combined data.
- (6) Analyze combined data to confirm relevance of predefined tasks and calculate exposure results.

The above six-step process is an iterative one involving an initial configuration, followed by acquisition (field testing), analysis, review, modification, and possible re-configuration. This approach is outlined in the following sections as applied to the observation of blast-hole drillers in conjunction with noise measurement using personal noise dosimeters. A graphical representation of the process to implement PDAs for data collection used in exposure assessment is shown in Figure 2--Observational Process Flow Chart. The flowchart describes the steps taken to acquire data. A description of the required data collection process is described in the following sections.

Some available software programs allow for easier modifications to observations in the field and may not require all the steps shown. However, one software program available does not allow for multiple activities to be selected on the PDA at the same time. The program therefore requires the user to program all possible combinations of activities before the combination can be selected and tracked.

Configuration

Define subjects and behaviors relevant to configuring PDA software

The first steps required when using a PDA may differ based on the software chosen for data collection. Originally developed by BIOOBSERVE to record and analyze animal behaviors and interactions, both Spectator and Spectator **GO!** (Basic and Professional versions) are software systems that allow users to rapidly record and analyze observational data in real time through direct observation in the field or via a video source. While Spectator runs



exclusively on desktops and laptops, Spectator *GO!* includes a more mobile data acquisition component designed to run on hand-held computers. The Professional version of Spectator *GO!* can accommodate observations for up to ten subjects and 56 behaviors, while the Basic version is limited to five subjects and 14 behaviors. Although the current discussion is limited to our experience using the Basic version of Spectator *GO!*, the overall approach of acquiring and analyzing observational data is basically the same for all three software versions.

In our research, we selected the Spectator *GO!* Basic software because it allowed for rapid and concise data collection in the field. However, this version of the software did not permit modification of tasks on the PDA. Thus, the researcher must gain a general understanding of the tasks and habits of the subject by conducting short trial observations of the subject or by reviewing past time-motion observations of similar subjects and equipment. The observations chosen should be separated into as few items as possible on the PDA while still capturing the required data. This seems like a difficult task at first, but the initial configuration can always be modified for the next data set. Additionally, any events which are not pre-programmed into the PDA can be recorded through note-taking in the field and added after the PDA data are downloaded.

Other available software allows the observer to quickly and easily add as many activities or descriptors as required. However, for our research, this option was outweighed by the additional time and complexity of navigating screens once in the field. We preferred to use a software package that displayed most, if not all of the tasks to be observed on one screen and permitted multiple tasks to be in-process concurrently without changing screens.

Once tasks are identified and divided into categories, the next step is to configure the software on the computer and download this configuration to the PDA. Using the software interface shown in Figure 3, the observer enters the tasks and behaviors of interest. The observations/behaviors can be set up to record a short duration of recorded data as an "Event" or can be tracked over a longer period of time as a "Status." A quick example of an event would be a person "sneezing," While an example of a "status" would be "walking."

For our research we decided to designate each of the individual rig operations as "Interactive." Doing this prevented the observer from leaving any of the mutually exclusive tasks on at the same time. For instance, the rig cannot "Tram" and "Drill" at the same time. If the observer tries to activate two of the interactive tasks at the same time,



he/she will be prompted to stop the first task in order to start the second. However, it must be noted that using this technique can complicate configurations when several subjects are to be observed. Verification of the task configuration should be completed in the lab/office before application in the field setting. Furthermore, timing on the PDA device should be synchronized with exposure assessment device timing, in our case a noise dosimeter. This can be accomplished by using any of the PDA clock sync programs available. Once the configuration is completed, it is transferred to the PDA by means of the HotSync operation. The PDA is now ready to collect data. For purposes of monitoring drill rig operations with the PDA, field observations were taken to identify tasks of a typical work day. In order to keep all tasks on one PDA screen, nine activities were identified. Five additional descriptors were chosen to clarify actions or positions of the rig operator and the position of cab doors. A representative work cycle is graphically depicted in Figure 4.

Acquisition

Establish exposure monitoring procedures

Before data are captured in the field, the exposure assessment device needs to be set up to record the most meaningful data possible. For purposes of collecting and analyzing an individual's noise exposure, personal dosimeters are often viewed as the standard method for collecting noise measurements (Malchaire and Piette 1997). Studies have noted the efficiency of personal dosimetry data collection based on the low error rate associated with this method (Shackleton and Piney, 1984).

The noise dosimeter is set up to record per both MSHA and NIOSH noise exposure criteria. The dosimeter is capable of recording the average sound pressure level (L_{eq}). A personal noise dosimeter (Larson Davis Spark 750+) records the operator's noise exposure in A-weighted sound levels using slow exponential-time-averaging. The dosimeter's microphone is positioned on the rig operator's right shoulder. For one style of rig, this shoulder is adjacent to the inside door, which is closest to the drilling mast for this drill rig. The dosimeter automatically records an L_{eq} while simultaneously logging three additional sound level measurements to allow for the computation of noise under the following three criteria:



- (1) Mine Safety and Health Administration (MSHA) hearing conservation program or Action Level (AL) with an 85-dBA criterion sound level (LC), 80-dBA threshold level (TL), and 5-dBA exchange rate (ER).
- (2) The MSHA Permissible Exposure Level (PEL) with a 90-dBA LC, 90-dBA TL, and 5-dBA ER.
- (3) The National Institute of Occupational Safety and Health (NIOSH) Recommended Exposure Level (REL) with an 85-dBA LC, 80-dBA TL, and 3-dBA ER.

In this study, a 5-second sample interval was used for the first field observation completed. However, during this initial visit the rig's cab doors were frequently opened by the operator for durations as brief as several seconds. Based on this observation, the sample interval was changed to a 1-second interval for all subsequent field observations. Using a 1-second sample interval, the dosimeter will clearly show a rise in the L_{eq} when cab doors are opened and closed quickly. The event can be captured on the PDA in almost "real time" meaning the event start and stop will be recorded at relatively the same time stamps as with the noise dosimeter. In contrast, using a pen/paper and stop watch, the door would have opened and closed before the observer could look at the clock and begin to write the time and information. Additionally, using a 1-second sample interval was consistent with the observational software program which recorded clock times for observed events in hours, minutes, and seconds. For observations that do not require this amount of time-specific detail, a longer sample interval could be used.

Acquire simultaneous observations and exposure monitoring under field conditions

Once in the field, data are captured on the PDA using the same principle as any other device or method used during workplace exposure assessment observation. The subject is required to be visible to the researcher and the researcher must be alert to the actions of the subject. To begin collecting data the researcher opens the PDA program, creates a filename for the experiment, selects the appropriate configuration, and starts the program. Data are collected using the PDA's stylus and touch screen. The researcher places the stylus tip onto the touch screen to select the subject and to turn tasks on and off.

Figure 5 shows the display on the PDA screen during the experiment. In this example, the researcher touches the stylus in the box next to the letters for the subject "op" which is the operator. Next, the observer touches the screen



on any of the 14 task/descriptor boxes in the lower portion of the screen to turn these items on or off. Depending on the configuration file transferred to the PDA the observer can have numerous tasks and descriptors running at one time. The subject observed is the rig operator as denoted by the check mark in the box next to the letters “op.” At the moment depicted in the figure there is one rig “Status,” and three rig “descriptors” recording data. Interpreting the screen through our research interest, the operator is tramping the rig with the throttle at its lowest setting while both the doors on the cab are open.

During the experiment/observation, the subject is likely to complete tasks not pre-programmed into the PDA configuration. These events should be recorded through note-taking and can be added to the data set later. If a single previously uncharacterized event occurs often during the observation, the configuration of the PDA should be changed to include this event for the next experiment/observation and further observations may be required. Furthermore, if a previously programmed task turns out to be uncommon during the observation, it should be removed from the configuration. The observer continues to collect data in this manner until the subject has completed the assigned work, or the observer has collected enough data to identify the main contributors of exposure.

If after several attempts the job tasks/descriptors cannot be combined into a pre-programmed configuration, the observer may choose to change to software which allows unlimited tasks to be added in the field. While time will be lost entering task names in the field, the data will still be time-stamped and organized in a computer program which is easy to convert into useable data. A PDA keyboard may be useful in this case to expedite data entry.

Analysis

Integrate observations with exposure readings and create graphic depictions for reviewing and editing combined data

For this research, the resultant observational PDA file and the dosimetry file were downloaded to a PC and exported to a spreadsheet in Microsoft Excel. Table 1 depicts a segment of the observational data with time stamps recorded for each instance an observation was turned ‘on’ or ‘off’. The numbers beneath the observational variables indicate



whether an observation is being initiated, ended, or is ongoing at the given time. An SPSS program (Version 12.0) was developed to read data from the spreadsheet and expand the time stamps to consecutive one-second recordings. Within these 1-second intervals, the program generated a value of either '1' or '0' for each observation variable to indicate whether the operation or activity was ongoing or absent, respectively, at any given time.

Similarly, for the initial data set, the dosimetry file of 5-second sound level recordings was expanded to 1-second recordings by duplicating the 5-second equivalent continuous sound level for the previous 4 seconds of time. This step was not required for the subsequent data sets since the sample interval was changed to 1-second. For each 1-second interval the corresponding dose, based on the MSHA PEL, was computed using the standard formulas for converting sound levels to dose given a time period of 1-second exposure duration.

Next, the 1-second dosimeter and observational files were merged into a single file using the 1-second time stamps as the joining variable. The 14 observational variables were then collapsed into two categorical variables, one denoting the current rig operation (i.e., tramping, setting up the hole, rig idling) and the other characterizing the operator's interactions with the rig (i.e., operator in-cab with inside door open, operator distant from rig). This allowed the dose and exposure time for the various combinations of rig operations and operator activities to be determined. To simplify the analysis, rig 'idling' included both periods of 'low' and 'high' idle in the absence of any other rig operation. Additionally, to facilitate an examination of the variability in sound levels due to one or both cab doors being open or closed, the observations for the cab doors were expanded to differentiate those times when both doors remained open or both doors were closed.

Figure 6 displays sound levels and observations for a 15-minute segment of a drilling cycle generated from the combined file. For graphing purposes, the observational variables were plotted as bars at fixed sound levels by temporarily assigning a value within the range of monitored sound levels to each observation. Preliminary visual review of these graphic displays throughout the shift allowed us to determine whether the observational configuration adequately characterized significant changes in sound levels.

As illustrated in Figure 6, sound levels dropping below 80dBA corresponded with times when the operator was either distant from the rig or in the cab with both doors closed during non-hammering sequences. Conversely, sound



levels in excess of 110dBA characterized those instances when the operator was in the cab during hammering sequences with the inside door (adjacent the drill steel) open. Not unexpectedly, the most variable sound levels occurred during hammering sequences when the operator was out of the cab and moving around or away from the rig.

Based on a review of these graphical timelines throughout the shift, we determined that the observational configuration adequately captured the range of rig operations and operator activities contributing to the operator's noise exposure. Observational errors in recording were easily identified and corrected by identifying distinct patterns of variations in sound levels associated with different combinations of operations and activities. In particular, errors involving delays in recording the doors opening or closing during hammering sequences were often easily corrected. Additional edits involved correcting sequences in which two mutually exclusive activities were recorded as occurring simultaneously. The most common sequence involved recording both 'tramping' and 'operator out-of-cab' at the same time. The operator was usually outside of the cab just prior to tramping to the next drilling location. Such sequences were of short duration and easily identified and corrected.

Results

A full shift of noise monitoring of a drill rig operator yielded an MSHA PEL dose of 356% during a run time of 456 minutes. Observations were collected using the PDA for 419 minutes of the shift, during which time the operator drilled 17 blast holes and accumulated a dose of 349%. During this time, the operator exited the cab 53 times, opened and closed the inside door 95 times, and opened and closed the outside door 33 times. Table 2 presents a breakdown of the dose and exposure time by both rig operations and operator activities, generated from the combined file of dosimeter recordings and observational variables. Among rig operations, noise generated during hammering accounted for the bulk of the total dose and exposure time. Furthermore, over two-thirds (69%) of the 269.9% dose resulting from hammering operations occurred while the operator was in the cab with the inside door open, either alone or with the outside door open as well.

By dividing the dose by the exposure time, a rate of the average dose accumulated per minute of exposure time was computed for each operator interaction observed during hammering sequences. The results, displayed in Figure 7,



indicate that during hammering operations, the dose per minute accumulated in the cab by the operator was five to six times greater with the inside door open than with the inside door closed.

Discussion

Using a PDA to collect workplace observation is one method to collect assessment information related to a variety of exposures that occur in the workplace. While this article details the assessment of noise exposure, research in various fields such as medicine, business, academics, and ergonomics shows that the technique can be applied to other areas of research (Fletcher et al., 2003; Greene, 2001; Malan et al., 2000; Navarrete, 1999; Schmidts, 2000).

Using a PDA to collect workplace observations has advantages over data collections using only a paper, pencil, and timing device. The PDA improves the ability to rapidly and accurately record pertinent observations which occur in rapid succession and/or simultaneously. This lessens the length of time it takes to record the events, which can result in greater accuracy of recording events as they occur in the work environment. In addition, the use of a PDA enhances consistency in data collection because it can better standardize the type of observations recorded; this is of greatest use when multiple field personnel are collecting data.

A work environment in a factory or a manufacturing line allows for consistency and repetition in the activities of the occupation and thus results in easier data collection. Conversely, a dynamic work environment such as blast-hole drilling changes regularly with the activities of the worker, the geology of the drilling medium, and the maintenance of the drill rig. In this dynamic work environment, a PDA is uniquely adaptable for collecting observational data.

Finally, workplace observational data collected with a PDA can shorten the time needed to transcribe data. What can often be a time-consuming process is improved through downloading PDA data into a database and analysis software package. This in turn improves the quality of data collection as modifications for improvement in task enumeration can be detected early on and changes easily made. The use of a PDA for observations also allows the observer to reduce the amount of time required for field observations. Multiple full-day observations may be unnecessary due to the accuracy of the data collected. The researcher can be confident in the exposure acquired by the worker for observed tasks once a repeatable pattern of operation and exposure becomes evident.



Compared to other on-site data collection methods, field data collection with a PDA has a few challenges associated with its usage (Fletcher et al., 2003). Most importantly, the efficacy of a PDA is impacted by what is recorded and observed in the field. The PDA will be rendered ineffective if particular incidents of exposure were not identified by the tasks observed and recorded. Another issue relates to analysis of the workplace observation data. Certain forms of analysis require computer programs to be written in order to perform the appropriate tasks. Finally, when conducting field research, modifications of observations found while collecting data cannot be immediately integrated into the PDA's defined tasks. Unless the PDA software is downloaded to a laptop computer, researchers will have to utilize pen and paper for additional observational notes.

Conclusion

Our research examined the determinants of noise exposure for surface drilling rig operators. We concluded that a worker's noise exposure was significantly impacted by how the worker used the drill rig machinery to complete the job activities. Collecting this information required not only the recording of the worker's completed work tasks but also an understand of how the machine, in this case the drill rig, was used by the worker.

Using a PDA helps to standardize the data collection of observations in dynamic work environments. After completing observations, data can be analyzed quickly to determine if more detailed observations are required to fully understand the cause of exposure or if tasks that show little or no effect on exposure can be eliminated. The PDA also proves useful in its relative ease and speed of combining task observations with the exposure monitoring data. The number and types of observations collected while at a field site increases over the traditional pen and paper method, and decreases the time between the recording and analyzing the data.

In our research, another benefit of using the PDA was that the research team could examine agreement between multiple researchers' field observations. As demonstrated in this study, PDA technology provides exposure assessment researchers another tool to examine determinants of exposure that impact health and safety in the workplace.



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Figure 1: Track-Mounted Drill Rig with Cab.

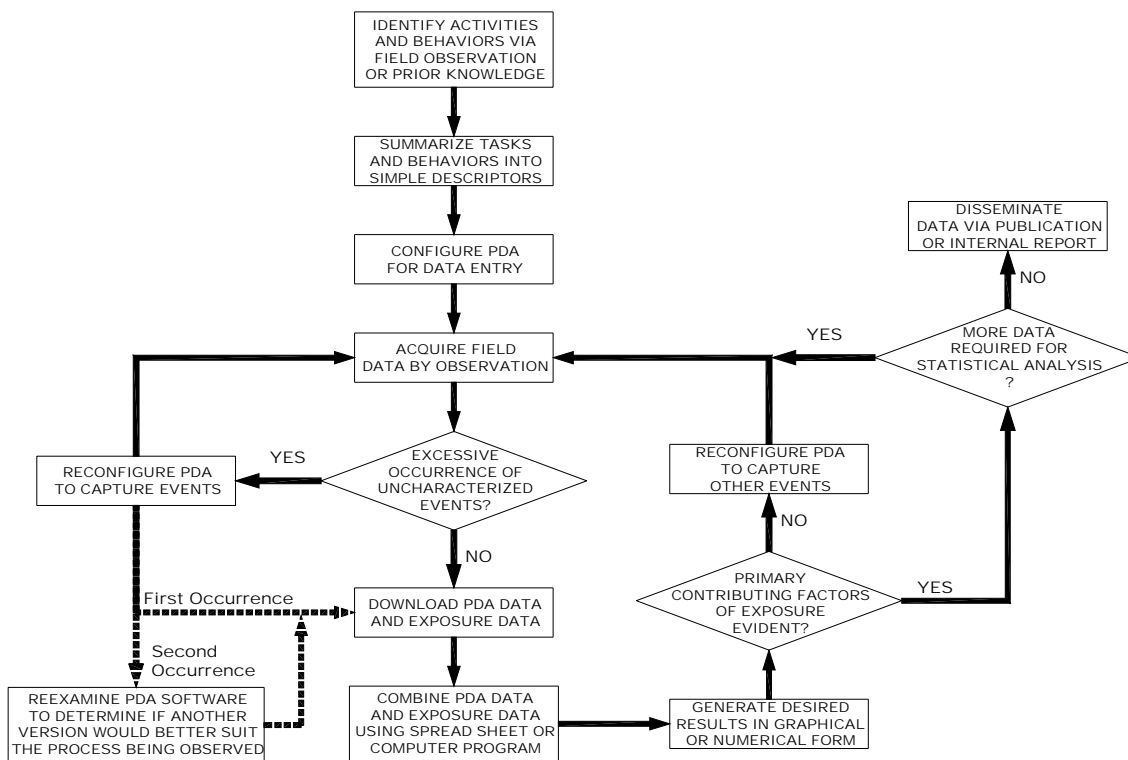


Figure 2. Observational Process Flow Chart.

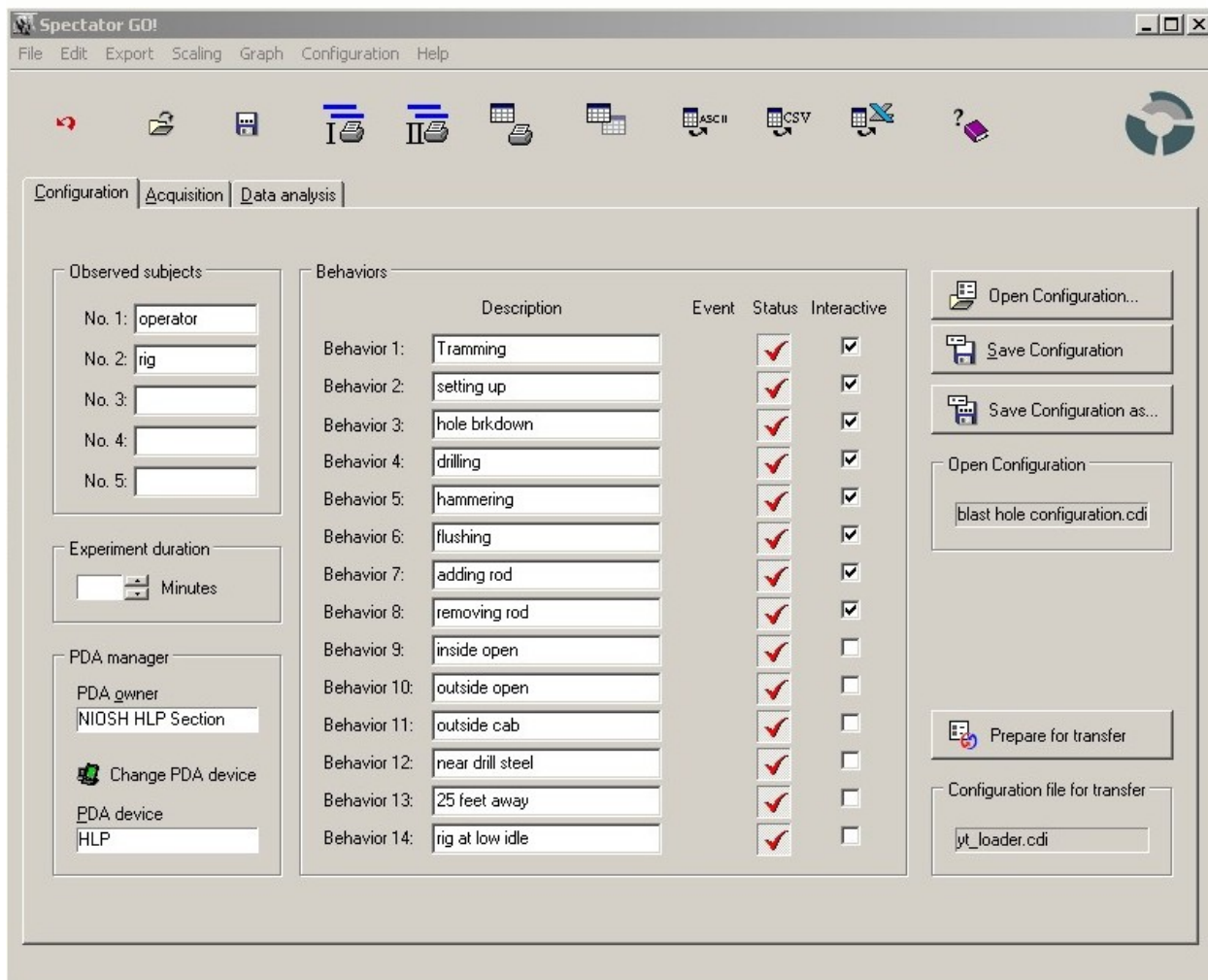


Figure 3. Spectator GO! Configuration Page.

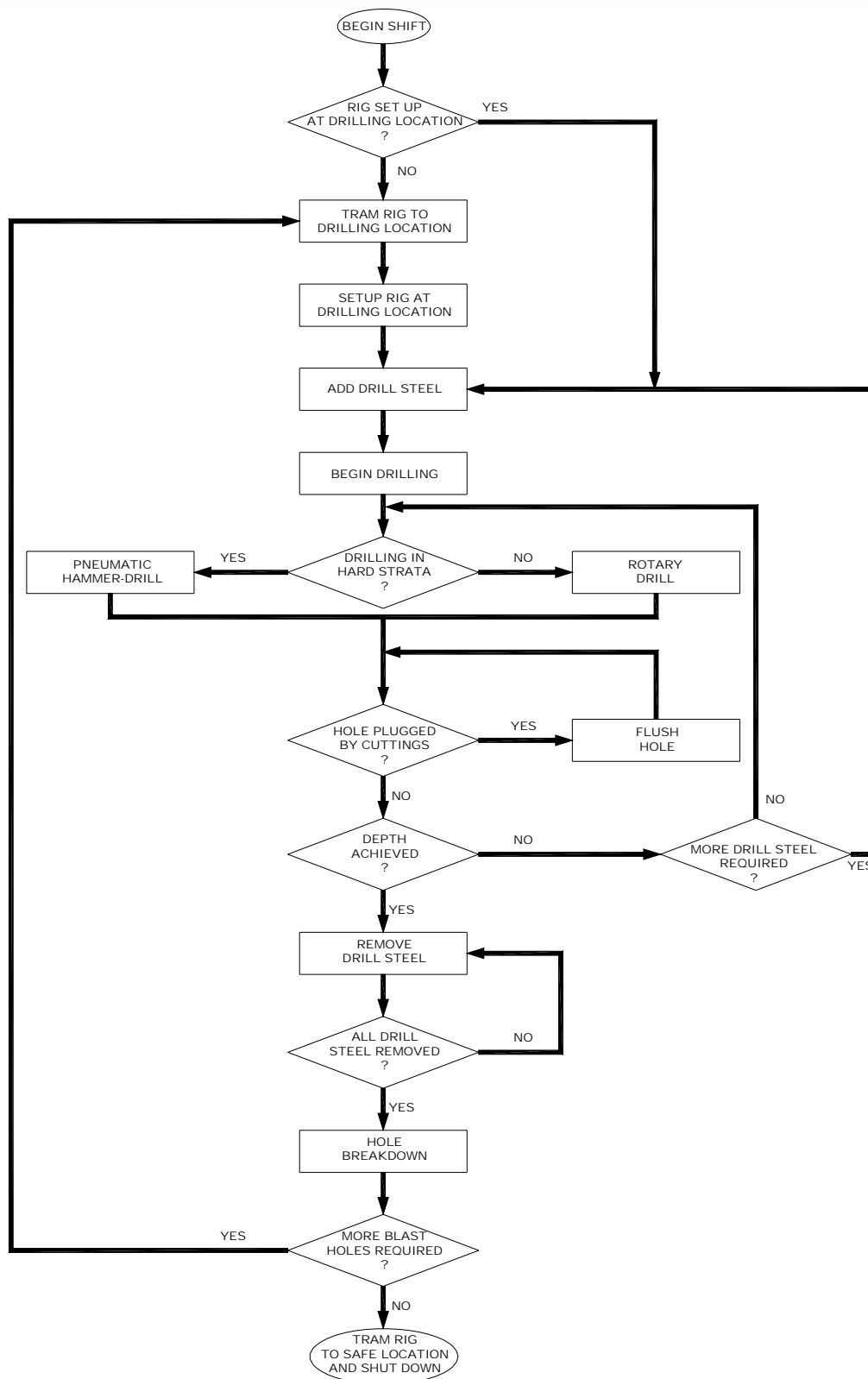


Figure 4. Work cycle for air rotary rig drilling blast holes.



Spectator GO		uBlastHoles	
<input checked="" type="checkbox"/>	op	<input type="checkbox"/>	ri
<input type="checkbox"/>	Tramming	removing rod	<input type="checkbox"/>
<input type="checkbox"/>	setting up	inside open	<input checked="" type="checkbox"/>
<input type="checkbox"/>	hole brkdown	outside open	<input checked="" type="checkbox"/>
<input type="checkbox"/>	drilling	outside cab	<input type="checkbox"/>
<input type="checkbox"/>	hammering	near drill steel	<input type="checkbox"/>
<input type="checkbox"/>	flushing	25 feet away	<input type="checkbox"/>
<input type="checkbox"/>	adding rod	rig at low idle	<input checked="" type="checkbox"/>

Figure 5. – Sample Spectator GO! Screen on PDA.

	A	G	H	I	J	K	L	M	N	O	P
4	Time	hammering	flushing	adding rod	removing rod	inside open	outside open	outside cab	near fan/steel	25'+ away	rig idle
549	10:49:51							4			
550	10:51:25							5			
551	10:51:29					4		5			
552	10:51:30					5	4	5			
553	10:51:31					5	5	6			
554	10:52:38					5	5				
555	10:52:46					5	5				
556	10:52:50					6	5				
557	10:52:51						6				
558	10:53:04					4					
559	10:53:16					5					
560	10:53:17	7				5					
561	10:53:50	8				6					
562	10:54:48	8					4				
563	10:55:18	8					5	4			
564	10:55:19	8					5	5	4		
565	10:55:46	8				4	5	5	5		
566	10:55:48	8				5	5	6	5		
567	10:55:48	8				5	5		6		
568	10:56:04	9				5	5				
569	10:56:15		7			5	5				
570	10:56:30		9			5	5				

Table 1: Observational Data Matrix in Excel.

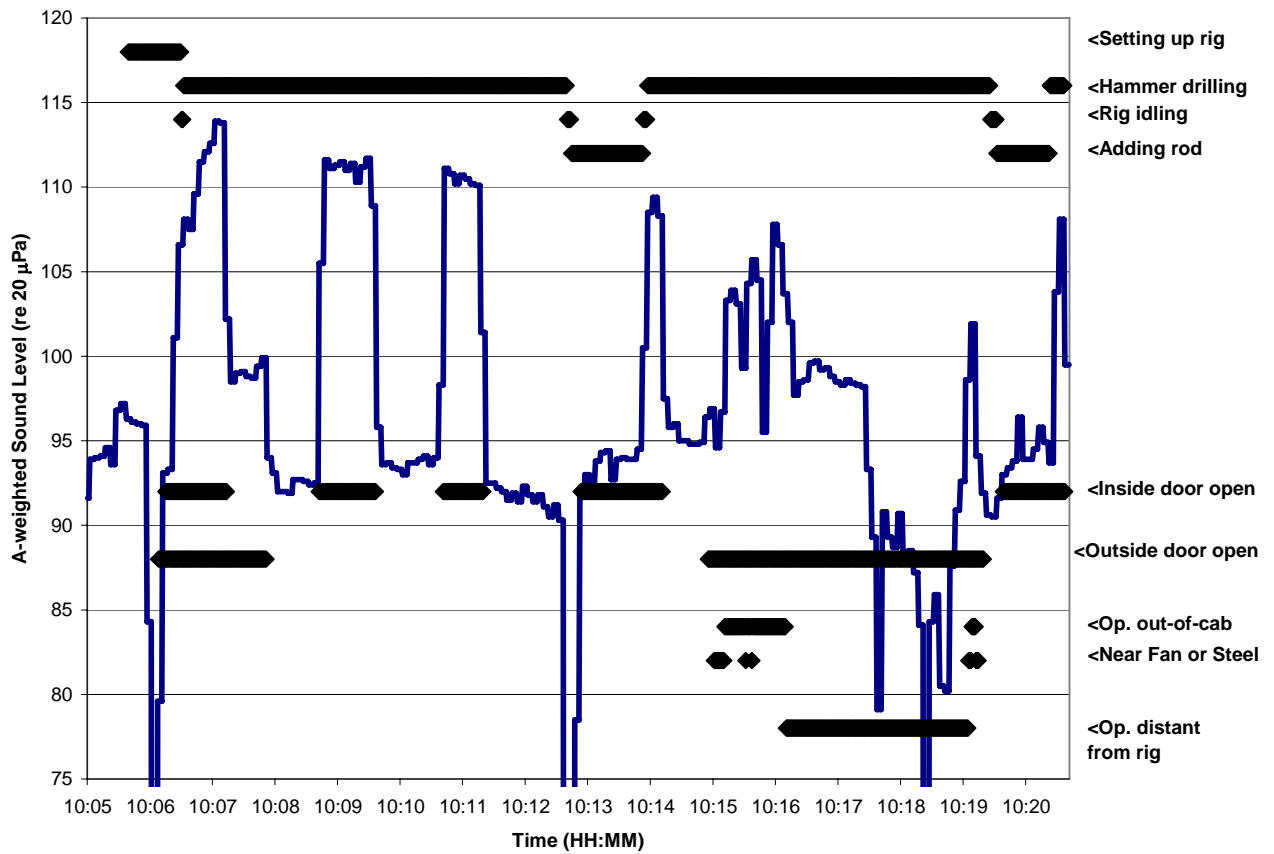


Figure 6. Sound levels and observations for a 15-minute segment of a drilling cycle.



Rig Operations	Operator Location and Position of Cab Doors							Totals
	Operator in-cab				Operator out-of-cab			
	Both doors closed	Both doors open	Inside door open	Outside door open	Near Drill Rig	Near fan or drill steel	Distant from cab (25ft.+)	
Tramming	.5 1.3	2.1 6.4	1.9 5.7	0.8 1.3	--	--	--	5.3% 14.7 min
Hole setup	.6 2.6	2.4 5.2	1.9 3.0	.9 3.1	--	--	--	5.9% 13.9 min
Adding rod	1.4 6.1	5.6 11.1	10.1 18.0	0.4 1.3	--	--	--	17.5% 36.5 min
Drilling	0.3 1.3	0.1 0.1	5.3 1.4	0.0 0.2	0.0 0.0	0.0 0.0	0.1 0.2	5.8% 3.2 min
Hammering	27.1 57.9	89.9 30.8	96.0 31.7	14.2 23.6	7.8 9.7	25.7 22.2	9.2 39.4	269.9% 215.2 min
Flushing	0.0 0.0	1.9 4.2	0.3 0.7	0.0 0.0	--	--	--	2.1% 4.9 min
Removing rod	1.9 9.8	4.9 12.5	9.1 23.7	0.6 2.3	--	--	--	16.4% 48.3 min
Hole Breakdown	0.3 7.3	0.3 1.8	0.6 4.9	0.4 3.0	--	--	--	1.6% 17.0 min
Rig idling	1.0 5.4	5.3 8.0	9.5 13.4	1.1 3.0	3.4 17.5	2.7 7.3	1.1 11.3	24.1% 65.9 min
Totals: MSHA PEL	33.1	112.5	134.6	18.3	11.2	28.4	10.4	348.6%
Minutes of Exposure	91.7	79.8	102.5	37.9	27.2	29.5	50.9	419.4 min

Table 2. Distribution of percent dose (MSHA PEL) and exposure time based on rig operations, operator location, and door position.

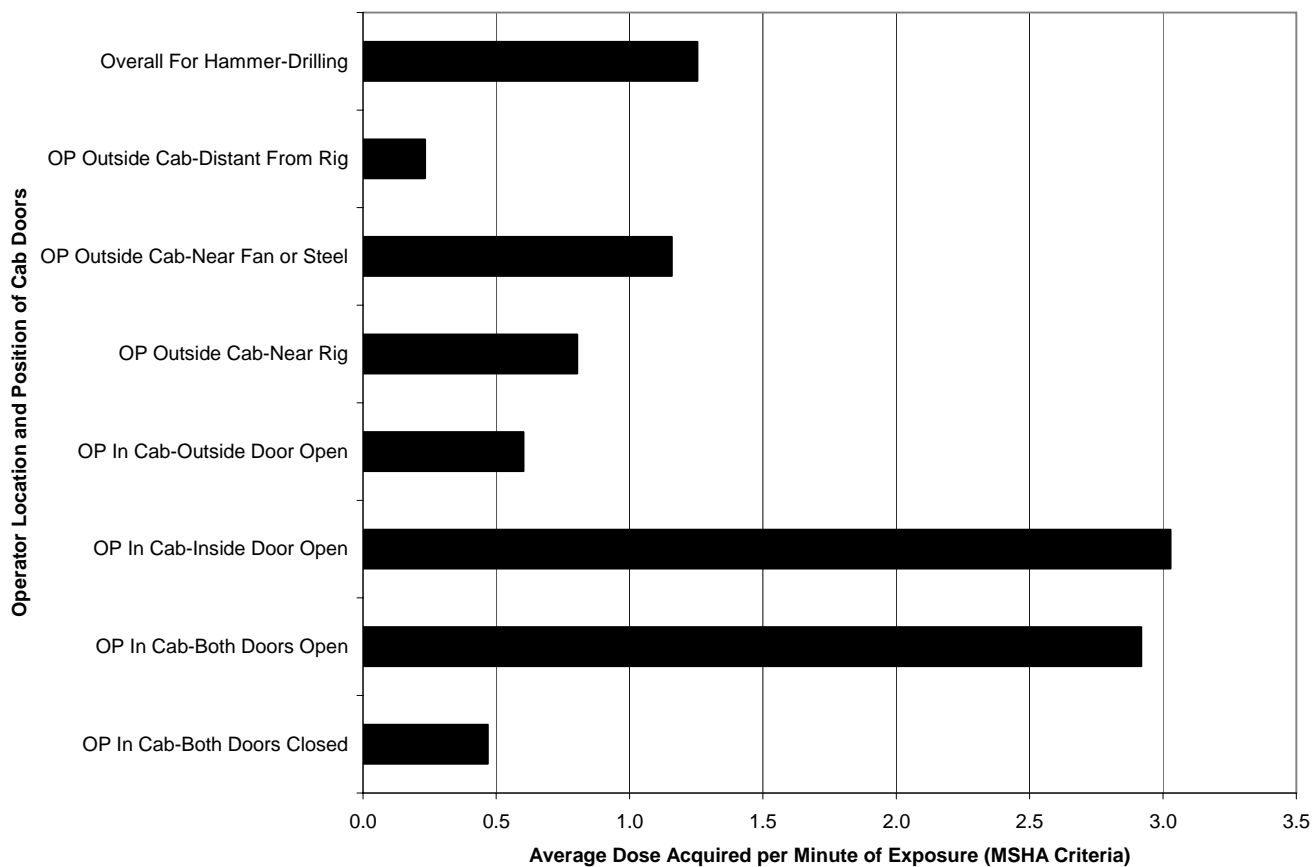


Figure 7: MSHA Dose per Minute During Hammer-Drilling vs. Operation Location and Position of Doors.