

AUDIBLE ALARMS AND WORKPLACE NOISE IN NURSING UNITS: AN ENVIRONMENTAL FACTORS CASE STUDY

By Rudolph P. Santacroce, P.E., Shands HealthCare

Abstract

Alarms, especially on inpatient units, deserve special attention in design because they communicate crucial information about a patient's well being and alert care providers to abnormal readings. Alarms do not always accomplish these functions and are sometimes ineffective due to the lack of clear design philosophy, confusion between multiple alarm sounds, and the use of too many competing alarms. The main concerns in auditory warning design are whether or not the alarms are set at the appropriate level of volume, pitch, frequency, etc. and psychological issues associated with urgent vs. non-urgent response. In a study by Momtahan and Tansley (1989), a medical staff was asked how many alarms they were capable of recognizing out of the 20 alarms present in the average operating or recovery room. In general, the staff overestimated the number they believed they could recognize. A study by Patterson and Milroy (1980) concluded that operators are usually capable of learning five or six warnings sounds. Beyond that point, it is very difficult to commit new warning sounds to memory. Warnings were also confused when they shared the same repetition rate that is multiple alarms sounding, pausing, and then sounding again within a similar block of time.

In late 2001, a Management Engineering human factors study was initiated to examine the types of alarms and the ambient environment of a hospital pediatric nursing unit. Alarms were classified into two categories: critical and non-critical. These categories referred to the timeliness of response to the alarm, and the overall result to the condition of the patient. Once these alarms were identified, decibel levels were obtained along with the decibel level of the ambient noise present on the unit during peak periods of the day, namely shift changes. A simple calculation was performed to identify the Equivalent Noise Level (Leq) of the nursing unit during peak periods. Using this calculation for Leq, all alarm sound levels were compared against it for compliance using the following guidelines:

- 6 – 10 dB above Leq is required for 100% detectability of the alarm
- 15 – 16 dB above Leq is required for RAPID RESPONSE alarms

- Less than 30 dB above Leq in order to minimize operator annoyance and disruption of communication

This study found that very few alarms were in compliance with the above-mentioned criteria. A number of recommendations were made to reduce the ambient level of noise on the nursing unit while increasing the response rate of the operator through facility layout and alarm monitoring techniques.

Alarms and Inpatient Units: Confusion, Congestion and Desensitization

The level of noise and confusion on any given day at the front counter of a nurses' station on an inpatient hospital floor is loud and confusing at best, only to worsen at shift change and other peak periods. When patient care providers are not physically in a patients' room, they rely on monitoring equipment to alert them if vital signs fall out of a specified range. This information is constantly hampered by false alarms caused by false information or patient movement. These problems become more prevalent in a pediatric inpatient unit where, in most cases the infant or small child cannot verbally alert care providers to problems; the child moving and shaking leads off of their bodies compound the situation. Along with the mechanical challenges of monitoring equipment, alarm desensitization challenges are also inherent. Desensitization problems are worsened if the alarm signal is averse or capable of disrupting ongoing activities (Patterson, 1982). As workload increases, auditory confusion increases. Analysis shows that overall alerted-monitored performance is highly dependent on the interaction of the parameters of the automated alerting subsystem and the operator's workload and monitoring strategy (Sorkin and Woods, 1984). Uniformity of alarms, or lack thereof, also poses a problem within hospital inpatient units. One patient may be connected to several machines, and each machine may have its own alarm sound and may have multiple alerts depending on the problem it is sensing. Several different manufacturers may produce the equipment, each incorporating their own auditory alarm into the monitoring equipment. The fact that hospital inpatient units use a variety of patient and situational warning devices poses another problem: humans can learn and physically respond

to a finite number of different alarm types. A study by Paterson and Milroy (1980) concluded that operators are usually capable of learning five or six warnings. Beyond that point, it is very difficult to commit new warning sounds to memory, and warnings that share the same repetition pattern are often confusing.

Management Engineering Conducts a Comprehensive Study of PEDS Inpatient Unit

In late 2001, Management Engineering was asked to conduct a study to recommend changes to reduce the ambient level of noise and to make alarm detection easier and more accurate on an inpatient Pediatrics unit. Nurses in this unit and on similar units were complaining that alarm detection of critical equipment, like the pulse oximeter, was becoming problematic. This could lead to the loss of a patient's life if the alarm was not responded to in a timely manner.

The study took place over the course of several weeks, and the team's initial objective was to document and understand the current situation. The team observed the unit during both peak and off-peak hours using a decibel meter to take sample readings of the general noise levels around the nursing station and of alarm producing equipment.

To better understand noise and decibel levels, refer to figure 1 below. Figure 1, Typical Noise Sources, compares a sound's source to the corresponding decibel level (dBA)

Sound Levels of
Typical Noise Sources

Source (Distance)	Sound Level (dBA)	Noise Environment
Military Jet Take-off (50 ft)	140	Aircraft Carrier Flight Deck
Civil Defense Siren (100 ft)	130	
Commercial Jet Take-off (200ft)	120	
Pile Driver (50 ft)	110	Rock Music Concert
Ambulance Siren (100 ft)	100	
Newspaper Press (5 ft)		
Power Lawn Mower (3 ft)		
Motorcycle (25 ft)	90	Boiler Room
Diesel Truck, 40 mph (50 ft)	80	Printing Press Plant
Kitchen Garbage Disposal (3 ft)		High Urban Ambient Sound
Passenger Car, 65 mph (25 ft)		70
Living Room Stereo (15 ft)		
Vacuum Cleaner (3 ft)		
Normal Conversation (5 ft)	60	Data Processing Center
Air Conditioning Unit (100 ft)	50	Department Store
Light Traffic (100 ft)		Private Business Office
Bird Calls (distant)		40
	30	Lower Limit of Urban Ambient Sound
Soft Whisper (5 ft)		Quiet Bedroom
		20
	10	Recording Studio
		Threshold of Hearing

Figure 1

and again to the corresponding environment. The range of normal human hearing ranges from 10 dBA (threshold of hearing) to 150+ dBA (threshold of pain).

In order to understand the environment and the urgency of alarm response, all major pieces of equipment on the inpatient unit were categorized into two categories: critical and non-critical. The distinction being that 'critical' equipment is any piece of medical equipment that alarms and, if not addressed by medical staff in a timely manner, may have a serious effect on the patient. A decibel meter was used to record the level of sound produced by each piece of 'critical' equipment.

Non-Critical

- * IV Pump
- * Med Cart
- * Med Fusion Pump
- * Pneumatic Tube System

Critical

- * A&B¹ Monitor (79dB)
- * Nurse Call (61dB)
- * Pulse Ox (62 dB)
- * Pulse Ox Monitor (72

dB)

- * Electric Thermometer

¹A&B - Apnea & Bradycardia

Sound Levels, the Environment, and Equivalent Noise Level

The equivalent level of sustained noise, *Leq*, expresses the average level of sound energy during a given period of time (Grandjean, 1988). *Leq* is an integration of all the varying sound levels in an environment over the specified time period. It compares the effect of the fluctuating noises with a continuous noise of steady intensity through the following equation:

$$Leq = (L50 + L1)/2$$

L50 = average noise level over the specified time period

L1 = peak noise level over the specified time period

Once *Leq* is calculated for a system, the level of an auditory warning signal can be determined by the following parameters, as described by Sorkin in the Handbook of Human Factors:

1. Signal levels 6 to 10 dB above the masked threshold will be sufficient for 100% detectability on controlled test situation.
2. Signal levels 15 to 16 dB above the masked threshold will be sufficient for situations requiring rapid response to a signal (such as a warning signal).
3. The level of an auditory warning signal should be less than 30 dB above the masked threshold in order to minimize operator annoyance and the disruption of communication.

Using the criteria described above, all of the unit's critical equipment should alarm at 15-16 dBA above the

masked threshold of sound (ambient noise of the unit) because those pieces of critical equipment require a rapid response by a health care provider.

Management Engineers sampled the sound level during morning and afternoon shift periods (evening and night periods were much lower). These sound readings were taken from the nurses' station because this is where the nurse or care provider would be if not involved in bedside care. The results of the sound readings are as follows:

Morning Shift

L_1 (morning peak) = 78.6 dB

L_{50} (morning average) = 62.1 dB

Afternoon Shift

L_1 (afternoon peak) = 76.6 dB

L_{50} (afternoon average) = 60.7 dB

Using the equation to calculate Leq :

$$Leq = (L_{50} + L_1)/2$$

Leq Summary

Leq (morning) = 70.35 dB

Leq (afternoon) = 68.65 dB

Leq (daily average) = 69.5 dB

Figure 2 below integrates critical equipment along with sound readings (Leq) from the nursing unit into the typical noise source chart found in Figure 1 (sound level readings taken where noted in parenthesis):

Integrated Sound Levels of

Typical Noise Sources and Alarm Equipment

Source (Distance)	Sound Level (dBA)	Noise Environment
Military Jet Take-off (50 ft)	140	Aircraft Carrier Flight Deck
Civil Defense Siren (100 ft)	130	
Commercial Jet Take-off (200ft)	120	
Pile Driver (50 ft)	110	Rock Music Concert
Ambulance Siren (100 ft)	100	
Newspaper Press (5 ft)		
Power Lawn Mower (3 ft)		
Motorcycle (25 ft)	90	Boiler Room
Diesel Truck, 40 mph (50 ft)	81	Printing Press Plant
New Pulse Ox (at bedside)		High Urban Ambient Sound
Kitchen Garbage Disposal (3 ft)		
A & B Monitor (at bedside)	79	
Current Pulse Ox (at nurse station)	72	Nurse station environment
	71.25	
Passenger Car, 65 mph (25 ft)	70	
Living Room Stereo (15 ft)	62	
Vacuum Cleaner (3 ft)		
Current Pulse Ox (at bedside)		
Nurse Call (at nurse station)	61	Data Processing Center
Normal Conversation (5 ft)	60	
Air Conditioning Unit (100 ft)	57	Department Store
New Pulse Ox (at nurse station)		Private Business Office
Light Traffic (100 ft)		
Bird Calls (distant)	40	Lower Limit of Urban Ambient Sound
Soft Whisper (5 ft)	30	Quiet Bedroom
	20	Recording Studio
	10	Threshold of Hearing

Figure 2

Summary of Findings and Equipment Compliance

Having found the ambient noise level, the decibel output of critical alarm equipment, and the recommended decibel range above the ambient noise level, Management Engineers were prepared to summarize and make recommendations. Figures 3 and 4 below summarize our findings based on the environmental factors of the inpatient pediatric unit in question:

Decibel Readings for Critical Equipment Summary

Equipment	Actual (dB)	Recommended (dB) ¹	Variance (dB)
A & B monitor	79	86.3	-7.3
Nurse Call Station	61	86.3	-25.3
Current Pulse Ox Monitor	72	86.3	-14.3
New Pulse Ox Monitor	57	86.3	-29.3

¹15-16 dB above the average equivalent sound level of the environment.

Figure 3

Figure 4

Equipment Compliance for Critical Alarms

	dB level	100% detect? ¹	100% rapid response? ²
A&B (apnea & bradycardia)	79	Y	N
Nurse Call System	61	Y	N
Old Pulse Ox (bedside)	62	N	N
Old Pulse Ox Monitor	72	N	N
New Pulse Ox (bedside)	81	Y	N
New Pulse Ox Monitor	57	N	N

¹6-10 dB above Leq

²15-16 dB above Leq

In reviewing the summaries above, it was clear that one of two things had to happen to prevent the situation in which critical equipment alarms are sounding and no one is able to hear above the level of environmental noise to respond to the patient quickly. One of the following solutions had to be implemented:

1. Raise the decibel level of all critical equipment alarms in order to be 15-16 dB above the ambient noise of the nursing unit and therefore have five independent alarm systems going off and producing 85dB of alarm noise.
2. Find solutions to lowering the ambient noise level of the unit, therefore making the existing alarms more effective.

Recommendations for Improvement

Through staff interviews and common sense (an 85dB alarm next to a hospitalized patient would not make for a pleasant stay), solution #2 was to be pursued. Management Engineers recommended a five-step phase of both short and long-term solutions to reduce the level of ambient noise, assist the clinical staff in responding more quickly to critical alarms, and make recommendations on alarm equipment specifications for new equipment purchases. Initial alarm response time was not studied due to the highly stochastic nature of alarm events and variables surrounding those events coupled with the very short time frame given to this project. Nurse interviews, however, indicated response time as great as eight minutes were not uncommon during high census peak times.

Five Step Process for Recommendations:

1. Reduce unnecessary noise on the Peds inpatient unit
2. Assign and enforce levels of responsibility for priority alarm response
3. Recommendations for new alarm equipment: operating specifications and user input
4. Unit layout recommendations
5. Follow-up

Recommendation 1: Reduce unnecessary noise on the Peds inpatient unit

In order to bring the **Leq** (ambient sound level) of the unit to a more manageable level, it was necessary to eliminate or reduce non-critical alarms on the following pieces of equipment:

- Med Dispensing Cart (lower alarm level)
- Electric thermometer (12 – 14 on the unit, beeps when not placed on the rechargeable stand; turn off alarm)
- Pneumatic Tube system (Situated behind nursing station, emits a high-pitched constant frequency when tube is in the receiver; turn off alarm)

Another recommendation to reduce **Leq** was to shift housekeeping functions such as vacuuming and carpet cleaning to off-peak hours where the ambient sound level is lower to begin with.

Recommendation 2: Assign and enforce levels of responsibility (protocol) for priority alarm response

Figure 5 below outlines the recommended primary and secondary responder for priority alarms with the following definition:

Nurse: The nurse responsible for a particular patient whose alarm is sounding

PCA (patient care assistant): Commonly located at the nurse station, floats

Clerk: Always positioned at the nurse station, alerts the patient's nurse

Levels of Responsibility for Critical Alarm Response

Critical Alarm	Primary Responder	Secondary Responder
A&B (apnea & bradycardia)	NURSE	PCA
Nurse Call System	CLERK	NURSE
New Pulse Ox	NURSE	CLERK
New Pulse Ox Monitor	CLERK	NURSE

¹Secondary responder should act if alarm is not responded to within 30 seconds

Figure 5

Recommendation 3: New alarm equipment: operating specifications and user input

Since the institution was already looking into purchasing new Pulse Ox machines and A&B systems, the following recommendations were proposed to the purchasing team in order to maximize the alarm function of new equipment:

1. Utilize an alarm system incorporating a supplement, such as a visual trigger
2. Vary pitch, tone, and repetition rate to produce a natural dimension of perceived urgency
3. Set alarms to recommended levels based on dB requirements
4. Do not allow nurses to have control over volume of alarm
5. Monitor sensitivity settings of equipment

Recommendation 4: Nursing unit layout and design

Future renovations for most inpatient units were scheduled to be phased in over a six-year period. Below are the recommendations given to the facility design group to keep in mind when re-designing the nursing unit:

1. Centralized vs. Decentralized nursing stations
2. Decentralized = health care team is spread evenly throughout the unit in pods and therefore closer to their assigned patients.
3. Reduces large gatherings of care providers and therefore reduces the level of environmental noise

Recommendation 5: Follow-up

1. Periodically take sound level readings to ensure **Leq** has not significantly increased with the addition of personnel or equipment (recommendation: quarterly)
2. Environmental factors training for health care team
3. Periodically assess critical alarm equipment to ensure it is operating within specified parameters (recommendation : monthly by clinical engineering)

Conclusion

Since this study concluded, all recommendations were implemented with enormous success. A new Pulse Ox system by Nelcore was used throughout the unit producing 81dB of alarm sound. The unit was redesigned and moved to another floor of the hospital incorporating a “pod-concept” where the care providers are stationed near the patients they serve and thus helping to eliminate the level of noise generated from people congregating in one place. The project raised enormous awareness of priority alarms and nurse response time, resulting in a safer and quieter environment for patients.

comprehensive design planning protocol for new health care facility development. He has also worked on value-added assessment and financial modeling, human factors, process improvement, and utilization and simulation models. Rudolph has been a member of SHS since 1999.

Works Cited

Grandjean, Etienne (1998). *Fitting the Task to the Man: A Textbook of Occupational Ergonomics*. London: Taylor & Francis Ltd.

Momtahan, K.L. and Tansley, B.W., 1989, ‘An ergonomic analysis of the auditory alarm signals in the operating room and recovery room’, presentation at the Annual Conference of the Canadian Acoustical Association, Halifax, Nova Scotia.

Patterson, R.D. (1982). *Guidelines for auditory warning systems on civil aircraft*. (CAA Paper 82071). London: Civil Aviation Authority.

Patterson, R.D. and Milroy, R., 1980. Auditory Warnings on Civil Aircraft: The Learning and Retention of Warnings, *Civil Aviation Authority report number 7D/S/0142*.

Sorkin, Robert D. (1987). Design of Auditory and Tactile Displays. In Gavriel Salvendy (Ed.) (1987) *Handbook of Human Factors*, Canada: John Wiley & Sons.

Sorkin, R.D. and Woods, D., (1984). Systems with Human Monitors: A Signal Detection Analysis. In *Human-Computer Interaction*, Lawrence Erlbaum Associates, Inc.

Biographical sketch

Rudolph Santacroce, P.E., BS Industrial Engineering, University of Florida, 1992; Masters of Science in Architecture, University of Florida, 1999: Rudolph has worked as a part of Shands HealthCare Management Engineering Consulting Services since 1993. As a Senior Management Engineer, Rudolph specializes in functional facility design and planning emphasizing process improvement initiatives. He has worked extensively integrating Management Engineering with Facilities Development and has been at the forefront in developing a