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사업장에서의 소음개선 적용 효과와 비용편익 분석에 대한 연구
A Study of Noise-control Implementation and Cost-effectiveness in a Workplace

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ABSTRACT

Objectives: 이 논문의 목적은 한 사업장에서 수십 년 동안 진행된 소음감소계획이 실제적이고, 경제적인 것을 증명하고 이를 바탕으로 소음의 공학적 개선방법과 효과적인 실행을 위한 실제 작동 가능한 모델을 제시하는 것이다.

Methods: 1967년도에 설립된 다국적 전자회사에서 1987년부터 2002년까지 실행된 각종 소음 감소 노력, 요소, 프로그램을 분석하고 이 기간 동안 소음감소가 어떻게 실제로 일어났는지 분석하였다. 특히 회사가 다른 여러 가지 노력을 한 후에도 실질적 효과를 기대하기 어려워 공학적 개선과 같이 도입한 Action Learning Team (ALT) 활동에 초점을 두고 개선 효과를 파악하였다.

Results: 실제 소음의 감소노력은 산업안전보건법의 변화에 따라 여러 가지 형태로 실행되었다. 주된 효과는 ALT활동이 있고 나서 이루어졌는데 평균 소음 노출수준이 86.9 dBA에서 79.8 dBA로 현저히 감소하였으며 소음 지역 (85 dBA 이상)도 10개 지역에서 3개 지역으로 70% 감소하였다. ALT 활동의 결과로 나타난 7개 지역의 소음 감소를 위해 투입된 총 비용이 6,767 달러였다. ALT 활동을 처음 시작한 첫해에 소음 감소지역을 줄임으로써 이 지역의 근로자가 청력검사를 받지 않아서 초기 396명의 근로자가 청력검사를 받던 것을 활동 후 130명만 받아 266명의 근로자가 청력검사를 받지 않아도 되어 청력검사 비용이 6,650 달러 절약되었다. 따라서 장기간으로 보면 매우 비용효과적인 방법으로 증명되었다.

Conclusions: 실제 소음감소가 현저히 일어나고, 비용효과적인 소음 감소가 일어나려면 기기 설비 공정담당자가 소음감소의 중요성을 잘 알고, 그 기법을 숙지하고 있어야 하며, 실제 활동을 할 수 있도록 관리자 층의 권한을 위임 받아 활동할 수 있어야 한다. 이 논문에서는 공학적 개선 태스크포스팀을 운영하여 ALT활동을 하였을 때 실제적이고, 비용효과적인 소음 감소를 증명하였다.

Key words : noise, control, action learning, cost effective, hearing conservation

Ⅰ. Introduction

Noise-induced hearing loss (NIHL) is a preventable, but irreversible, sensorineural auditory deficit and one of the most common occupational diseases in the world. The World Health Organization (WHO) attributes about 16% of disabling hearing loss worldwide to occupational noise exposure (WHO, 2002; Nelson et al., 2005). The number of insurance claims for NIHL increased throughout the 1980s and 1990s (Daniell et al., 2006), and as many as 22 million workers in the U.S. are exposed to noise levels that pose an auditory health hazard (Tak & Calvert, 2008; Tak & Davis, 2009).

Mandatory hearing conservation programs (HCPs) have been in effect since 1972 in the U.S. (OSHA, 1971; 1981; 1983). However, NIHL persists, since workers do not use hearing protectors consistently, and the protectors may not meet manufacturer’s specifications in real

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world conditions (Brink et al., 2002). The incidence of NIHL has not changed substantially in the U.S. since the 1970s, when the OSHA noise regulation was enacted (NIOSH, 1999). Many companies rely on hearing protection devices (HPDs), which are often a method of last resort, when other means such as engineering control or removal of the person from the noisy environment are seen as impractical or uneconomical (Berger et al., 2003). However, convincing employees to use HPDs can be difficult. Many workers report that they do not want to wear HPDs because they have trouble communicating while wearing HPDs (NIOSH, 1999). The percentage of workers wearing HPDs scarcely exceeded 80% (El Dib & Mathew, 2009).

Noise control is the best way to prevent NIHL. Many studies proved that industrial noise control is practical and effective control of industrial noise does not require sophisticated and expensive techniques(Hutton, 1968; Malchaire, 2000). Despite these studies, practical and economical methods of reducing workers' noise exposure through noise control have not yet been investigated sufficiently in real workplaces. This study examines one company as a case study and proposes a working model of noise engineering training and effective noise control implementation. This study shall addressthat noise control can be practical and economically feasible when technician chiefs and manufacturing middle managers are trained as key members of an ALT to implement noise control measures.

Ⅱ. Methods

1. Subject

The company is a multinational electronics company that has assembled and tested semiconductor devices, which are electronic components that exploit the electronic properties of semiconductor materials, in Korea since 1967. During the period studied, the average number of employees was around 2,500. In 1987, with enactment of the Korean Occupational Safety and Health Act in 1981 (Korean Ministry of Employment and Labor, 1990), the company started noise monitoring and annual audiometric testing for employees who worked in "noise areas". From 1992 to 1997, a HCP was fully implemented that aligned with the American OSHA program, as required by the company's U.S. headquarters. Even with the implementation of a HCP, the number of noise areas increased. Eight employees were identified by 1997 as having hearing loss corresponding to 50 dB or more at 4000 Hz, with average losses exceeding 30 dB at 500 Hz, 1000 Hz, and 2000 Hz, in pure tone audiometric testing (KOSHRI, 1999).The failure of the HCP to stem the tide of NIHL created the motivation to change from a policy of trying to protect employees from noise to a policy of noise control that would eliminate excess noise. Management decided that the problem could be solved using company-wide problem-solving skills, such as implementing a task force team and using the action learning protocol.

2. ALT (Action Learning Team)

A noise-control training program was implemented by a company-wide task force team using the action learning protocol.Action learning emphasizes learning by doing, conducted in teams. The ALT was composed of members from all the noise areas united to solve the single problem of noisereduction during a defined three-month period. Team members participated in these activities partially by performing their regular jobs during working hours. The action learning process is an educational process whereby participants study their own actions and experiences in order to improve performance (Revans, 1980). Typically, action learning consists of experiential learning, creative complex problem-solving, acquiring relevant knowledge, and co-learning group support. Typically, action learning calls the group a "set" since the focus is essentially on the individual (McGill & Beaty, 2001). In this study, "team" is used instead of "set," and the assigned task was "engineering noise control." The action learning steps taken in this study were composed of 7 steps (**Table 1**).

3. Noise Monitoring Program

Noise was monitored once a year by HCP (Hearing Conservation Program). This noise monitoring as a part

Table 1. The steps and contents of Action Learning Team

Step		Contents
Step 1.	Clarify the objective of the ALT for noise reduction	Not only to reduce noise areas by controlling noise sources, but also to instill in team members who actively participated in the activities a sense of awareness that would lead to future management of excessive noise levels after implementation.
Step 2.	Noise task force team formation	A cross-functional team composed of middle managers and chief technicians from each department as the team members, an industrial hygienist as a facilitator, and a noise-control professional as a noise reduction-method advisor.
Step 3.	Identify noise equipment and noise engineering survey	Team members identify all of the pieces of noise equipment in noise areas and conduct a noise engineering survey to find noise sources.
Step 4.	Present activities and problems	Team members present their activities and problems during team activities at the team meetings.
Step 5.	Reframe the problems to prioritize the control methods	Team members reframe the problems to prioritize the control methods considering noise level, work flow, and the technical and economical feasibility of dealing with the identified noise sources.
Step 6.	Determine goals to prevent noise-induced hearing loss in employees	Team members determine goals to prevent noise-induced hearing loss in employees by eliminating noise areas through noise engineering control.
Step 7.	Develop action strategies and review the progress of the actions taken	Team members develop action strategies by first taking internal actions and then cooperating with outside noise professionals. They identify all of the noise sources and take all of the actions technically and economically feasible to meet noise goals. At the meetings, the team members review the progress of the actions taken. A team member presents the changes in noise levels resulting from the actions that were taken, and listens to advice from other team members.

of a HCP is not for noise engineering control, but to identify noise areas. All employees working in a noise area were enrolled in the HCP. Noise engineering control surveys should be conducted separately from annual noise monitoring. A noise area was defined as an area with an 8-hour TWA ≥85 dBA measured using a dosimeter (Quest 400, Quest Technologies, USA) and calibrated with a calibrator (QC-10, Quest Technologies, USA). The instruments were set to frequency weighting A with an 80 dB threshold, 5 dB exchange rate, slow meter response, and 90 dB criterion level, as specified by OSHA (OSHA, 1983).

4. Noise Engineering Control

One of the most challenging aspects of noise control is to identify actual noise sources. Initially, the team members identified (1) all of the equipment and processes that made noise in noise areas and (2) component parts of individual pieces of equipment. Using the noise measurements, machines producing noise ≥ 82 dBA in workers' hearing zones and "component noise parts" ≥ 85 dBA 20 cm from the noise point of the machines were listed for possible action. The survey information collected included the measurement date, location, surveyor, time (shift), department name, process name, equipment name, battery check, calibration, noise level at workers'positions, background noise level, overall noise levels (A-weighted sound pressure level, dBA; and C-weighted sound pressure level, dBC), one-third octave band sound pressure levels (dBC by wavelength) for noisy parts of the equipment, and a sketch of the equipment indicating the noise measurement points. The point of noise measurement used for engineering control was approximately 20 cm from the noise source. When possible, the measurements were madewith all other equipment that was part of the same process turned off. The measuring time was 10 seconds because the duty cycle of most machines was 10 seconds or less. A Rion NL 21 (Rion Corporation, Japan) integrating sound pressure level meter was used to obtain noise equivalent levels for 10 seconds. Data for the 1/3 octave band analysis were measured by a Rion NX-01A device (Rion Corporation, Japan). The instruments were calibrated before each survey according to the manufacturer's specifications.

When evaluating workers' noise exposure at the company, the most dominant noise sources could not be determined easily because workers moved around in their working zones during working hours. The strategy of the ALT was to take as many noise-control actions as possible among the listed noise sources in noise areas rather than search for the most dominant sources. The listed noise sources and available noise-control actions were matched considering the applicable noise-control method with the type of noise source.Priority was based on the noise level of noise sources, technical and economic feasibility, and effect of controls on product flow.

Ⅲ. Results

Table 2 shows the trend in the number of hearing consevation areas (85 dBA and greater, 8-hr TWA) and the number of employees enrolled in the HCP. There were 6~10 noise areas and 329~396 workers who worked at the noise areas during 1993~1997. The number of noise areas was reduced from ten to three (70%) after the ALThad completed its task, and the number of employees enrolled in the HCP was reduced from 396 to 130 (67.2%) (**Table 2**).

The Action Learning Team identified 255 component noise parts that measured more than 85 dBA 20cm from the noise source and 81 pieces of noise equipment that measured above 82 dBA in the workers'hearing zones. The main noise sources were compressed air, vibration, impact, and friction. The first step in controlling compressed air noise was to reduce the air velocity to as low a value as practical. High-velocity air flow was one of the major noise sources controlled by many internal actions. Table 3 shows the noise control methods and reduction of the noise level at the sources. One of the major noises associated with solder stemmed from the separators. This was intermittent noise. The product separating mechanism was set to a lower velocity and kept at the same capacity by reinforcement of the shaft. This led to a 7dB reduction, from 88 dB SPL to 81 dB (**Table 3**).

Table 2. The number of hearing consevation areas and employees enrolled in the Hearing Conservation Program

Year	No. of above 85dB area	No. of employees at noise areas
1993	7	329
1994	6	361
1995	8	365
1996	10	389
1997	10	396
1998	3	130
1999	0	15
2000	0	15
2001	0	15
2002	0	15

The average noise level was significantly reduced from 86.9 (SD = 2.3) dBA TWA to 79.8 (SD = 2.2) dBA TWA by the ALT ($p < 0.05$). The Small Signal Plastic department was consisted of two production lines and included 45 pieces of noise equipment. The noise levels were reduced 2 and 8 dBA TWA. The Zener Glass department was consisted of three production lines and included 18 pieces of noise equipment. The noise levels were reduced 6~8 dBA TWA. The Optoelectronics department had two pieces of noise equipment and the noise level was reduced 4 dBA TWA. The Metal Finishing department had one piece of noise equipment and the noise level was reduced 5 dBA TWA. The Sensor Pressure department had 9 pieces of noise equipment and the noise level was reduced 7 dBA TWA. The Crushing Room departmenthad one piece of noise equipment and the noise level was reduced 16 dBA TWA. The Machine Shop department had 5 pieces of noise equipment the noise level was reduced 8 dBA TWA (**Table 4**).

1. Cost-benefit analysis for noise control

The totalcost of the seven noise area reductions was \$6,766. In detail, vibration damping material cost was \$250, rubber pad for vibration isolation cost was \$545, sound absorbers cost was \$247, exchange of less noise parts cost was \$1,250, plate for transmission loss cost was \$135, fee for noise control consulting cost was \$3,300, and air gun silence cost was \$1,040. The only benefit of audiometric testing from noise reduction was \$6,650 for the first year. Audiometric testing cost was \$25 for a person and the audiometric testing subjects was reduced from 396 to 130 workers so the benefit was \$6,650 for 266 workers excluded for audiometric testing (**Table 5**).

Table 3. Noise control methods and reduction of the noise level at the source

Machine	Component Part	Noise Source	Acoustic Control Elements	Major Frequency (Hz)	Noise reduction (dBA)
In-Line Solder	2-Pole Motor	Magnetic, Bearing	Exchange of Bearing	4000	6.0 (88.0→82.0)
	Brush	Friction Noise	Cutting the Contacted Points	4000	3.9 (84.9→81.0)
	Guide Hopper	Structural Vibration	Maintenance, Damping	63	2.1 (85.0→82.9)
	Pusher Side	Mechanical, Open Area	Maintenance, Absorption	1000	1.9 (83.0→81.1)
	Dust Suction Fan	Air Moving	Transmission, Absorption	63	5.9 (86.0→80.1)
Tape and Reel	Bowl Feeder	Structural Vibration	Exchange bowl, Damping, Isolation	125	12.0 (92.0→80.0)
	Tape/Reel	Mechanical, Reverberation	Maintenance, Absorption, Damping	1000	12.0 (86.0→74.0)
Handler	Head	Pusher Hitting, Pulse Air	Absorption, Enclosure	8000	4.7 (88.5→83.8)
	Exhaust Air for Vacuum	Exh. Air for Vacuum	Change to Suction	4000	18.0 (100.0→82.0)
Laser Mark	Marker(Box)	Reverberation, Leak Part	Absorption, Enclosure	4000	8.2 (90.0→81.8)
	Laser Beam Pipe	Leak Part	Transmission	8000	9.3 (93.0→83.7)
Pre Heater	Fan Motor Housing	Motor, Structural Vibration	Absorption, Damping	4000	7.1 (86.9→79.8)
	Fan Exh.Area	High Speed Air Moving	Transmission, Absorption, Silencer	125	6.5 (83.5→77.0)
Air Gun	Air Blast Nozzle	Air Moving(Blow Off) Turbulent	Silencer	4000	11.0 (94.0→83.0)
Marking	Air Nozzle	Air Blast	Silencer	4000	12.0 (96.0→84.0)
	Body Coating	Air Blast, Roller Operation	Absorption, Damping	1000	10.0 (96.0→86.0)
Solder	Separator	Impact, Bearing	Change to 2 shaft	4000	7.0 (88.0→81.0)
Assembly	Bowl Feeder	Structural Vibration	Absorption, Damping	-	6.0 (86.0→80.0)
	Feeding Impact	Impact (hitting)	Isolation	-	5.3 (91.0→85.7)
	Exhaust Fan	Motor, Air Moving	Change to other Fan	-	26.4 (108.0→81.6)
Pneumatic Feeder	Enclosure	Reverberation, Open Part	Absorption, Enclosure	4000	12.0 (97.0→85.0)

Table 4. Noise source characteristics and noise levels reduction in noise areas

Department	Noise equipments	Noise Levels (dBA)		
		Before ALT	After ALT	Noise reduction
Small Signal Plastic				
In-line Solder	31	87	79	8
Marking	14	86	84	2
Zener Glass				
Assembly	4	87	80	7
Marking	7	86	78	8
Solder	7	87	81	6
Optoelectronics	2	86	82	4
Metal Finishing	1	85	80	5
Sensor Pressure	9	87	80	7
Crushing Room	1	93	77	16
Machine Shop	5	85	77	8
Average (SD)	-	86.9 (2.3)*	79.8 (2.2)*	7.1 (3.7)

* $p < 0.05$

Table 5. Cost-benefit analysis for noise control during the first year.

Category	Contents	Amount ($)
Cost	Vibration Damping Material	250
	Rubber Pad for Vibration Isolation	545
	Sound Absorbers	247
	Exchange of Less Noise Parts	1,250
	Plate for Transmission Loss	135
	Fee for Noise Control Consulting	3,300
	Air Gun Silencer	1,040
	Subtotal	6,767
Benefit	Saving audiometric testing cost	6,650
Cost-benefit		-117

Ⅳ. Discussion

The purpose of action learning is to enable participants to take responsibility for their learning and actions and to develop autonomy. Inevitably, in the early stages of action learning, the facilitator plays a significant role in guiding and directing how the team works (McGill & Beaty, 2001), which was the case with the ALT. The production managers, such as middle managers and chief technicians, are aware of the responsibility and feasibility of noise control, and they can control noise as part of their jobs after being a part of the ALT. The learning experience must be transformed such that the experience is embedded and, to some extent, changes the individual's thought processes (Elgstrand & Petersson, 2009). When production people become aware of the responsibility and feasibility of noise control, they can transform their learning experiences by testing or implementing ideas.

The main noise sources were compressed air, vibration, impact, and friction. The first step in controlling compressed air noise was to reduce the air velocity to as low a value as practical. This resulted in noise reductions of 5~20 dB. High-velocity air flow was one of the major noise sources controlled by many internal actions. Fiberglass blanket material, acoustical baffles, mufflers, and simple system modifications were utilized to good effect in combating problems of high noise levels. Ford and Lee also reported on noise-control methods(Ford, 1967; Lee & Smith, 1971).

The cost of the seven noise area reductions ($6,767) during the ALT period was almost entirely compensated during the first year after team activities due to only the cost reduction in audiometric testing ($6,650). The recuperation of total noise-control costs took about 1 year when using only the cost of audiometric tests among HCP participants, but this does not include other savings from the reduced NIHL compensation claims. Noise-control implementation can easily save companies money.

When noise-control modifications to equipment reduce the employee's TWA below 85 dBA and that level is maintained, the potential for significant on-the-job noise induced hearing loss is eliminated, and the other phases of the HCP become unnecessary (Berger et al., 2003). Roth suggested eight additional reasons to have a low-noise workplace (NIOSH, 1999).The literature indicates that the cost of noise control needed to achieve a TWA of 90 or 85 dBA is strongly dependent on the type of industry (Gibson & Norton, 1981, Alice et al., 2012). If reducing the noise of production equipment is expected to increase productivity, then management may implement the noise-control program. If, however, the noise-control solution decreases productivity, then management may decide the cost outweighs the benefits (Berger et al., 2003). However, many industries may have only consulted outside noise-control professionals without incorporating their own workforce into the procedures. If production personnel are actively included in noise-control activities, as they were in this study, they can implement solutions that do not impede production flow.

Ⅴ. Conclusion

In conclusion, noise control can be practical and economically feasible when maintenance staff and middle manufacturing managers are trained as key members of an Action Learning Team to implement noise control.

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