

# **An Ergonomics Study of a Semiconductors Factory in an IDC for Improvement in Occupational Health and Safety**

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*The study aimed to conduct an ergonomic intervention on a conventional line (CL) in a semiconductor factory in Malaysia, an industrially developing country (IDC), to improve workers' occupational health and safety (OHS). Low-cost and simple (LCS) ergonomics methods were used (suitable for IDCs), e.g., subjective assessment, direct observation, use of archival data and assessment of noise. It was found that workers were facing noise irritation, neck and back pains and headache in the various processes in the CL. LCS ergonomic interventions to rectify the problems included installing noise insulating covers, providing earplugs, installing elevated platforms, slanting visual display terminals and installing extra exhaust fans. The interventions cost less than 3000 USD but they significantly improved workers' OHS, which directly correlated with an improvement in working conditions and job satisfaction. The findings are useful in solving OHS problems in electronics industries in IDCs as they share similar manufacturing processes, problems and limitations.*

ergonomics methods    ergonomic interventions    occupational health and safety (OHS)  
semiconductor industry    industrially developing countries (IDCs)

## **1. INTRODUCTION**

Ergonomics can contribute immensely to occupational health and safety (OHS) improvements in factories. This is because OHS problems such as back and neck pains, eyestrain and headaches are often associated with poor ergonomics in manufacturing processes such as highly repetitive movement and poor workstation design [1, 2, 3, 4, 5, 6, 7]. In addition, noise irritation caused by noisy machines can influence workers' behaviour and consequently their exposure would lead to some occupational risks [8, 9]. Therefore, ergonomics and its benefits should be introduced

to factories particularly in industrially developing countries (IDCs). In addition, many studies show that OHS can be improved using low-cost and simple (LCS) ergonomics methods and solutions [2, 3, 10, 11]. These LCS methods and solutions are particularly useful for IDCs, which have limited funds, expertise and resources [12].

Ergonomics is new in IDCs [12], particularly in the electronics industry. Several ergonomics studies have been conducted in electronic motherboard factories in an IDC to improve OHS [1, 2, 3, 10, 11]. Several ergonomics studies have also been conducted in semiconductor factories in developed countries, e.g., Pocekay,

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McCurdy, Samuels, et al. conducted a study in a semiconductor factory in the USA and found inadequate equipment design and repetitive wafer-handling activities to be risk factors associated with musculoskeletal disorders for semiconductor industry workers [13]. However, no ergonomics study has been conducted in a semiconductor factory in an IDC. Pocekay et al.'s research indicated that the same musculoskeletal disorders could occur in semiconductor factories located in IDCs but no ergonomic interventions/solutions were given on how to address OHS problems.

Therefore, this research attempts to fill this gap, i.e., to conduct an ergonomics study on a semiconductor factory with the intention of discovering the OHS problems and find LCS ergonomics solutions. The OHS problems addressed include task risks and danger, and body stress. The study was done on a conventional line (CL) in a semiconductor factory, i.e., one of the most common lines used in most semiconductor factories in Malaysia. The integrated circuits produced on the line were used as voltage regulators, switching devices, current and temperature protection control. Most products were assembled in automotive and industrial modules, e.g., power windows, car automated breaking systems, fuel injection control and power supplies for computer motherboards.

2. MANUFACTURING PROCESSES

Manufacturing processes can be categorized as front-of-line (FOL), end-of-line (EOL), testing

and marking (TEST MARK) and, finally, quality check and packing processes (Figure 1).

2.1. Front-of-Line (FOL)

FOL processes include die-bonding and wire-bonding; both processes take place in a clean room environment, i.e., in a closed room with windows on all sides with the number of particles not exceeding 10000 units/m<sup>3</sup>. Workers must wear a full-face covered uniform to avoid product contamination with vapour and dust. The following two are FOL processes:

- die bonding and die attachment are assembly processes in which after a wafer has been blade-sawed into individual dies, the die is mounted and fixed to the package or support structure like a lead frame;
- wire bonding is a method of making interconnections between a microchip (die) and other electronics as part (in this case, the lead frame) of semiconductor devices assembly. The wires are generally made of gold, aluminium or copper. Ultrathin wires (~15 µm in diameter, one third the diameter of human hair) connect the bonding pad of each device to the lead frame. Figure 1 shows the aluminium wires bonding head, where the wire-bonding speeds may be up to 10000 wires/h.

2.2. End-of-Line (EOL)

The processes in EOL include moulding, electroplating and trim-form. These processes are not conducted in a clean-room environment. There are many types of heavy machinery in the EOL

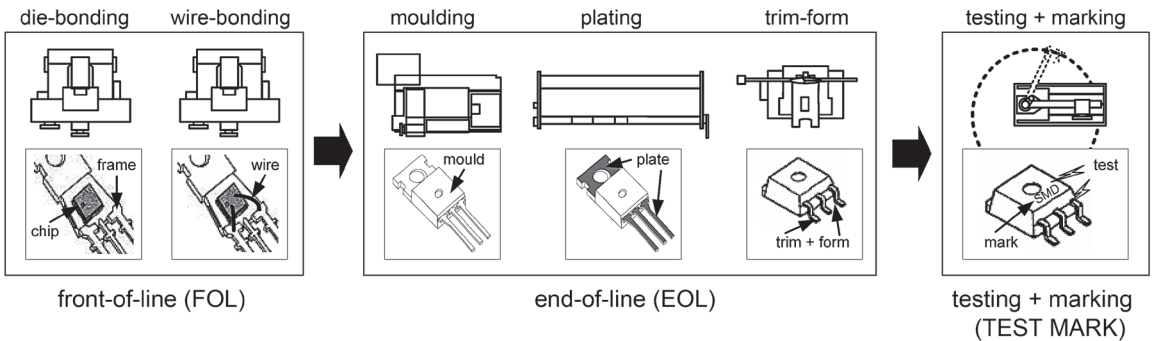


Figure 1. Overview of semiconductors manufacturing processes.

module, e.g., injection moulding machines, cutting and forming tools and electroplating machines. The following three are EOL processes:

- moulding is the process of sealing a microchip die with a ceramic or plastic enclosure (tablet) to prevent physical damage or corrosion. This is done after wire-bonding has been completed. Operators load and unload magazines (metal boxes containing up to 40 lead frames) to the moulding machine. Mould compound tablets (1.5 cm in diameter) are auto-loaded into the machines where the lead frames will be covered by the tablets after moulding. The process takes ~3 min to complete;
- electroplating (or plating) is the general name used in semiconductor manufacturing for a surface-covering technique. It is a process by which metals in ionic form are supplied with electrons to form a non-ionic coating (plate) on a desired substrate. A plate is indispensable because it is a corrosion inhibitor for semiconductor components. Electroplating machines integrate many chemical baths and a conveyer belt carries the components across the chemical baths. The operators' task is to monitor the electroplating machines throughout the process;

- trim-form consists in a moulded strip of components being loaded into a machine that cuts it into individual units called integrated chips (IC). After trimming, the same machine will perform "leg forming" where IC legs are bent, cut and formed into a desired shape.

### 2.3. Testing and Marking (TEST MARK) Processes

In the testing (TEST) process, ICs are 100% tested with a machine. The test includes placing the IC in cold ( $-40^{\circ}\text{C}$ ) or hot temperature ( $+150^{\circ}\text{C}$ ), and inducing electrical stress (up to 1 000 V) to test IC robustness and its functions. Figure 2 shows a fully automated IC testing and marking machine.

The marking (MARK) process is incorporated in a testing machine where good ICs will be marked with product information (product codes, date, logo, etc.) immediately after testing.

### 2.4. CL

The CL is a traditional production line. Its main characteristics are stand-alone machines, where individual machines are separated by one-meter walkways. Each machine has its own

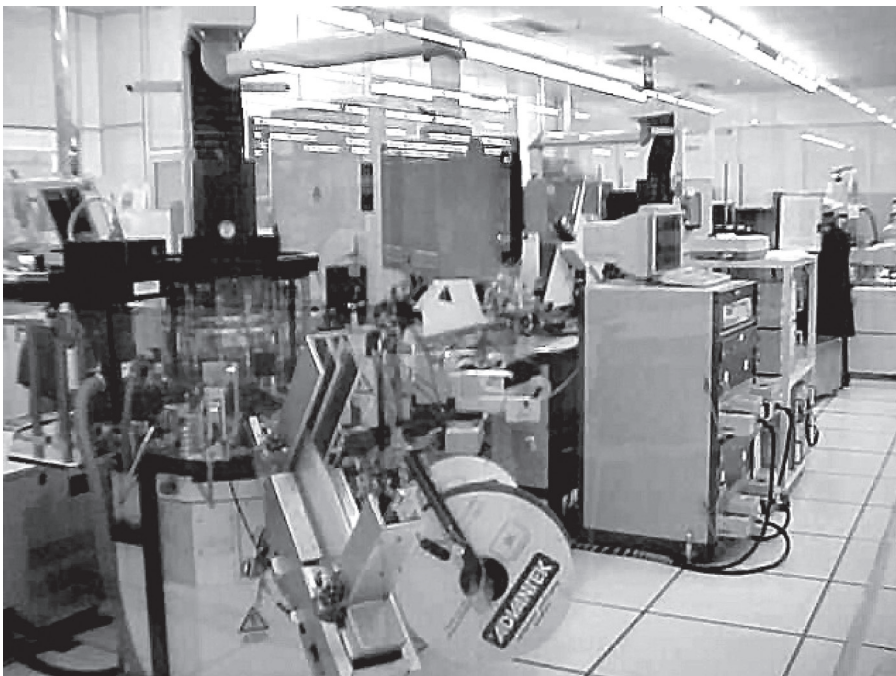


Figure 2. Testing+Marking (TEST + MARK) processes.

infrastructure facility attached, i.e., electrical power, exhaust, water coolant, etc. All workers are functional specialists, each handling only one or two machines with the same process routine. All the machines/tools/workstations are arranged in a conventional layout where they are grouped by process, starting with die-bonding, followed by wire-bonding, moulding, electroplating, trim-form, testing, marking and ending with a quality check and packing.

3. METHOD

Four ergonomics methods were used to investigate ergonomics problems in the lines: subjective assessment [14] through survey questionnaire, direct observation [15] of the production lines, the use of archival production data [16] and assessment of auditory environment and noise [17]. Ergonomic interventions were made to rectify the problems found and data were collected again to determine the effectiveness of the interventions.

3.1. Questionnaire

A validated questionnaire was designed on the basis of Sinclair’s [14] and Sekaran’s [18] guidelines. It adopted questions from Cooper [19], Cooper, Cooper and Eaken [20] and Amat, Fontaine and Chong [21]. This set of questions was also sent for expert opinions of the heads of engineering and production departments. The respondents were asked to indicate their agreement or disagreement on 16 items using a 5-point Likert scale, ranging from 1 (*strongly disagree*) to 5 (*strongly agree*). Seven items were related to working conditions, three to risk and danger posed by the tasks and danger, and six to physical body stress. The questionnaire also requested information on the employees’ demographic data, including age, gender and years of service in present position. Work-shift (morning, afternoon or night) and processes (wire-bonding, die-bonding, moulding, plating, trim-form or testing) information was also included in the survey questionnaire.

3.2. Subject Selection

The factory operated three shifts a day (morning, afternoon and night). The shifts rotated weekly. No workers were physically handicapped or unfit for work at the time of the survey. They were called to a conference room and briefed before they filled in the questionnaire. They were fully informed of the procedures and assured of the confidentiality of their response. To avoid possible bias, supervisors and managers were excluded from the room. About 30% of the workers were randomly sampled from FOL, EOL and TEST processes (Table 1).

TABLE 1. Distribution of Subjects

Statistics for	FOL	EOL	Test	Total
Total workers	32	32	68	132
Sample	10	10	20	40
Sample (%)	31	31	29	30

Notes. FOL—front-of-line, EOL—end-of-line.

3.3. Direct Observation and Archival Data

Direct observation [15] took place on the production line to ascertain the problems highlighted in the questionnaire, to look for insight on appropriate ergonomic interventions and to validate the effectiveness of those interventions. In addition, archival production data [16] were taken, e.g., the process speeds were obtained from the industrial engineering department where they were monitored and recorded with a stopwatch.

3.4. Assessment of Auditory Environment and Noise

Assessment of auditory environment and noise [17] was conducted on the CL to determine the extent of noise in production. Sound level was measured to determine whether the level exceeded the 90-dB limit set by Malaysian law [22].

## 4. RESULTS

### 4.1. Demographics of the Subjects

Table 2 shows frequency distributions of the demographic details.

**TABLE 2. Demographic Details of Subjects**

Statistics for	Frequency (%)	Cumulative %
Gender		
male	26 (65)	65.0
female	14 (35)	100
total	40 (100)	
Age (years)		
<25	7 (17.5)	17.5
25–32	12 (30.0)	47.5
33–40	13 (32.5)	80.0
>40	8 (20.0)	100
total	40 (100)	
Processes		
die-bonding	5 (12.5)	12.5
wire-bonding	5 (12.5)	25.0
moulding	2 (5.0)	30.0
(electro)plating	3 (7.5)	37.5
trim-form	5 (12.5)	50.0
testing	20 (50.0)	100
total	40 (100)	

### 4.2. Variables Correlation Analysis

Table 3 shows the Pearson correlation matrix obtained for the five interval-scaled variables.

**TABLE 3. Pearson Correlation Analysis (*N* = 40)**

		Working Conditions Rating	Risk and Danger Rating	Body Stress Rating	Job Satisfaction Rating
Working Conditions Rating	Pearson correlation	1	–.369**	–.369**	.398**
	significance (1-tailed)		.010	.010	.005
Risk and Danger Rating	Pearson correlation	–.369**	1	.517**	–.888**
	significance (1-tailed)	.010		0	0
Body Stress Rating	Pearson correlation	–.369**	.517**	1	–.363*
	significance (1-tailed)	.010	0		.011
Job Satisfaction Rating	Pearson correlation	.398**	–.888**	–.363*	1
	significance (1-tailed)	.005	0	.011	

Notes. \*— significant at .05 (1-tailed), \*\*— significant at .01 (1-tailed).

As expected, the working conditions (WC) factor was negatively correlated with the risk and danger (RD) and body stress (BS) factors; thus, WC would deteriorate with an increase in RD and BS. In addition, RD and BS were negatively correlated with job satisfaction (JS) and WC was positively correlated with JS. These show that the JS rating would increase with the betterment of WC and decrease with the prevalence of OHS problems such as RD and BS.

### 4.3. Ergonomics Problems in the CL

Table 4 shows the relative ergonomics problems of shopfloor workers in the CL. The table indicates primary problems through highlighting the low mean ratings (MRs) of the CL processes. MR is the average rating from all the subjects from respective processes. The factors (WC, RD, BC) are ranked on the basis of the MR where the lower the MR, the higher the workers' dissatisfaction.

#### 4.3.1. Noise irritation

Malaysian law specifies that no employee shall be exposed to noise level equivalent to or exceeding continuous sound level of 90 dB [22]. The measurements of noise disturbance in trim form (115 dB) and testing processes (110 dB) in the CL were much higher than 90 dB. The



TABLE 4. Main Ergonomics Problems

Statement	Die Bonding	Wire Bonding	Moulding	Plating	Trim Form	Testing	MS	SD
Working conditions								
I regard the working conditions as too hot	4.8	3.8	3.0	4.0	4.2	4.0	4.05	1.06
The line has good lighting	3.2	3.6	4.0	3.3	3.4	3.9	3.65	0.89
The working condition is noisy	3.0	2.2	3.0	2.0	1.6	1.9	2.08	0.97
The workplace is tidy	3.0	2.8	3.5	2.7	3.4	3.3	3.18	0.75
The machinery is well-arranged	3.0	3.2	3.5	4.0	3.4	3.3	3.33	1.02
Working areas are spacious	1.8	3.4	4.5	3.0	2.8	2.7	2.80	1.18
Ventilation is good	3.0	3.6	3.5	3.0	3.6	3.4	3.36	0.99
Risk and danger								
My job is risky	4.0	3.8	3.0	2.7	2.6	3.5	3.40	1.03
My job will not affect my health	3.0	3.0	3.0	3.0	3.4	3.2	3.13	0.83
PPE provided is adequate	2.5	3.4	3.5	3.7	3.2	3.2	3.21	1.10
Body strain								
I occasionally suffer from eyestrain	2.4	2.4	3.0	2.7	3.0	3.2	2.83	0.97
I occasionally suffer from headaches	2.2	3.0	3.0	1.7	3.0	3.0	2.71	1.05
I occasionally suffer from tension and pressure on neck and back	1.6	1.8	4.0	2.3	3.0	2.5	2.32	0.90
I occasionally suffer from sensory irritation	2.8	2.6	3.0	2.7	3.0	3.0	2.85	0.86
I occasionally suffer from strain on my wrist	2.6	3.0	2.5	2.0	4.0	3.3	2.93	1.02
PPE provided is comfortable	2.3	3.4	3.5	3.7	4.0	3.0	3.10	1.23
average							3.05	0.00

Notes. Shaded mean ratings represent major ergonomics problems in the conventional line as they have very low mean ratings. All ratings are based on a 5-point Likert scale: 1—*strongly disagree*, 2—*disagree*, 3—*neither disagree nor agree*, 4—*agree*, 5—*strongly agree*; MS—mean scores; PPE—personal protective equipment.

operators were exposed to noise for the whole 8-h shift. Direct observation showed noise was caused by

- cutting and forming machines (in the trim-form process) continuously running at 7200 units/h, generating considerable irritating noise;
- the air nozzles used to blow and clean ICs in both trim-form and testing processes. The nozzles are attached to machines directly opposite the workers;

- metal tubes (used to collect ICs in the testing area) knocking against each other during the auto-load tube changing process.

4.3.2. Neck and back pains

Subjective assessment showed that workers were suffering from neck and back pains. Further analysis showed most complaints came from the processes in FOL where MR < 2.0 (die bonding MR = 1.6, wire bonding MR = 1.8).

Direct observation showed the causes of neck and back pains.



**Figure 3. Monitoring bonding machines through viewing video display terminals and microscopes.**

- Die-bonding and wire-bonding VDTs were located  $25 \pm 10$  cm above the workers' eye level. The strips of lead frames (up to 40 frames/batch) required continuous monitoring by checking both the VDTs and microscopes to ensure the wires were precisely placed, bonded and moved (Figure 3).
- Workers checked and verified from the VDTs and microscopes, and recorded information on a lot traveler (a document attached to the production batch, used to record the process parameter, time, yield and events during the process).
- Workers were required to raise their arms to perform bonding at workstations ~20 cm higher than the elbow level.

These activities were performed throughout 8-h shifts, i.e., arms were raised and the neck was in a cramped posture for extended periods. In this way workload accumulated. Looking up at the VDTs and down when using the microscopes and recording the traveler many times in a shift, caused repetitive strain injuries. According to Kroemer and Grandjean, the working height is critically important in the design of workstations; if work is raised too high, the shoulders must

frequently be lifted to compensate, which may lead to cramps in the neck and shoulders [24].

#### **4.3.3. Headaches**

The survey (Table 4) showed workers were suffering from headaches, especially in the plating process (score = 1.7). Plating is a centralized process located in a separate building where all the production batches are sent. The process is carried out in a closed room with more than 15 types of chemicals. The area is congested with pipes and container baths. The chemicals are hazardous (e.g., toluene, cadmium, arsenic, benzene and trichloroethylene).

Poor air circulation in the plating room caused headaches. Although the workers' perception of air circulation was reasonable, the air change per hour (ACPH) was not sufficient. By requirement, the ACPH for an electroplating shop is 10–12 times (equivalent to 11250–13500 m<sup>3</sup>/h) [23]. The electroplating room was 1125 m<sup>3</sup> and it had four exhaust fans, each with an air flow capacity of 2500 m<sup>3</sup>/h (total = 10000 m<sup>3</sup>/h), thus equivalent to ACPH 8.9 times. This analysis showed that actual air circulation was not sufficient in the plating room to clear the heavy chemical stench.

TABLE 5. Ergonomic Interventions to Address the Main Problems: With Mean Rating (MR) < 2.0

Process	OHS Problem/s	MR	Root Cause/s	Actual Intervention/s
Die-bonding	neck & back pains	1.6	VDT is 25 ± 10 cm above the operators	install 25-cm high platforms
Wire-bonding	neck & back pains	1.8	workers frequently bending their neck up to view VDTs and down when recording on lot travelers/using microscopes; thus causing RSI	slant VDTs by 10° to face the operators (these interventions reduced bending of neck)
Plating	headaches	1.7	chemical stench (from chemical baths) due to poor air circulation (ACPH = 8.9 times)	install two extra exhaust fans (total ACPH = 13.8 times). this has improved air circulation and reduced the chemical stench
Trim-form	noise	1.6	noise from trim-form machines (115 dB) noise from air nozzles used for cleaning ICs	cover trim-form machines with noise insulating covers provide earplugs for workers install earplugs storage box at the entrance for easy access
Testing	noise	1.9	noise from knocking of metal tubes during auto-load process (110 dB) noise from air nozzles used for cleaning ICs	provide earplugs for workers install earplugs storage box at the entrance for easy access

Notes. OHS—occupational health and safety, VDT—video display terminal; RSI—repetitive strain injury; ACPH—air change per hour; IC—integrated chip.

4.4. Ergonomic Interventions

4.4.1. Noise irritation

The interventions were as follows:

- clear high density plastic was used to cover the cutting tools to minimize the noise from the trim-form process;
- earplugs (of noise-reduction ratings of 30 dB) were provided for the workers in trim-form and testing processes. They reduced the noise from 115 to 85 dB. All workers had a one-point lesson (i.e., a 5-min lesson using single-page pictorial instructions) on the correct way of wearing earplugs;
- a special storage box with spare earplugs was installed at the entrance of the processes so that the workers could have easy access to the earplugs.

4.4.2. Neck and back pains

Interventions consisted in

- installing a raised platform (25 cm in height) for persons of short stature to minimize the back and neck strain. Thus the VDTs and the workers' eyes were at the same level;

- raising the platform because the most favorable working height of handwork while standing is 5–10 cm below elbow level [25]. By raising the platform, the elbow level was above the working bench, which relieved the discomfort cramps in the shoulders and the neck;
- adjusting bonding machines' VDT screens by a 10° downward slant to face the workers, making their eyes level with the top of the screen as the eye movement should be no more than 5° above the horizontal plane, and the head and neck should not be bent forward by more than 30° when the trunk is erect [24]. Otherwise fatigue and cramps in the neck and back are likely to occur. This also applies to the preferred viewing angles of VDT operators watching their computer screens.

4.4.3. Headaches

The findings showed that poor air circulation in the plating room was the major cause of headaches. To improve air circulation, the ACPH had to be increased from 8.9 to a minimum of 10 times. To achieve this, two additional exhaust fans of 2772 m<sup>3</sup>/h were installed to increase the ACPH from 8.9 to 13.8 times (15544 m<sup>3</sup>/h). This



reduced the chemical stench, thus improving the workers' health.

## 5. DISCUSSION

### 5.1. LCS Ergonomics Methods

The study showed that LCS ergonomics methods such as subjective assessment [14], direct observation [15], the use of archival production data [16] and the assessment of auditory environment and noise [17] are very useful in identifying ergonomics problems in an electronic factory. In fact, there were many other electronic factory studies that used these methods successfully, such as Sen and Yeow's [10, 11] ergonomics study on manual component insertion (MCI) lines and an ergonomics redesign of an electronic motherboard in electronic factories, and Yeow and Sen's [1, 2, 3] on the test work station, visual inspection and MCI lines in electronic factories. Those studies were conducted in Malaysia, an IDC, like the present study. However, the present study focused on the component manufacturing industry (upstream of the supply chain in the electronic industry) while the former ones focused on the printed circuit board assembly industry (downstream of the supply chain). The aims were very similar, i.e., identifying OHS problems in the shopfloor and finding the root causes of the problems. All those studies validate the effectiveness of LCS ergonomics methods to be used in the electronic industry in IDC, regardless of whether it is up- or downstream manufacturing.

### 5.2. LCS Ergonomic interventions in Manufacturing Lines

Some ergonomics studies showed that LCS ergonomic interventions could be effective in preventing problems, e.g., Farhang and Michael [26] reported that a proper application of LCS personal protective equipment (PPE) could prevent up to 37.6% of occupational injuries and illnesses; Sen and Yeow [10, 11] and Yeow and Sen [1, 2, 3] presented examples of LCS ergonomic interventions in manufacturing lines that succeeded in preventing OHS problems

(e.g., workstation redesign, LCS process change and product redesign). Like in the present study, the LCS ergonomic interventions used included introducing PPE such as earplugs, minimizing the lead-frames cutting noise by covering the trim-form machines with high density plastic covers, raising floor level with metal platforms for die-bonding and wire-bonding, etc. These interventions succeeded in improving workers' OHS through reducing noise, neck and back pains and headaches, and improving the work environment because of better ventilation and lesser noise. The cost of the interventions was low, i.e., the cost of installing two exhaust fans, providing earplugs to workers in trim-form and testing processes, and installing platforms at die-bonding and wire-bonding processes. All these cost less than 3000 USD and thus did not require high capital investment; however, they had a great impact on the workers' OHS. Indeed, these simple ergonomics solutions made ergonomics more acceptable in factories in IDCs like Malaysia, where resources are limited and managers are not aware of the benefits of ergonomics. These solutions can be used to help managers to accept the concept of ergonomics, particularly the idea that ergonomics need not be expensive but can produce good results.

Even though most ergonomic interventions were LCS, there were other ones that required higher costs. The factory management is currently weighing the cost and benefits of changing the metal tubes material to a less noisy material like that of composite metal tubes. In addition, a long-term intervention decision is to outsource the plating process to a local company that has the expertise and resources to manage waste and maintain product quality. That would eliminate the stench and solve the problem of no floor space highlighted in section 4.3. Although these interventions are costly, they will benefit the workers' OHS, reduce environmental pollution, minimize maintenance cost, and boost the employees' morale. Nevertheless, the LCS ergonomic interventions had successfully contained most of the OHS problems in the factory.

### 5.3. OHS improvements in Electronics Industry

Most processes in CL shown in section 2.1 are common in semiconductor factories. This has identified major OHS problems in a factory, such as noise irritation, neck and back pains, and headaches. Chee, Rampal and Chandrasakaran did a similar study of semiconductor factories in peninsular Malaysia [27]. They identified some ergonomic risk factors in work processes and concluded that FOL, EOL and TEST process workers suffered from pain in different parts of their bodies. Karlqvist also experimented at four different VDT workstations with 39 subjects and found musculoskeletal problems; the study suggested the use of armrest as a solution [28]. The present study found that it was very important to place VDTs at the correct height to reduce the need to bend the neck, particularly for operators performing routine task for a long time (e.g., throughout an 8-h shift). Yeow and Sen redesigned an electrical test workstation of a printed circuit assembly factory [1]. In the redesign, the VDT was put on a lower platform to reduce the need for operators to bend their necks while looking at it. All those studies indicate that the findings of the present research may be generalized to other factories in the electronics industry as the processes involved are similar.

### 5.4. Correlations with Working Conditions and Job Satisfaction

The correlation between working conditions and job satisfaction was tested empirically (section 4.2). This research offers some LCS solutions to reduce risk and danger (such as improving air circulation in the chemical-filled plating room and reducing the level of noise in trim-form and testing processes) and body stress (such as back and neck pains due to viewing VDTs which are located too high). Job satisfaction in any factory brings many benefits, including higher work morale, reduced turnover, higher commitment, increased productivity, etc. This shows the value of improvements in OHS, as they benefit both workers and employers.

### 5.5. Limitations of the Study

There are not many workers in semiconductor manufacturing lines. Since those lines depend on machine precision, not much manual labor is required, e.g., some processes have only 4 workers (e.g., the moulding process). Gathering data from all workers was not possible without stopping the processes (which was impossible as the factory would lose revenue). Therefore, only a small sample size of 40 out of 132 workers was collected. However, this is still substantial because this was about one third of the population and more than the minimum of 30 required for statistical analysis. Nevertheless, the sample was not big enough for a more detailed study of the effects of gender, age and working processes.

Another limitation is that the operators in this study were homogeneous in height, therefore, the installation of the fixed 25 cm-high platforms was acceptable. However, if the study is replicated in a factory with operators with very different heights, they may require adjustable platforms.

## 6. CONCLUSIONS

The present study was conducted in a semiconductor factory in an IDC with the intention of finding suitable methods of improving workers' OHS. LCS (and effective) ergonomics methods were used, i.e., subjective assessment, direct observation, archival production data, and assessment of auditory environment and noise. In addition, LCS ergonomic interventions were made to rectify the problems, resulting in OHS improvement.

It was found that the workers experienced noise irritation, neck and back pains, and headache in the various processes in the CL. LCS ergonomic interventions to rectify the problems included installing noise insulating covers, providing earplug, installing elevated platform, slanting VDT, and installing extra exhaust fans. The results can be used in other semiconductor/electronics factories particularly in IDCs as they share similar manufacturing processes. The

research also empirically proved that improved OHS led to better working conditions and increased job satisfaction.

## REFERENCES

1. Yeow PHP, Sen RN. Quality, productivity, occupational health and safety and cost effectiveness of ergonomic improvements in the test workstations of an electronic factory. *Int J Ind Ergon.* 2003;32:147–63.
2. Yeow PHP, Sen RN. Ergonomics improvements of the visual inspection process of a printed circuit assembly factory. *International Journal of Occupational Safety and Ergonomics (JOSE).* 2004;10:365–81.
3. Yeow PHP, Sen RN. Productivity and quality improvements, revenue increment and rejection cost reduction in the manual component insertion lines through the application of ergonomics. *Int J Ind Ergon.* 2006;36:367–77.
4. Burchfiel CM, Boice JA, Stanfford BA, Bond GG. Prevalence of back pain and joint problems in a manufacturing company. *Appl Ergon.* 1992;24:298–9.
5. Schierhout GH, Myers JE, Bridger RS. Musculoskeletal pain and workplace ergonomic stressors in manufacturing industry in South Africa. *Int J Ind Ergon.* 1993;12:3–11.
6. Jefferson JR, McGrath PJ. Back pain and peripheral joint pain in an industrial setting. *Arch Phys Med Rehabil.* 1996;77:385–90.
7. Anderson A, Nordgren B, Hall J. Measurements of movements during highly repetitive industrial work. *Appl Ergon.* 1996;27:343–4.
8. Chatillon J. Influence of source directivity on noise levels in industrial halls: simulation and experiments. *Appl Acoust.* 2006;68:682–98.
9. Arezes PM, Miguel AS. Risk perception and safety behaviour: a study in an occupational environment. *Saf Sci.* 2008;46(6):900–7.
10. Sen RN, Yeow PHP. Ergonomic study on the manual component insertion lines for occupational health and safety improvements. *International Journal of Occupational Safety and Ergonomics (JOSE).* 2003;9:55–72.
11. Sen RN, Yeow PHP. Costs effectiveness of ergonomic redesign of electronic motherboard. *Appl Ergon.* 2003;34:453–63.
12. Yeow PHP, Sen RN. The promoters of ergonomics in industrially developing countries (IDCs), their work and challenges. In: Thatcher A, Fisher J, Miller K, editors. *Proceedings of 3rd CybErg 2002: The Third International Cyberspace Conference on Ergonomics.* Johannesburg, South Africa: International Ergonomics Association Press, University of the Witwatersrand; 2002. p. 18–30.
13. Pocekay D, McCurdy SA, Samuels SJ, Hammond K, Schenker MB. A cross-sectional study of musculoskeletal symptoms and risk factors in semiconductor workers. *Am J Ind Med.* 1995;28:861–71.
14. Sinclair MA. Subjective assessment. In: Wilson JR, Corlett EN, editors. *Evaluation of human work—a practical ergonomics methodology.* London, UK: Taylor & Francis; 1995. p. 69–100.
15. Drury CG. Methods for direct observation of performance. In: Wilson JR, Corlett EN, editors. *Evaluation of human work—a practical ergonomics methodology.* London, UK: Taylor & Francis; 1995. p. 45–68.
16. Drury CG. The use of archival data. In: Wilson JR, Corlett EN, editors. *Evaluation of human work—a practical ergonomics methodology.* London, UK: Taylor & Francis; 1995. p. 101–12.
17. Haslegrave CM. Auditory environment and noise assessment. In: Wilson JR, Corlett EN, editors. *Evaluation of human work—a practical ergonomics methodology.* London, UK: Taylor & Francis; 1995. p. 506–40.
18. Sekaran U. *Research methods for business: a skill building approach.* New York, NY, USA: Wiley; 2003.
19. Cooper CL. Executive stress: a ten-country comparison. *Hum Resour Manage.* 1984; 23:395–407.
20. Cooper CL, Cooper RD, Eaken LH. *Living with stress.* London, UK: Penguin Books; 1988.
21. Amat T, Fontaine R, Chong SC. Occupational stress among managers: a Malaysian survey. *Journal of Managerial Psychology.* 2003;18:622–8.
22. *Factories and Machinery Act & Regulations.* Kuala Lumpur, Malaysia: MDC; 2001.

23. W. Tombling Ltd. Calculating industrial fan capacity 2004. Retrieved May 20, 2006, from <http://www.tombling.com/cooling/ventilation-fan.htm>
24. Kroemer KHE, Grandjean E. Fitting the task to the human: a textbok of occupational ergonomics. 5th ed. London, UK: Taylor & Francis; 1997. p. 54–65.
25. Pheasant ST, Steenbekkers LPA. Anthropometry and the design of workspaces. In: Wilson JR, Corlett EN, editors. Evaluation of human work—a practical ergonomics methodology. 3rd ed. London, UK: Taylor & Francis; 2005. p. 715–728.
26. Farhang AK, Michael SB. Comfort of personal protective equipment. *Appl Ergon.* 1995;26:195–8.
27. Chee HL, Rampal KG, Chandrasakaran A. Ergonomic risk factors of work processes in the semiconductor industry in peninsular Malaysia. *Ind Health.* 2004;42:373–81.
28. Karlqvist L. A process for development, specification and evaluation of VDU work tables. *Appl Ergon.* 1998;29:423–32.