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Ergonomic Study on the Manual Component Insertion Lines for Occupational Health and Safety Improvements

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The study aimed at reducing the occupational health and safety problems faced by the manual component insertion operators. Subjective and objective assessments, and direct observations were made in the printed circuit assembly factory. Simple and low-cost ergonomic interventions were implemented, that is, repairing chairs, reducing high workloads, assigning operators to a maximum of 2 workstations, confining machines that emitted bad smell and much noise, and providing finger work aids. The results of the interventions were reductions in operators' work discomforts, that is, chair discomfort (by 90%), high work stress, and discomfort due to frequent change of their workstations. Their health hazards were also eliminated, that is, inhalation of toxic fumes, exposure to too much noise, and pain due to pressing sharp components.

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1. INTRODUCTION

Ergonomics has been applied in various sectors in manufacturing particularly in the electronic industry. However, very little research has been conducted in

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the printed circuit assembly (PCA) industry, where electronic motherboards are manufactured. Wick (1991) did an ergonomic study on a manual component insertion (MCI) workstation and found that operators were facing occupational health and safety (OHS) problems, particularly postural, upper, and lower extremity stress. He redesigned the workstations to reduce these problems. In the present study, the focus is on other OHS health problems faced by MCI operators, such as bad smell from the inhalation of flux fumes, too much noise, high work stress, cuts on fingers, and so forth.

Sen and Yeow (Sen & Yeow, 1999, 2001, 2003; Yeow & Sen, 1999a, b, 2000, 2002) did several ergonomic studies on the MCI, visual inspections, electrical tests, and surface mounted technology (SMT) component placement processes in the PCA industry. In their studies on the MCI process (Sen & Yeow, 1999; Yeow & Sen, 1999a), only the preliminary results of ergonomic interventions in OHS problems were dealt with. In the present paper, more detailed results of the different aspects of the study are presented.

The MCI process in the present study was performed on manual assembly workstations. Similarly, there were many studies conducted on the manual assembly workstations of other industries to improve OHS. For heavy industry, Häkkänen, Viikari-Juntura, and Takala (1997) studied the effects of ergonomic interventions on the cumulative exposure of force imposed on the upper limbs and low-back of furniture assemblers and fixers in a trailer assembly plant. They found that simple and low-cost solutions in changing work methods, materials, and work organisation could reduce risk of upper extremity and low-back disorders. In medium-sized industry, Herring and Wick (1998) did an ergonomic improvement study in an electronic printer assembly factory to reduce ergonomic risk factors. The results of the study showed that the reduction of risk factors could contribute to the reduction in occupational injuries. For small-sized industry, Li and Haslegrave (1999) studied the seated work postures for a manual peg-hole assembly task, a visual character identification task, and a combined task. The results showed that the type and difficulty of the task could influence the work posture adopted and poor postures could be improved by adjusting task design and work layout.

There were also studies conducted in the laboratory simulating the actual factory process. For example, Lim and Hoffmann (1997) studied the effects of workplace design of a simulated hacksaw assembly process on the operators' occupational health risk. They found that ergonomic interventions in workplace design, such as providing an appropriate assembly jig, instructions on the proper use of the jig, and layout of components within the zone of convenient reach could reduce occupational health risks.

However, the present study was conducted in a real life factory environment, that is, a medium-sized PCA factory located in Malaysia. The factory produced motherboards for computer peripherals, such as printers, displays, and disk drives. The factory ran on two shifts, 12 hrs each.

The factory (before the ergonomic interventions) was facing many complaints from the MCI operators about poor working conditions and occupational hazards, such as seating discomfort, bad smell, noise, bleeding fingers, insufficient time to complete work, and so forth. The quality and productivity were also affected due to those problems. Because of the limitation of the length of the present paper, the investigations and the improvements in OHS only are presented. The quality and productivity aspects are presented in another paper.

1.1. Manual Component Insertion (MCI) Process

For a better understanding, the MCI process is explained. The MCI operators were seated at their workstations with components in nearby component bins ready for insertion. The PCA boards were moved from one workstation to another by a conveyor system. The operators took the components, inserted them manually into the correct locations, pressed them right in, and checked them for insertion errors (see Figure 1). The boards were then inspected

Figure 1. Manual component insertion process.

for insertion errors by a pre-wave solder (PWS) operator before being loaded into the wave solder machine (WSM). The WSM soldered the component wire leads to the component pads on the boards by (a) heating using solder flux bubbles and then (b) passing the leads and pads over a pot of melted solder waves.

2. METHODS

A preliminary subjective questionnaire was designed (Sinclair, 1995) through interviews with the operation managers, engineers, and supervisors to find out the plausible problems and their root causes. The questionnaire was first used on 3 operators and based on the pilot study, it was modified. The finalised questionnaire was used on 31 MCI operators out of the total of 42 operators from both shifts.

The results of the survey were analysed to determine the average ratings of the scores. The more critical problems with higher ratings were investigated using subjective assessment (Sinclair, 1995), direct observations (Drury, 1995a), auditory environment and noise assessment (Haslegrave, 1995), and the use of operations and archival data (Drury, 1995b) methods. A personal noise dose meter (Model TES-1355 manufactured by TES Electrical Electronic Corp., Taiwan) was used to evaluate the noise condition of the working environment. Noise dose was taken by clipping the microphone of the meter near the operator’s ear for the whole workday (12 hrs). The criterion selected for the meter was 85 dBA for 8 hrs for a 100% dose. Correction was made by multiplying the recorded reading by 0.67 (8 hrs/12 hrs) to get the actual noise dose reading because the operator was working 12 hrs per day instead of 8 hrs. Appropriate ergonomic interventions were made to overcome the problems. Follow-up studies were done using the same methods to confirm the effectiveness of the interventions.

2.1. Preliminary Questionnaire

The preliminary interview questionnaire was to highlight the OHS problems faced by a sample of 3 operators out of the total of 42 operators. The questionnaire covered four problem areas, that is, problems in work organisation, work environment, work methods, and work materials. It also covered the operators’ responses about their work problems.

The questionnaire had many open-ended questions, such as “What are the difficulties that you face at work?” so as to cover a wide area in the investigation of the problems in the MCI operation.

The Likert Scaling method was used. An ordinal scale from 1 to 5 was used for answers to the questions with 1 representing operators’ strong disagreement, 3—a neutral response, and 5—operators’ strong agreement. This was to gauge the levels of their answers to the problems, which were highlighted earlier by the operation managers, engineers, and supervisors.

The interviews conducted for each of the operators went on for about 2.5 hrs. In-depth investigation on the problems was made through follow-up questions after the trial runs. Operators’ suggestions to overcome the problems were also noted.

2.2. Finalised Questionnaire

The problems highlighted in the preliminary questionnaire interviews were changed into questions in the finalised version of the questionnaire.

In the finalised questionnaire, the ordinal scale of 1 to 5 was used for all questions so as to reduce the time taken to answer the questionnaire.

The finalised questionnaire survey took about 20 min for each operator to complete. It still took a long time because time was allocated for a careful explanation of the purpose of the survey and clarification of some difficult questions so as to avoid any misunderstanding that may affect the survey results. Much time was also given so as to allow careful thinking before answering.

Only one or two operators at a time were taken out of the line for the survey to avoid any line stoppage that may jeopardise the revenue earning of the plant.

The operators were stationed in their cubicles while completing their questionnaires. This was to prevent any peer influences that may affect their answers and eventually skew the overall results.

After completing the questionnaires, the operators were tested on the consistency of some of their answers by rephrasing the questions and asking them again. If any operators’ answers were inconsistent, explanations were given again to the operator on how to fill in the ordinal scale. The operator was then required to check all the answers and was tested again on the consistency of his or her answers.

3. RESULTS

Table 1 shows the results of the preliminary and finalised questionnaire surveys. The table includes information on the OHS problems highlighted by the operators in the preliminary questionnaire interviews and the number of operators (out of 3) who highlighted them. These problems are grouped into problem areas and arranged from the most to the least critical according to the mean ratings taken from the finalised questionnaire survey.

TABLE 1. Preliminary Questionnaire (Pre Q) and Finalised Questionnaire (Final Q) Results Related to Operators' OHS Problems

SN	OHS problem	Pre Q Highlight[a]	Final Q Rating[b]
	Work Organisation		
1i	Shortage of chairs	2	4.7 ± 0.5
1ii	Chair discomfort	3	4.2 ± 1.2
1iii	Electrostatic discharge wrist strap restricts hand movements	1	3.7 ± 1.3
1iv	Too cramped sitting	1	3.0 ± 1.4
	Work Environment		
2i	Bad smell of solder fumes from the wave solder machine	2	4.7 ± 0.5
2ii	Too much noise in manual component insertion area	2	4.1 ± 0.9
2iii	Too hot	1	2.5 ± 1.4
2iv	Litter and dust	1	2.4 ± 1.4
2v	Insufficient lighting	1	1.7 ± 0.9
	Work Method		
3i	Too many components to be inserted	1	4.1 ± 0.9
3ii	Difficulty in adapting to too many workstations every day	2	3.8 ± 1.4
3iii	Too little time for the PWS operator to perform visual inspections	2	3.6 ± 1.3
3iv	Difficulty in finding the line leader	1	1.8 ± 1.2
	Work Material		
4i	Pain when inserting certain components because of the need to press their sharp top edges	2	4.1 ± 1.0
4ii	Difficulty in inserting certain components because of the need to press very hard	3	3.8 ± 1.3

Notes. SN—serial number of the problem, PWS—pre-wave solder, a—number of operators highlighting the problem, b—mean rating (based on the Likert Scale).

The problem descriptions, root-causes and OHS consequences of the critical problems, and the improvements attained from the ergonomic interventions are shown in Table 2.

TABLE 2. Problems, Root-Causes, OHS Consequences of Critical Problems, and Improvements Resulting From Ergonomic Interventions

SN	Problem	Root-Cause	OHS Consequence	Ergonomic Intervention	Improvement
1i	Shortage of chairs	Overtime and trainee operators do not have chairs to sit on	↑ Discomfort due to standing throughout 12-hr shifts	Allocated a sufficient number of chairs	Eliminated standing for 12 hrs
1ii	Chair discomfort	1.2 ± 0.38 defects per chair	↑ 90% complained of seating discomfort, accidents, and injuries	Repaired all defective chairs	Eliminated all complaints
2i	Bad smell of solder fumes from the WSM	The toxic fumes were from the solder flux in the WSM	↑ 83.3% complained of headache, loss of concentration, dizziness, and nausea	Increased chute suctions pressure and compartmentalised the WSM area to minimise bad smell	Eliminated all complaints
2ii	Too much noise in MCI area	The nearby SMT and AI machines were noisy	↑ Health hazards ↑ Noise dose: 95.8 ± 7.2% (Standard used: 85 dBA and 8 hrs for a 100% dose)	Compartmentalised the SMT and AI machines to minimise noise Earplugs were introduced	↓ Health hazards ↓ Noise dose: 15.4 ± 3.3%
3i	Too many components to be inserted	High number of components to be inserted per PCA board by each operator within a short time	↑ 66.7% complained of high work stress	Reduced the number of components to be inserted per PCA board by each operator Reduced the maximum number of component types Set appropriate conveyor speed	↓ Complaints about work stress down to 26.7%
3ii	Difficulty in adapting to too many workstations every day	Operators changed workstations so as to allow flexibility to substitute for absent operators	↑ 76.6% of operators had problems adapting to too many different workstations	Operators were allocated a maximum of 2 workstations	↓ Complaints about work adaptation down to 6.7%
3iii	Too little time for the PWS operator to perform visual inspections	Each operator's task: inspect 73 components, repair errors, and load PCA board into WSM within the allocated time of 45 s per board	↑ 63.3% of operators complained of high work stress	Added one operator for visual inspection and repair work	↓ Complaints about work stress down to 6.7%
4i	Pain when inserting certain components	The components had sharp top edges	↑ 33.3% complained of minor cuts on fingers	Use of ergonomic finger work aids for pressing the sharp top-edged components and tight-pin connectors without pain	↓ Work hazard Eliminated complaints about pain and cuts on fingers
4ii	Difficulty in inserting certain components	Need to press hard the tight-pin connectors to ensure they are well inserted	↑ 53.3% complained of pain in fingers ↑ Work hazard		

Notes. SN—serial number of the problem, OHS—occupational health and safety, ↑—very high, ↓—reduced, WSM—wave solder machine, MCI—manual component insertion, SMT—surface mounted technology, $x + y$—average ± *SD*, AI—auto insertion, PWS—pre-wave solder, PCA—printed circuit assembly.

3.1. Shortage of Chairs and Chair Discomfort

Previously, the operators rated highly on the problem of an insufficient number of chairs. Chairs were allocated just sufficient for the production line. However, there were no extra chairs allocated for operators undergoing training, who assisted and learned from the experienced operators. There were no extra chairs also for overtime operators, who worked on the additional lines or did rework or assisted the existing lines to increase the production rate to meet the production targets especially during peak demand seasons. As a result, some operators did not have any chair to sit on, thus having to stand for long hours; operators also had to rush to book a chair, which often caused conflicts when two operators booked a chair at the same time.

The operators rated highly on the chair discomfort problem. The chairs in the production line had several defects, such as they were wobbly (caused by an uneven base or a seat not being firm), they had loose back support, damaged armrests, dysfunctional height adjustment, damaged legs (chairs were supported by 3 legs instead of 4 or 5), and their seats tilted downwards or upwards. These defects had resulted in many operators' complaints about seating discomfort and minor accidents, such as falling or sliding off the chair with minor injuries.

Ergonomic interventions were implemented by purchasing more chairs for the operators undergoing training and overtime work. Foldable chairs were used so that they could be easily transferred in and out of the lines. Small foldable seats were also fixed in specific positions so that they would not take up much space when they were not in use.

The defective chairs were segregated from the line and repaired or scrapped (because some were irreparable). In addition, the management fixed a weekly committee to check on defective chairs so that prompt repairs could be made.

After 1 month of implementation, all operators' complaints about chair discomfort were eliminated.

3.2. Bad Smell of the Solder Fumes from the WSM

Previously, the operators rated highly on the problem concerning the high emission of solder fumes from the wave solder machine (WSM). This occurred hourly when the technician opened the WSM for maintenance, which took about 5 min. The MCI operators and the solder touch-up operators who were working near the WSM were most affected by the bad smell of the solder fumes. Many operators complained of health hazards, such as headache, loss of concentration, dizziness, and nausea.

Ergonomic intervention was implemented by building four partitioned walls around the WSM to compartmentalise the machine so that the solder fumes could be contained to that area only.

Two small rectangular openings were made for the conveyors to go in and out of the WSM. Curtains were put at the rectangular holes to minimise any escape of solder fumes from the WSM compartment. Chute suction pressure was also increased during the periodic cleaning when the WSM door had to be opened.

In addition, any personnel going into the WSM compartment was required to wear a mask to prevent inhalation of the solder fumes.

After 1 month of implementation, all operators' complaints were totally eliminated.

3.3. Too Much Noise in MCI Area

Previously, the operators rated highly on the problem concerning the noisy surface mounted technology (SMT) machines and auto insertion (AI) machines, which were situated close to the MCI workstations. This affected the operators, particularly those who were seated near the machines.

Ten sound level measurements were taken in the workplace of 10 operators who were seated near the machines and the reading ranged from 85.7 to 86.8 dBA. In addition, 10 noise dose readings were taken from the same operators (based on the standard of 85 dBA and 8 hrs for a 100% dose). The average reading was very close to the maximum permitted noise dose (see Table 2), thus it could cause hearing loss in the long run.

Ergonomic intervention was implemented by confining and isolating the SMT and AI machines to restricted areas to minimise noise spreading to MCI and other areas that did not have noisy machines (see Figure 2). In fact, the ground floor was allocated for the SMT and AI machine areas and the first floor was allocated for the MCI and other areas. Anyone going to the ground floor was required to wear earplugs to protect their ears.

The implementation reduced the noise dose in the MCI area to a very safe level (see Table 2).

Figure 2. **To minimise noise spreading to the manual component insertion area, noisy machines were confined to isolated areas. Operators were required to wear earplugs while entering those areas.**

3.4. Too Many Components to Be Inserted

Previously, the operators rated very highly on the problem concerning too many components to be inserted by an individual operator within a specified time. On average, there were 9.1 ± 2.9 components inserted by an operator for each PCA board. Each component insertion required 5 steps, which included searching for the component bins, taking the components, locating the positions on the board, inserting the components, and checking the insertion. Thus, there were $9.1 \times 5 = 45.5$ steps. The operators were given very little time (45 s per PCA board) to perform all these steps. Consequently, many operators complained of high work stress.

Ergonomic interventions were implemented by reducing the number of inserted components by each operator for each PCA board to 7.5 ± 1.5. Minimum and maximum limits were set from 5 to 9 (previously, from 6 to 12). In addition, the number of types of component was also limited to a maximum of 6 (the previous maximum was 10). The conveyor speed was adjusted to suit the speed of the operators' learning curve, slower during the initial production runs and faster during mass production, that is, after operators' familiarisation with the MCI process.

The implementations reduced operators' complaints about high work stress by 40%.

3.5. Difficulty in Adapting to Too Many Workstations Every Day

Previously, operators did not work in the same workstation every day. They were placed randomly at any of the 7 to 10 workstations because the supervisors were concerned about absenteeism. If the operators were placed at the same workstation all the time, they might not be able to adapt to a new workstation when replacing an absent operator.

However, in the survey, the operators rated highly on the difficulty in adapting to too many workstations every day. They were frustrated because the sequences of insertions learnt the previous day were not applicable the next day.

Ergonomic intervention was implemented by assigning operators to a maximum of 2 workstations on any day. This was to improve their working conditions and also to increase their efficiency and productivity.

Operators were required to give 3 days' advance notice before going on leave so as to give more time for their supervisors to find replacement. This was to avoid failure in getting an experienced replacement.

After 1 month of ergonomic interventions, 93.3% of the operators reported that they could better adapt themselves. The others still experienced problems in adaptation but to a lesser degree.

3.6. Too Little Time to Perform Visual Inspections

Previously, PWS operators (one for each production line) had very little time for visual inspections because there were too many tasks to be performed within a short period of 45 s. The operator had to inspect many components in each PCA board for wrong, missing, lifted or tilted states, wrong polarity, and other types of rejects. The operator also had to repair the rejects by reinserting or replacing the components, which required moving 10 m away from the seat over to the correct MCI workstation to get the components. In addition, the operator had to place the board on a wave solder pallet and load it into the WSM. In the survey, this problem had a high rating of 3.6 ± 1.3. In addition, 63.3% of the operators complained of high work stress.

Ergonomic intervention was implemented by adding one more operator to the line to perform PWS visual inspections and repair work. This reduced the inspection and repair work of the original operators by half.

Furthermore, components were placed on every PWS workstation so that each operator did not have to move 10 m to get the components. However, the operator had to mark the error on a check-sheet. On an hourly basis, the line leader would give feedback on the errors made (which were written on the check-sheet) to the respective MCI operators.

After 1 month of implementing interventions on all 12 PWS operators from three different MCI lines (each line with 4 operators taking turns to be the PWS operator at one time), the operators' complaints about high work stress were reduced by 56.6%. The operators still facing some work stress reported reduction in the degree of the stress.

3.7. Pain and Difficulty in Inserting Certain Components

Previously, the operators rated highly on the difficulty in inserting and pressing some sharp top-edged components (e.g., transistors) into the holes of the PCA board. The process of pressing the components caused pain in the fingers. Some operators also complained of cuts on their fingers.

There were some large connectors with tight pins that the operators found difficult to insert into the holes of the PCA board. The operators rated highly on this problem because they were required to press hard the heads of the connectors by using two fingers, which was rather painful after many repeated operations.

Ergonomic interventions were implemented by providing the operators with finger work aids for pressing sharp top-edged and tight components (see Figure 3). The finger work aid was made of a special metal thimble (used for sewing cloth) with a piece of rubber glued to the base. The rubber was to reduce the impact on the finger during pressing. The inside of the thimble

Figure 3. Finger work aids were used for pressing sharp top-edged and tight components.

was lined with a rubber finger cot so that the thimble would have a good grip on the finger and also to increase comfort (due to the softness of the rubber finger cot).

After 1 month of implementation, all operators found it more comfortable to use the finger work aids for pressing as compared to using bare fingers. The operators' complaints about cuts and finger pain were totally eliminated

4. DISCUSSION

4.1. Cost Justification of the Ergonomic Interventions

The cost of all the ergonomic interventions was very low with the exception of the compartmentalisation of the WSM, SMT, and AI machines.

The costs of isolating and compartmentalising the SMT and AI machines were about US $5,000, which required moving the machines, some rewiring in the factory, and building new walls. The cost of compartmentalising the WSM was about US $1,500. These costs were justified by the factory's move towards attaining ISO 14000 certification, which the company would use as an asset to promote their factory. Moreover, the company had recently started a Total Quality Management (TQM) programme, which focussed on the company's health, of which the operators' OHS was a major part.

The cost of hiring an additional operator for PWS visual inspections was US $132 per month. There were three MCI lines, with 3 operators, costing US $396 per month. This was a small cost in the short term to improve the operators' OHS. In the long term, PWS visual inspection work would be reduced as the MCI operators gained more experience down the line, thus eliminating the need for additional inspection operators.

The repairs of defective chairs were performed on overtime basis without any subcontractor's help and thus they were not at all costly. The purchase of 15 foldable chairs (to resolve the problem of the shortage of chairs) was cheap, costing less than US $300.

The cost of fabricating the finger work aids for pressing sharp top-edged components was insignificant, costing less than US $1 each.

The reduction of the number of components to be inserted by the operators had improved their quality of work, which was shown in the reduction of rejects by about 22.5%. This was translated to a savings of US $14,200 per month on rejection cost.

The other ergonomic intervention, that is, assigning operators to 2 workstations, did not have any significant monetary cost.

4.2. Comparison With Other Studies

Wick (1991) found that appropriate backrest was vital to support the lumbar spine in the MCI task, especially when the operator had to bend a little forward while seated to insert small parts into small targets. In the present study, operators were facing much seating discomfort because the backrest was loose. If the backrest was in a good condition, it would at least provide some support to the lumbar spine. This became extremely intolerable when they had to bear with the discomfort for the whole 12-hr shift.

The damaged armrests of the chairs could increase loads on the L3 vertebral disk because shoulder flexion was unsupported (Andersson & Ortengren, 1974). In addition, they also caused stress to the shoulders (Wick, 1991).

The dysfunctional height adjustment of the chairs put stress on the neck due to the high head/neck flexion angle (about 40º). This was caused by the PCA board (visual target) being too low and horizontal (as it was lying on a flat conveyor belt as shown in Figure 1). The operators could not adjust the height of the chair (to make it lower and the PCA board higher) so as to reduce the flexion angle.

Wick (1991) emphasised the importance of MCI operators’ control of work pace. Lim and Hoffmann (1997) found that there was a learning curve in assembly operations. Thus, in the present study, it was important to set the conveyor speed based not on production target but on the speed of the operators’ learning curve and the maximum possible speed of the MCI, which was dependent on the jigs used, the layout, and the zone of convenient reach (Lim & Hoffmann, 1997). Other ways of setting the right speed was by using a gravity conveyor (Wick, 1991) where the operator moved the PCA board into position, inserted the components, and then pushed the board to the next operator. However, to adopt this method, all the operators must have the same level of experience so that no operator slows down the whole line.

In the present study, the ergonomic interventions in the problem areas, that is, work methods, materials, and organisation tremendously improved the operators’ OHS. Similarly, in the heavy industry, Häkkänen et al. (1997) found that ergonomic interventions in the same problem areas also improved the workers’ OHS by reducing injury risks. As in the present study, their study also made use of simple and low-cost solutions.

Herring and Wick's (1998) study showed a 70% reduction in injury incidence rate after ergonomic interventions were implemented on printer assembly workstations. Similarly, the present study also showed very good results in implementing ergonomic interventions on MCI workstations, that is, a 90% reduction in operators' complaints about minor accidents and injuries due to defective chairs and a 33% reduction in minor cuts on fingers.

It would have been best if the results of the present study could have been directly compared with a study done on the same industry and on similar MCI workstations. However, to our knowledge, there have not been any similar studies that revealed any statistics on OHS consequences or cost figures on the ergonomic interventions implemented.

Sen and Quek (2000) carried out a study on environmental and work stress of personnel working in the electronic chip manufacturing industry. They found that technicians faced critical mental and physical load when they had to attend to several repetitive operations and too many machine errors and stoppages. Ergonomic interventions made by implementing different alarm tones and coloured lights to differentiate the severity of machine errors could reduce the workers' stress. Similarly, in the present study, MCI operators faced critical mental and physical load when they had to insert and inspect too many components within a short time. The ergonomic interventions made by reducing the operators' workload tremendously reduced their work stress. It was necessary to reduce the operators' extreme work stress because failing to do so could cause workplace hazard, such as employee turnover, absenteeism, declining morale, and poor productivity (Farren, 1999). Operators might even develop health problems like gastrointestinal disorders, which could lead to gastric or duodenal ulcers (Kroemer & Grandjean, 1997).

4.3. Limitation of the Study

Controlled experiments were not performed in the other studies done on real life manual assembly workstations, such as studies by Häkkänen et al. (1997), Wick (1991), and Herring and Wick (1998). In the present study, controlled experiments could not be conducted because there were too few MCI operators. To find an identical factory producing the same products, with similar operators was a very difficult task, which would have required a lot of resources to search for and interview the companies; therefore, this was not done. However, the results of the ergonomic interventions were accurate, as the duration of the intervention was only 1 month, which was not a long time that could cause other factors in the factory to change and have an impact on the results. Also, based on an interview with the management right after the ergonomic interventions, there were no major changes during that period, such as replacement of old machines, declaration of good bonuses and so forth.

The ergonomic intervention studies were done on a small sample size, that is, 31 operators for the MCI-related interventions and 12 operators for the PWS-related interventions. Larger sample size could not be obtained, as there was a limited number of operators working in the factory. A similar limitation was found in studies presented in Häkkänen et al. (1997), Wick (1991), and Herring and Wick (1998).

Detailed factor-by-factor studies using experimental design techniques could not be conducted on some of the problems because the management of the factory was too pressed for time to find solutions to the problems. For example, the management did not allow finding an optimum number of components to be inserted per operator, an optimum number of component types, and an optimum conveyor speed for operators with varying levels of experience.

A follow-up survey after the ergonomic interventions (using the same questionnaire as before the interventions) was not allowed by the management because it was too time consuming for the operators. An alternative assessment method was used to compensate for this limitation, that is, an assessment of the individual effects of the ergonomic interventions. For example, the percentage of operators’ complaints about a particular problem was surveyed before and after the ergonomic interventions, and measurements (such as noise dose) were taken or direct observations (such as observations of operators pressing sharp top-edged components) were made before and after the ergonomic interventions.

5. CONCLUSION

Although the ergonomic intervention studies had limitations due to the constraints of the real world factory environment, they succeeded in achieving much improvement in OHS. The operators’ work discomfort, that is, chair discomfort and high work stress were reduced to a great extent. The operators’ health hazards were eliminated, that is, inhalation of toxic flux fumes, exposure to too much noise from the machines, and pain and cuts caused by pressing sharp top-edged components. All these improvements showed the effectiveness of ergonomics applied to PCA manufacturing, particularly for improvement in OHS.

In Malaysia, an industrially developing country, ergonomics is a new field (Sen, 1984, 1998). A similar ergonomic study should be conducted in other factories in the PCA industry for OHS improvement. Improvement particularly in the PCA industry is very important for Malaysians because the industry is supplying motherboards to the electronic industry, which is the largest revenue-generating industry in Malaysia.

The success of the ergonomic study was also due to excellent teamwork and co-operation between the management and the workers of the factory. Similarly, teamwork was found to be one of the key reasons for success in Herring and Wick's (1998) study. The management gave their support to the workers by investing in the compartmentalisation of the machines, hiring an OHS officer, and encouraging operators to give feedback on their work-related problems. The operators also did their part by giving feedback on their work problems and suggesting how those problems could be rectified.

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