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Human Factor in Equipment Safety of Hard Disk Manufacturing

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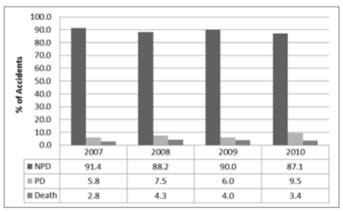
Graphical abstract



Abstract

The focus of this paper is on the human factors aspect of equipment safety focusing on process hazard analysis and safety programs. The objectives of this study are to determine the level of awareness, involvement and perceptions on occupational safety and health among workers. These are accomplished by conducting a survey using questionnaire and interviews involving 98 respondents in two hard disk manufacturing companies. Majority of the respondents were executives with high academic qualifications and possessed high level of safety awareness. The results conclude that despite the existence of various legislations, human factors and its interactions with facilities and management system is the main contributor to incidents. It is also found that most of the incidents involved power driven machineries. For the improvement of equipment safety, it is recommended that Process Hazard Analysis techniques be used to play significant role, along with both engineering and administrative control measures and safety programs.

Keywords: Equipment safety; industrial incidents; process hazard analysis; hard disk industry

1.0 INTRODUCTION

Malaysia has made significant progress in the manufacturing sector since its introduction in the 1970's. 1n 2010 the manufacturing sector contributed 27.6 % of the GDP, and 3 % of GDP growth, almost half of the total growth of 7.2 % [1]. The electrical and electronic sector represented 29 % of the total contribution of the manufacturing sector to the country's economy. With such an important contribution, the standards of occupational safety and health (OSH) among workers are to be addressed earnestly to ensure sustainability. This is realized through the Occupational Safety and Health Act (OSHA) 1994, and with its regulations. Using the new format of accidents reporting introduced in 2007, resulting from the Notification of Accident, Dangerous Occurrence, Occupational Poisoning and Occupational Disease (NADOPOD) Regulation 2004, accidents data are reasonably well-documented by relevant parties. This facilitates research works on occupational safety in Malaysia.

Figure 1 shows the accident statistics for the period between 2007 and 2010 [2] showing manufacturing as the main sector with a record of about two third of the total reported accidents. Following a downhill trend for the first 3 years, 2010 recorded a slight increase in reported accidents. Based on the data illustrated in Figure 2, out of the total accidents occurring each year, 85% - 90% involves non-permanent disability (NPD) injuries. Although the percentage for higher consequence is lower, i.e., 5.8%-9.5% for injuries with permanent disability and 2.8%-4.3% for fatality, the number is still significantly high.

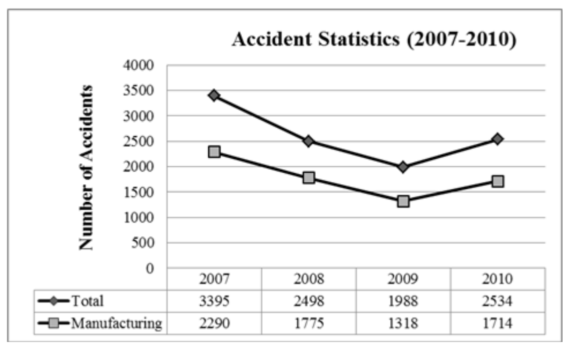


Figure 1 Accident Statistics in Malaysia (2007-2010)

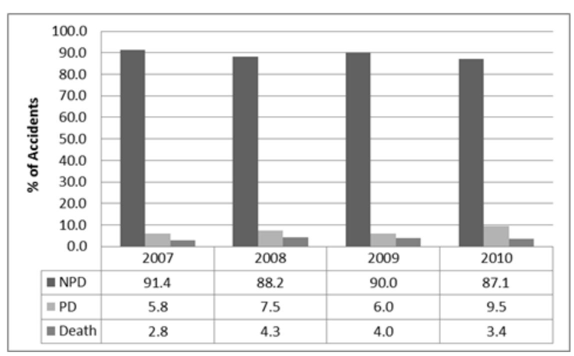


Figure 2 Breakdown for accidents in manufacturing sector in Malaysia

By and large, there could be many contributors to industrial incidents including the lacking of design configuration, weakness in installation leading to difficulties in equipment handling, defects in manufacturing of the installed components, lack of maintenance and etc.

However, human factors could be the prime contributor to industrial accidents considering its inevitable human roles in each of the above tasks, hence the focus of the paper. Examples are plentiful and could be observed in aviation and maritime industry where 70% of accidents were due to human [3]. Statistics show that majority of accidents and incidents (over 80%) in the chemical and petrochemical industries are contributed by human failure as a main and primary cause [3]. Taking manufacturing industry as a whole, research suggests that human error contributes to unsafe practices and accidents encompassing more than two third of the total cases of accidents [4]. Human factors are also frequently cited as the initiator of error-events which leads to incidents in the hazardous industries such as the chemical, oil and gas, rail or nuclear. It is therefore important to properly understand various human factors issues such as the organizational provision and culture, in addition to management of change, adequacy of operating procedures, training and incident investigation to ensure safety at work place [5].

It is by no means different in Malaysia where human factor could be the major contributor to industrial incidents. However, reported works on this matter are scarce. The study by Hussin and co-workers [6] on small and medium-sized food processing industries revealed that the main cause of incidents was human factors, where employers seldom took serious attentions on accidents at the workplace. This paper discusses the results of the survey carried out on two similar manufacturing plants on the level of awareness, involvements and perceptions of workers towards occupational safety issues relevant to their workplace. Among others, the focus is on human factors, Process Hazard Analysis (PHA) and safety programs.

■2.0 SAFETY ISSUES IN HARD DISK INDUSTRIES

2.1 Process Description

Hard disk manufacturing process can be divided into two major sections, i.e., the front-end processing to produce polished substrates and the back-end processing that transforms the substrates into finished products. Figure 3 illustrates the typical front-end hard disk process flow. The activities carried out in each step of the process flow and equipment involved are shown in Table 1.

In the cassette exchanger, products are transferred into the process cassettes from the receiving cassettes, are then grouped according to different thickness in the groupers, followed by the electro-plating process. The plated products are then polished using slurries by the polishers and cleaned in the cleaning machines. The cleaned product is then subjected to inspection before being bagged for shipping.

Table 1 Substrate manufacturing activities and machine/equipment

Process Flow	Activities	Machine/ Equipment
Cassette Exchange	Products are transferred into process cassettes from receiving cassettes	Cassette Exchangers
Grouping	Products are grouped according to different thickness	Groupers
Plating	Products are plated using electro-plating process	Plating Line with tanks
Polishing	Products are polished by using slurry	Polishers
Cleaning	Products are cleaned from contaminants	Cleaning Machines with washer and dryers
Testing & Certification	Automated Inspection is carried out as the final test	Automated Optical Instruments (AOI)
Bagging & Shipping	Products are bagged in the shipping cassettes and sent to warehouse for shipping	Conveyors Sealers

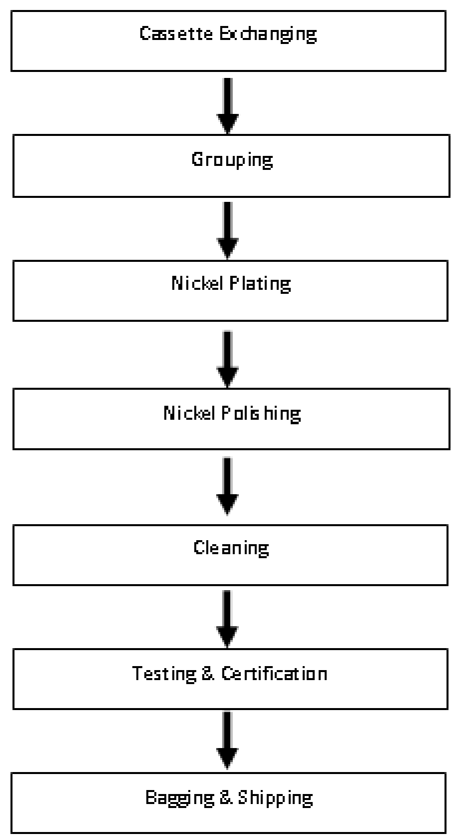


Figure 3 Typical front-end hard disk process flow

2.2 Machinery Hazard

Industrial Accident Prevention Association [7] identified safety and health hazard caused by machine as presented in Table 2:

Table 2 IAPA identified machinery hazard

Safety Hazard	Health Hazard
Contact with moving parts	Contact with harmful chemicals
Contact with electricity, heat, fire, cold and other energies	Contact with harmful noise, radiation and vibration
	Lack of adequate workplace ergonomics : handling and process design
Contact with pressurized liquid or gas	Harmful action to the environment and community

For the plants considered in this study, machinery hazards can be listed according to the workers' activities carried out at respective equipment, and is summarized in Table 3. The tabulated potential occupational safety and health hazards are gathered from the selected substrate plants. Since automated equipment are used in most process, higher safety risks are more probable during preventive maintenance and troubleshooting where the equipment safety features might be switched off.

Table 3 Potential safety and health hazards of substrate manufacturing equipment

Equipment	Activities	Safety Hazards	Health Hazards
Cassette Exchangers	1. Loading / Unloading at the conveyor 2. Clean and align the moving parts during maintenance	Contact with moving parts such as conveyor	Ergonomic with repetitive movement
Groupers	1. Loading / Unloading at the conveyor 2. Clean and align the moving parts during maintenance	Contact with moving parts	Ergonomic hazard with repetitive movement
Plating Line	1. Cleaning of plating line 2. Troubleshooting of damaged parts	1. Contact with moving part such as hoist 2. Contact with heat up thermocouple	Chemical Exposure
Polishers	1. Manual loading / unloading of products onto the polisher 2. Troubleshooting and Preventive maintenance	1. Crashing of upper platen onto workers 2. Caught in between upper & lower platen	Chemical Exposure
Cleaning Machines	1. Troubleshooting of damaged parts 2. Preventive maintenance	Caught in between moving parts	Chemical Exposure
Automated Optical Instruments (AOI)	1. Align the laser 2. Align moving parts	1. Caught in between moving parts 2. Hit by robotic arm	Radiation exposure – laser (loss of eye sight)

3.0 METHODOLOGY

3.1 Plant Description

Two major hard disk factories were selected, both producing similar products and using similar equipment. Following a preliminary study by interviews and site visits to identify major safety issues and safety related programs implemented, data requirement was determined and survey questionnaires were designed. The previous incident statistics and safety programs were obtained from the company records. Since the substrate cutting and grinding processes are not common to both factories, these processes were excluded from the study.

3.2 Design of Questionnaire

The questionnaire was divided into five sections. The first part focuses on the respondent's background, while the remaining sections address issues of equipment handling and safety in the factories including the respondents' awareness on the various types of risk assessment and its application in their factories as well as current safety equipment issues. Multiple choice questions were used, but in some questions, the respondents were required to provide ratings based on Likert's 5-Level Scale of 1 (Disagree) to 5 (Strongly Agree). Based on these ratings, the average indices were computed using the following equation.

$$\text{Average index} = \frac{\sum \mu n}{N} \quad (1)$$

Here, is the weightage given to each factor by the respondent, n is the frequency of the respondents and N is the total number of respondents.

As recommended by Abd Majid and McCaffer [8], rating scales were determined to indicate agreement (Table 4) and improvement (Table 5). Pearson Correlation Coefficients were computed using the Statistical Analysis Package SPSS to test hypotheses. An r value nearing 1 shows strong correlation between the variables and a p value 0.05 indicates that the Pearson is significant.

Table 4 Rating scale for agreement average index

Rating	Average index
1 = Strongly Disagree	(1.00 ≤ Average Index < 1.50)
2 = Disagree	(1.50 ≤ Average Index < 2.50)
3 = Neutral	(2.50 ≤ Average Index < 3.50)
4 = Agree	(3.50 ≤ Average Index < 4.50)
5 = Strongly Agree	(4.50 ≤ Average Index < 5.00)

3.3 Data Collection

Based on the recommendation by Bartlett [9], the sample size was determined using Cochran relationships [10], and for a population of 400, a minimum of 92 respondents were required. For convenience, 50 workers were selected from each company, thus giving a total of 100 respondents. This purposive sampling was designed to include those who were mostly involved in either equipment handling or process hazard analysis. In addition, interviews were conducted to clarify inconsistencies in responses. When further information involving incidents were required, the safety and health officials and equipment personnel were consulted.

Table 5 Rating Scale for average improvement index

Rating	Average index
0 = Never	(0.00 ≤ Average Index < 1.00)
1 = Little	(1.00 ≤ Average Index < 1.50)
2 = Same	(1.50 ≤ Average Index < 2.50)
3 = Good	(2.50 ≤ Average Index < 3.50)
4 = Excellent	(3.50 ≤ Average Index < 4.00)

4.0 RESULTS AND DISCUSSION

4.1 Background of the Respondents

The survey was conducted at two companies, i.e., company 1 and 2. The former was commissioned in 2007 and the latter (i.e., company 2) has been in operation since the year 2000. Majority of the respondents have worked for more than a year and should be able to provide constructive feedbacks (see Table 6).

Table 6 Respondent demography - number of years in employment

Years in Service	< 1 year	1-5 years	6-10 years	>10 years	Total
Company 1	10	40	0	0	50
Company 2	7	27	11	3	48

The respondents were selected from among those who were either actually handling the equipment and/or involved in incident investigations to guarantee general understanding of the issues to be discussed. Of the total 98 respondents, 29.3 % were from the process or engineering section, 34.35 % were handling equipment, 11.11 % were from manufacturing, 7.7 % from quality assurance, 6.6 % from the safety and health and 11.1 % were from other sections. In terms of job responsibility, 82.84 % were engineers or executives, 9.9 % were managers and senior engineering positions, 2.2 % from the top management and 2.5 % were non-executives. As a whole, the respondents were mostly executives (or higher) with high academic qualifications

4.2 Nature of Equipment Incidents

Table 7 shows the total incidents reported, with polisher (51%) involving highest number of incidents, followed by plating operators (22%) and cleaning machines operators (13%). Similarly, the highest number of injuries was also involving polishers, (28 cases) followed by the operator of cleaning machines (12 cases). Smaller number of incidents was reported on Grinders and Grouper machines (both contributed 3 % each), as the activities involved only loading and unloading of products at conveyors. The results conclude that power driven machineries dominate the incidents. This is consistent with the study conducted on accidents in the Korean manufacturing industry [11].

Other non-production equipment contributing to the incident statistics were wastewater treatment equipment and testing equipment. Moreover, interviews with the Safety and Health official of the organizations revealed that only operators and technicians were involved in accidents with injury.

Table 7 Equipment incidents according to types of equipment

Types of Equipment	Types of Incidents			Total Incidents	
	Near Miss (no injury)	Accident with injury	Fatality	Number	Percentage
Grinder	3	0	0	3	3%
Grouper	0	3	0	3	3%
Plating	15	5	0	20	22%
Polisher	18	28	0	46	51%
Cleaning machines (with washer / dryer)	0	12	0	12	13%
Others	3	3	0	6	7%
Total	39	51	0	90	100%

Having been in operation for several years, the frequency of incidents for Company 2 is now low, with less than 10 incidents per year. To provide direct comparison, data for the first three years of operation were used (See Figure 4). Similar for both companies, incidents with injuries were dominated by workers being caught in between and struck by object. Near misses were mostly chemical related (50% in company 2, 90.2 % in company 1). Moreover, there was no consistency on increment or decrement of incidents throughout the early years, but Company 1 recorded more incidents.

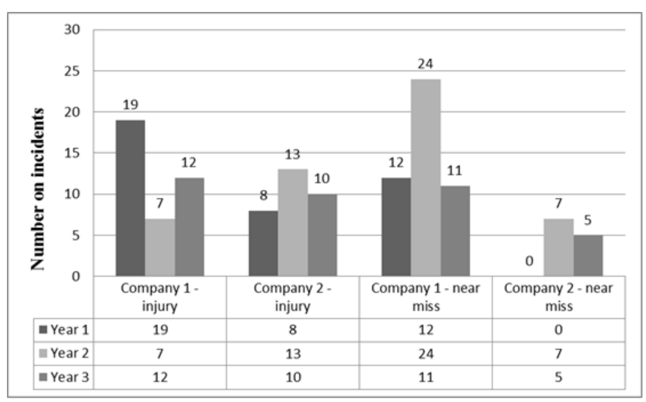


Figure 4 Incident data for first 3 years of operation

4.3 Root Causes of Equipment Incidents

Majority of the respondents also believed (average index of 4.2) that the root causes of the accidents were related to human factors such as carelessness, fatigue, negligence or lack of awareness. Other factors include inadequate equipment safety features, inadequate procedures and instructions, inadequate training and lack of supervision. Nevertheless the average indices obtained were in the vicinity of 3.0.

Similar observations have also been observed in a study involving eleven companies in Jordan [12]. It is therefore important to manage human factors (specifically human errors) by implementing engineering control mechanisms such as automation, installation of guarding, interlock and alarms systems as well as various sensors and indicators for relevant task functions.

4.4 Process Hazard Analysis

Process hazard analysis (PHA) is now becoming applicable to manufacturing industries in Malaysia. In the survey, 64% of the respondents have carried out PHA. For both companies, Failure Mode and Effect Analysis (FMEA) is the most preferred method (75% for Company 1, 90 % in Company 2 and 83 % overall) and Hazard and Operability (HAZOP) study is carried out only selectively on certain equipment (19 % for Company 1 and 10 % for Company 2). Testing or support equipment are normally exempted from PHA along with equipment perceived to have negligible risk. The survey also revealed that PHA contributed significantly towards increasing the understanding of equipment safety requirement.

Figure 5 shows the frequency of the PHA being carried out on equipment. The frequency for newly installed equipment was almost the same for less than 6 months, 6 months to 1 year, every year and more than 1 year. For older equipment, PHA was carried on yearly basis.

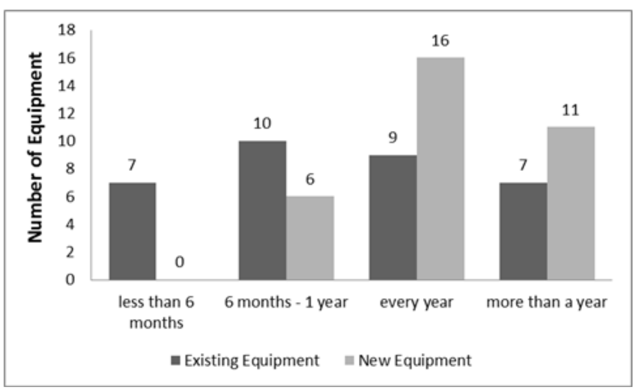


Figure 5 Frequency of risk assessment being carried out

Implementing PHA in process plant is beneficial not only in terms of providing useful insights for control measures, but also facilitating human factors positively towards safety. This is especially true in processing plant where better understanding on how to synchronize and improve the human factor with engineering practices can be achieved to prevent recurrence of similar incidents. By integrating human factor with process hazard analysis, it will help to identify, understand, control and prevent human related failure which can result in an incident or accident during operation of chemical processing plant [3].

4.5 Control Measures

Majority of the respondents (83.7%) were required to handle variety of equipment in their daily duties. Of these, 65 % have used 1-5 different types, 6 % with 6-10 types and 29 % have the experience with more than 10 types of equipment. The results also revealed that majority of the respondents agreed that control measures including safety training, equipment buyoff, safe work procedure and automation improved equipment safety. Pearson correlation show that equipment safety could be improved not only by conducting PHA, but also implementing other control measures, with r=0.715 for safety training, r=0.477 for equipment buyoff, r = 0.734 for safe work procedure and, r=0.450 for automation. The *p* value is <0.45 proved that the correlation was significant.

In addition, the use of administrative control measures such as training, equipment buyoff and safe work procedures can serve as positive reinforcement. This is because major accidents are typically resulting from combination of events including some previous actions and failures. Furthermore, the study by Mital and Pentatur [13] also revealed the importance of designing features within automation system that allow human supports to compensate for technological limitations.

4.6 Safety Program

The respondents have had the opinion that organizational safety programs such as safety training, safety campaign, equipment buyoff and safe work procedures would improve the equipment safety. The survey has recorded a score of higher than 3.5. Among these, safety training and safety campaign scored highest with r = 0.647 and 0.714 respectively. Establishing safety programs that integrate various units within the organization is an effective way to reduce equipment incidents since such integrations nurture better teamwork and commitment to the workplace. This is also the conclusion obtained by other researchers [14].

Although there is the perceived importance of management encouragement in establishing safety programs at work, the respondents have provided the results totally opposite in nature. This is probably due to the fact that only 60 % of the respondents have had subordinates who would most unlikely be influenced in their decisions, all due to their high level of academic qualification and training.

4.7 Safety Awareness

The survey also revealed the high awareness on incidents occurrences where 91% of the respondents giving positive feedbacks. This is high when compared to their awareness on the companies' involvement with safety management system certification, which recorded lower values (50 % for company 2 and 70 % for company 1), perhaps indicating that they are more concerned with employees, instead of the employer. A higher awareness for company 1 was expected as the company was already certified under OHSAS 18001.

5.0 CONCLUSION

A survey on safety related issues has been carried out in two hard disk manufacturing companies, involving 98 respondents. Majority of the respondents were executives with higher academic qualifications. Due to this fact, they have reasonable exposures to safety issues and high level of awareness. The results also conclude that despite the existence of various legislations, human factor and its interactions with facilities and management system is the main contributor to incidents. Some of the important conclusions based on the findings include:

(1) Power driven machineries dominate the incidents, in this case, incidents are dominated by polishing plating and cleaning machines.

(2) The major root cause of the accidents are related to human factors

(3) PHA contributed significantly towards increasing the understanding of safety requirement.

(4) Both engineering and administrative control measures improve equipment safety

(5) Safety programs such as safety training, safety campaign, equipment buyoff and safe work procedures improve equipment safety

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