A STUDY OF ERGONOMIC INDUSTRIAL ROBOT IN KLANG VALLEY, MALAYSIA

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Abstract: The objective of this paper is to study the relationship between ergonomic and the level of accident in work place which is involving industrial robot. The level of accident involving robot is shown the effectiveness of the ergonomic application in work place for optimizing robotic system. The sets of questionnaire were distributed to the 160 factories in Klang Valley, Malaysia based on the type of industries and robot’s group and structure which are about the robotic system such as work cell layout, type of robot driver system, safety device provided in work place and the level of accident in robot work cell. The study shows that, 40 out of 160 questionnaires were received. The results indicate that 72.9% of respondents had the experiences of the robot accident which 28 % of the accident occurred because of malfunction of robot system.

1. INTRODUCTION

Today robots are used in many different areas and applications, their safety-related problems have significantly increased. Each new area and application may call for specific precautions for operators, maintenance workers, robot systems, and so on (Karwowski, 2000). In the past, robot safety did not receive as much attention as it deserved from both manufacturers and users. This scenario is changing in recent years, robot-related accidents could be one of the factors behind this change. The establishment of the American National Standard for Industrial Robots and Robot Systems: Safety Requirement and the Japanese Industrial Safety and Health association document entitled, “An Interpretation of the Technical Guidance on Safety Standards in the Use, etc. of Industrial Robot” are two prime examples of robot safety consciousness in recent years.

Factors such as increasing productivity and replacing humans in performing difficult and hazardous tasks play a key role in the installation of robots in industry. Poor robot planning from the standpoint of safety may create hazardous situations other than that which the robot may be replacing. It means, for successful robot application, that safety must be carefully considered in the planning phase (Elgelberberg, 1980).

There are three basic types of robot hazards; impact, trapping point and those that from application itself. Impact is being struck by the robot’s moving part or by items being carried by the robot. This basic hazard also includes being struck by flying objects ejected or dropped by the robot. The trapping hazard is generally the result of movements of the robot with respect to the fixed objects: machines, posts, etc. In the same space, hazard that develops from the application include burns, electric shock, exposure to toxic substances and arc flush and so on (Ziskovsky, 1984).

There are many unique robot safety problems faced by the safety professionals. Some of them are:-
(i) A robot’s presence receives great attention from humans, who are frequently ignorant of the possible associated hazards.
(ii) A robot may lead to high risk of fire or an explosion if it is placed in an unacceptable environment.
(iii) Robots create potentially hazardous situations because they manipulate items of varying sizes and weights.
(iv) Maintenance procedures associated with robots may lead to hazardous conditions.
(v) Management attitudes lead to misunderstanding of robot safety concept.
(vi) Robot mechanical design problems may lead hazards such as pining, pinching and grabbing.

The risks of hazard should be reduced as much as possible. In order to minimize the hazard, it is important to consider the ergonomics of the robot. The robot generally does not play its task alone but they are used with other machine and operated by human operator. Therefore, consideration on robots ergonomics must include the robot arm, robot classification, production of robot and robot and human interface and work cell that robots are compatible to complete its tasks.
Basically, ergonomic means application of human biological science in conjunction with engineering science to achieve the optimum mutual adjustment of humans and their work, the benefits being measured in terms of human efficiency and well being. When this application is integrated to the robot, it can be concluded as manipulation of robot anatomy, physical, controller and other robot components and capability to achieve the optimum robotic system, including efficiency, performance, safety, health and also comfort associated with working system. In workplace with human and robot incorporating, robots are considered as an important ergonomic investment for manufacturer which it they can improve efficiency as well as quality [ABB Manufacturer].

### 1.1 The Role of Robot Ergonomics

The word ergonomics, in Greek means “the natural laws of work”. Traditionally, it has meant the study of the anatomical, physiological, and psychological aspects of humans in working environments for the purpose efficiency, health, safety and comfort associated with work systems.

Correct and effective introduction of robot to industrial work requires use ergonomics in the same purpose; optimizing the robot tasks [Nof, 1986]. Basically, robot work should be optimized to:

- Minimize the time per unit of work produced
- Minimize the amount of effort and energy expended by operators
- Minimize the amount of waste, scrap, and rework
- Optimize quality of work produced
- Maximize safety

A general ergonomics procedure for optimizing industrial robot work is depicted in Figure 1 [Nof, 1986]. For given job requirements, it entails the analysis and evaluation of whether a human or a robot should be employed for the job. If a robot, the best combination of robot models and work method, implying also the best workplace, should be selected. In integrated human and robot systems the best combination must be designed. The subsequent sections cover the ergonomics techniques that are useful to follow the foregoing procedure in practice.

![Figure 1 Ergonomics procedure for optimizing robot, human or integrated work.](Image)
1.2 Ergonomic Consideration In Work Cell Design

There are several issues that must be considered in the design of the work cell. Among these elementary considerations are the following [Nof, 1986]:

i. Random load-unload station
ii. Wrap-around station
iii. Load-unload with pallets
iv. Load-unload with conveyors
v. Safety considerations
vi. Same work-height.

In random load-unload station, the work stations in work cell are located randomly while in wrap-around station, the conveyor wrap around the robot. For load-unload with pallets, at least three axes of motion required and robot program must consider parts organization. For load-unload with conveyors consideration, at least two axes of motion requires but parts location must be known very well.

Safety considerations means the work cell must protect human personnel from harm in and around robot work cell. This is generally accomplished by means of fences or other barriers, interlock gates, emergency stop, sensor device and other safety device which can protect human and robot to unsafe conditions. Example of the work cell safety system is shown in Appendix B. The Figure B1 shows the location of the safety device such as light curtain, removable barrier, emergency stop and gate [Regh, 1992]. This figure also shows the location of the robot and equipment in the work cell. For same work-height consideration, the robot has simpler robot program and required less motion axes. This consideration can minimize the energy expended and reduce the cycle time.

In order to optimize the robot work, number of workstation and distance of each of work station also must be considered. The number and distance of work station can influence the robot cell arrangement. If the arrangement is complex, the system tends to be complicated and the probability of accident is high.

1.3 Summary

The early studies of industrial robot ergonomics have been embarked in the 1970s [Nof, 1986]. Then, models, methods, and tools of robot ergonomics have been widely practiced for the design and optimizing of the robotics system. Knowledge on robot ergonomic covers robot anatomy, robot peripheral and the entire robot work environment. Robot anatomy includes robot configuration, robot work distribution, robot motion which represents by joint and link, degree of freedom and robot configuration. Robot anatomy will determine the design of work layout and the correct system to the robot.

Techniques and principles developed by robot companies, users and researchers have been identified and described as necessary for planning effective robot system. Traditional engineering tools have been extended to design robotic and human-robot work system. New techniques have evolved from traditional methods for design of robots for specific planned work.

New work environment (human-robot work environment) require perceive safety consideration. Knowledge of robot ergonomic in work environment such robot movement (speed and motion path), work volume, robot configuration and equipment which interfacing with human and robot will contribute to maximum safety.

2. METHODOLOGY

2.1 Designing The Questionnaire

Before designing the questionnaire, an overview of the robot systems and robotic industries especially on the problems encountered by industrial robots safety from literature review. The questionnaire is designed based on combination of literature review and safety evaluation by Department of Energy (DOE) OSH; Technical – Risk Assessment conducted by U.S Department of Labour, Occupational Safety and Health Administration; The questionnaires will be divided into five major sections under the following topics; Overview of Company’s data, Particulars on Robot, Work Cell Layout, Human- Robot Interaction and Level of Accident.

2.1.1 Overview of Company’s Data

This section will be mainly on the company’s profile. This section includes company’s name, address, type of industries and the application of robot used. In this study, it is important to know the type of industry sector and application field of robot because it shows the usage of robot technology in
Malaysia industry. This section also will provide information on which industry is mostly exposed to robot accident.

2.1.2 Particulars on Robot

This section is considered as ‘heart’ of this case study. In this section, the questions are designed to identify the current robot structure and systems in manufacturing plant. Analysis can be carried on the robot manufacturer, brand of the implemented robot, type of robot, type of installation of robot applied in production line, driver system of the robot, robot configuration, reason to choose the type of robot, effect of chosen type of robot and type of robot’s arm tooling. All these questions are important to obtain the information of the robot structure and anatomy and the robotic system as well. It will give the specification of the ergonomics of industrial robot. The information about the robot anatomy will show how ergonomic applied in production line in order to optimize the robot work and its system.

2.1.3 Work Cell Layout

The implementation of robot require convenient and compatibility condition and situation. The questions in this section are adapted from Risk Assessment – (DOE) OSH and Work Cell Safety (Regg, 1992). This section covers the type of layout arrangement, the consideration of work cell design, number of work station, distance of each work station and safety device provided in robot work cell. It is important to know the arrangement of the robot working environment because the result will show the application of ergonomics. The design of the work cell will show the effectiveness ergonomic application in the robotic system and in reducing hazard in work area.

2.1.4 Human-Robot Interaction

This section covers the availability of training provided to the person who work with robot, the distance between robot and operator, the compatibility of the pendant to the operator and the height of table or conveyor (specific to the pick and place application). This section is just like extension of robot work cell layout. It is important to know the distance between robot and operator and size of table used in work cell whether it is ergonomic to the both human and robot.

2.1.5 Level of Accident

Safety in work cell is the most important concern in this project in order to relate the effectiveness of the robot ergonomic application in production line. Level of accident will show the level of robotic system in Malaysia industry. This section includes the frequency of the robot accident, activity that accident mostly occurs, common robot accident, type of maintenance, area of robot accident, main cause of robot accident, result of robot accident and major effect of the robot accident.

2.2 Sampling

The questionnaire was sent to the companies in Klang Valley and Selangor. The sample was selected based on the type of industry like iron and steel, electric and electronic, transport/vehicle equipment, plastic products and machinery and engineering industry in more less in equal quantity. The type of respondents sector was selected according to business categorized by Federal Malaysia Manufacturer in e-Directory.com.my. e- Directory also provides address of the companies.

2.3 Data Analysis

The data received through the survey was analysed. This process is the last step in completing this case study. The raw data were analysed by using Microsoft Excel and the result were shown in the bar and pie charts type. The result analysis is based on percentage and frequency of accidents based on robot operations and yearly. The data is analysed from section to section of questionnaire to find the correlation between particulars of robot, robot’s work cell which represent robot ergonomic and the effectiveness robot system and robot safety. Finally, a full discussion and conclusion were made based on the overall survey result.

3. RESULTS AND DISCUSSION

The questionnaire was sent to 160 selected companies based on the business field which obtained from e-Directory founded by Federal Manufacturer Malaysia (FMM). 35 sets of questionnaire were sent to Electric and Electronic industries, 30 sets of questionnaire were sent to Iron and Steel industries, 30 sets of questionnaire were sent to Plastic product industries, 30 sets of questionnaire were sent to Machinery and engineering, 30 sets of questionnaire were sent to transport/vehicle equipment industries and the other 5 sets were sent to other type of industries.
From 35 samples of electric and electronic industries, 17 were responded, about 42.5%. From 30 samples of Iron and Steel industries, 6 were responded, about 20%. While in transport and vehicle industries, 12 out of 30 were responded, about 40%. For machinery and engineering industries, there were 4 respondents out of 30 samples and 1 respondent from other industries. Unfortunately, there was no respondent from plastic products industries. Therefore, total respondents are 40. Figure 2 below shows the respondents based on manufacturing subsector.

![Graph showing respondents by manufacturing subsector]

Figure 2 Manufacturing subsector of business

Figure 4 shows the percentage of the application robot according to its task or production line. The highest percentage of application area uses robot is welding where 18%. Spray painting sat at second ranking where there are 17% of robots are used in this application area. The third is load and unloading application, 16%. For grinding and polishing, there are 9% of robots are used in this application field. In quality inspection, there are 7% of the robots in this application. There 6% of robots used assembly, material handling, 5%, metal cutting, 4% and the other application are 3%. This result is not showing how many company used this type of robot application. It show how many robot used in Malaysia industries based on application areas. In welding and spray painting, these applications require many robots in one company to execute the task. In one company, the quantity of robot needed may be in 15 to 23 robots.

![Graph showing percentage of robot applications]

Figure 4 Number of robot in production line application
3.1 Particular on Robot

Most of the robots are bought from Japan. There are 14 companies bought robots made in Japan and followed by Korea where 9 companies use robot from there. The third is robot made from China where 7 companies bought robot from there. USA was at the fourth place where 5 companies from the respondents use robot from there and the fifth is robot from Germany, 3 companies bought from there. Many companies bought robots from Japan because Japan is the money exchange is low and good for their capital and also for long investment. Besides, Japan is leading in the use of industrial robots and application of high technology (Ernest L. Hall and Nathan Mundhenk).

72% of the companies in Malaysia implement Cartesian robot. This is because the Cartesian robot is the simplest robot and for sure, it is cheaper than others. The second highest type of robot used in Malaysia is the SCARA robot. Although this type of robot more complicated than other types, SCARA robot is used to perform more complicate task and for job required mere accuracy and reliability.

Type of robot configuration also contribute important factor in considering ergonomic program in robot work environment. The configurations of robots determine the work envelope of robot. The work envelope of robot work will guide robot programmer the right program such as relevant path of robot motion, number of work cell, optimum speed which is all these parameters are used to optimum robot system.

The robot’s brand listed is not most popular among Malaysia industry. Only 7 companies implement both Kawasaki and Adept robot. From 40 respondents, 19 of them implement other type of robot. The other type robot are Custom made type, KUKA, ABB, Hyundai, Cincinnati robot and etc.

There are many type of robot installation in work cell. The type of robot installation depends on the robot task. Proper robot installation will lead correct programming for robot. Figure 8 shows the result for type of robot installation in production plant. There 25 respondents installed the floor installation in robot work cell. The rest types of robot installation only have below than 10 respondents. For omnidirectional wheel-based robot, there are 7 respondent, console installation, 5, and gantry overhead robot, 3. Many of manufacture installed the floor installation to their production plant because this type arrangement is convenient to many application fields such as pick and place, material handling and welding. The gantry overhead installation is not popular among manufacturer because it required high initial cost to construct the overhead rail.

3.2 Work Cell Layout

Figure 5 shows the type of layout arrangement. It can be seen from the bar chart above, most of the layout arrangement are robot-centered cell where 18 respondents applied this type of layout arrangement. It is followed by in-line robot cell, 13, and overhead rail system. The lowest type of layout arrangement is mobile robot. Robot-centered cell can be applied in many application fields such as pick and place, load and unloading, and material handling. In-line robot is mostly used in spray painting, welding, quality inspection, and assembly.
Figure 6 shows the elementary consideration of work cell design. More than 50% of respondents choose they consider the load-unload with conveyer. There are 57% respondents choose this elementary consideration while there are 19% respondents choose safety consideration come first before design the workcell of robot. The other types of consideration which should be considered by manufacturer are same work height, load-unload pallets and wrap-around station. The lowest popular consideration is random load-unload station which only 2%. Consideration for same work height is more refer to human-robot integration. It is important to give maximum comfortably to human operator. This consideration considers the ergonomics of human and match to robot ergonomics.

Figure 7 and Figure 8 show the safety device provided in work cell. Safety device is the most important things to ensure that all the operator and robot itself are protected from any accident. For physical barrier, 36 of 40 companies use wire meshing fence as the barrier of the robot work envelope and the rest use safety rails. For sensing device, 39 out of 40 respondents use interlock on gates/doors. Only 18 companies use light curtain as the sensing device and 15 companies install single beam photoelectric. Only 5 companies out of 40 respondents install presence sensor as safety device in the robot work envelope while no respondent use mats as sensing device.
3.3 Human-Robot Interaction

In order to handle the robot correctly, all the respondents give training to the robot operator as result shows in Figure 9. Figure 10 shows the type of the training given to robot operators. 31% employers give on-job training while 24% of the companies choose to send their robot operator to be trained by supplier who knows the specification of robot very well. Besides these two types of training, some employers also give off-job training by skilled worker, 19%, and some employers prefer to send their robot operator to special training center, 17%. Other type of training only comes 9%. Many respondents prefer to give on-job training by skilled because this training will not required more cost and new robot operator can adapt to the type of robot easily.

Figure 11 shows the distance between human operator and the robot. For safety purpose, no companies have distance between human and robot less than 1 meter. 15 companies have 1 meter human-robot distance and 12 companies have 1.5 meter distance. 8 companies have more than 2 meter human-robot distance and 5 have 2 meter distance. 1 meter distance looks the most suitable distance between human and robot for pick and place, material handling and loading and unloading application. For more than 2 meter distance, mostly used for more hazardous work area such as spray painting.
Teach station on robot may consist of teach pendants, programming units, controller front panels, and DOS- or Windows-based software running on microcomputers. Position of teach station is one of the important in ergonomic application especially to standard Malaysian size. Inconvenient of teach station position may occurred come kinds of accident such as neck fatigue, back ache, and so on. In Figure 12, all the respondents find the teach station position is convenient to the operator during handle the robot.

![Figure 12 Compatibility of teach station to operator](image)

Bar chart in Figure 13 above shows the height of table or conveyer in the work station for human-robot interaction in pick and place, material handling and loading and unloading, assembly, quality inspection and other application. Most of the work cell have 1.0-meter height table in order to satisfy the ergonomics of human. It is about 13 companies have 1.0-meter height table. For 0.75 and 1.25 meter height table have same value. There are 5 companies for each categories of table in work cell. It seems not too convenient actually because 0.75-meter height is too low for Malaysia size that has about 1.60 meter height for man. 1 respondent use 0.3 meter height of table in their production line.1.0 meter also can still be considered as quite low for Malaysia standard size if the operators have to stand while running the operation.

3.4 Level of Robot Accident

![Figure 14 Average frequency of robot accident](image)
Bar chart in Figure 14 above shows the average frequency of robot accident in Malaysia industry. From the chart shown, there are 16 respondents chose 1 case per year while 6 companies find that there 0.5 case per year. The other average frequencies are 1.5 times per year which about 5 companies, 2 times per year, 3, and no respondents tick 2.5 times per year robot accidents experience.

Figure 15 Area of robot accident

Figure 15 above shows that the area of robot accident always happened. Generally, the accident rarely happened during its normal operation which is only 4 cases recorded. The highest case of accident happen during doing maintenance where it has 30 cases and during programming has 9 cases.

The accident involving robot is not just physical accident like body impacted or body crushed. It can be the computer system halted, malfunction, unpredicted movement or speed and also injury suffer by operator. From Figure 16, most of the respondents tick robot system malfunction as a major robot accident cases in their production line. It caused by the complexity of robot configuration and less understanding on robot ergonomics. So, it may cause lack of knowledge on robot behaviour. There are 27% robot accidents caused by robot malfunction. The other is the second major type of accident where 27% cases recorded. The other accident include fatigue eye which suffer by human operator who doing programming and maintenance. Besides, it also include robot halted and unpredicted robot movement. The third is back ache accident which is also suffered by human operator. The rest of robot accidents are teach pendant not available, 18%, and only 4% operator pinned.

Figure 16 Common robot accidents

For safety purpose, maintenance should be doing although majority of the accident case happened during maintenance activity. There are three types of maintenance. They are periodic maintenance which is may be doing once in three month or may be once in a half year, reactive or corrective maintenance is doing when any accident happen and the last one is the preventive maintenance is doing as a prevention step of robot accident. Figure 17 shows, there are 48% companies prefer to do reactive/corrective maintenance and 33% companies choose to do periodic maintenance. Only 19% companies do preventive maintenance. Supposedly, most of the companies do periodic maintenance. However, those companies do not any accident in their production plant, they rarely make any reactive maintenance. A good preventive maintenance program can eliminate some accident attributed to robot or robot system failure.
Figure 17 Type of maintenance

Figure 18 Production line where accident always happen

Figure 18 above shows the production line where robot accidents always occur. Most of the accidents happen in pick and place activity and loading and unloading. Each activity recorded 15 cases. The other activities are metal cutting, 8, material handling, 7, and the last one is quality inspection, 2 cases recorded. In welding operation, 1 case was recorded. For the rest production line, no accident case recorded.

<table>
<thead>
<tr>
<th>Cause</th>
<th>%</th>
</tr>
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<tbody>
<tr>
<td>Incorrect action of the robot during normal operation because fault</td>
<td>8</td>
</tr>
<tr>
<td>Incorrect action or operation of peripheral equipment in the robot work cell during normal operation</td>
<td>10</td>
</tr>
<tr>
<td>Careless approach of the robot by operator, programmer, maintenance personnel, or unauthorized employee</td>
<td>14</td>
</tr>
<tr>
<td>Incorrect action of the robot during manual operation because of system fault</td>
<td>10</td>
</tr>
<tr>
<td>Human error in teaching or testing</td>
<td>16</td>
</tr>
<tr>
<td>Incorrect action of the robot during testing</td>
<td>16</td>
</tr>
<tr>
<td>Incorrect action or operation of peripheral equipment in the robot work cell during testing and repairing</td>
<td>15</td>
</tr>
<tr>
<td>Other</td>
<td>11</td>
</tr>
</tbody>
</table>

Table 1 Main cause of robot accident in production plant.

Robot accident may cause by eight different situations that cover the three area of robot accident which has mentioned in the previous discussion. They are regular operation, programing and maintenance. Some of the accidents the cause involve failure or incorrect action of the robot system or some peripheral machine or device. From Table1, 16% respondents choose human error in teaching or testing and incorrect action of the robot during testing as the main cause of the robot accident. 15% of the respondents choose incorrect action or operation of peripheral equipment in the robot work cell during testing and repairing as another main cause of accident. During programming or testing, it is
often necessary for the programmer to be visually closed to the tooling to assure that alignment with the part or fixture is present before the point is programmed. During this time the programmer is moving the tooling with motions buttons on the teach pendant. When a manually taught point is the programming technique required for the robot cell, the programmer must be closed to the robot with the drives system active. This activity exposes the operator to the harm.

![Figure 19 Result of robot accident](image)

Figure 19 shows the result of the robot accident. 31% respondents find that the accident results unpredicted program change. The present program of robot after accident is not same to the robot programmed install before. The speed of arm and point direction may be changed. 31% of the respondents choose robot accidents may cause unpredicted movement after robot accident happen especially when the robot accident are robot malfunction or robot arm collided with operator body or another machine or equipment in work cell. 24% of respondents find that robot accident may result the component malfunction. The component in the work cell, whether components of robot itself or other equipment may be affected by the accident.

It can be seen that the major effect of the robot accident is stop the operation. The operation has to stop in order to make an investigation on the robot accident and make reactive maintenance. The other effect is affected of the operation stop. The accidents also increased the production cost. The companies will be penalty by OSHA, must pay for insurance to injured employees and additive maintenance should be done and need to spend additive cost for repairing.

4. CONCLUSION

The understanding in industrial robot ergonomics is one of the important things to all the persons involved in manufacturing industry. From the result obtained and discussed in the previous chapter, 72.5% of respondents had experienced in robot accident. 16 of 29 companies had at least once a year as frequency of robot accident. The highest percentage type of robot accident is robot malfunction. There are 27% of respondents had experience in this type of accident. Although many of the manufacturers use the simpler robot configuration, the robot system still faults. This accident occurred because ergonomic consideration in designing work cell is not applied correctly. Robot accident shows the level of awareness of the public on the robot safety and level of robot ergonomic application especially robot work cell which robot work cell clearly represents the robot system. Even if the programmer selected points that were in the clear, the robot controller might select a path between points that result collision. Therefore, robot ergonomic knowledge would guide to programmer to install right robot programming such as number of motion, and relevant motion path. As a conclusion, knowledge on industrial robot ergonomics should be spread widely especially to the person who work with robot.

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