Enhancing the management of the noise level using six sigma method: a case study on the machining industry

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Abstract. The hearing disorder is caused by noises in the workplace, it has been a concern for numerous researchers. This study aims to improve the performance of the management of the noise level by applying the six sigma method. Data collection is done directly by using a sound level meter. In addition, several key informants also used in order to gather information related to the problem. The results showed the values of Cp and Cpk on the entire department are still below the recommended value. Moreover, the results also showed the potential failure (DPMO) approximately 115,260.6 and equivalent to the Sigma value is approximately 2.70. Furthermore, the highest value of the RPN in FMEA analysis is the workers not wear factor of earplug which is about 56. Thus, it is necessary to make enhancements to the process of managing the noise level in the framework of continuous improvement.

Keywords: Noise, six-sigma, FMEA, Fishbone, DPMO

1. Introduction

Noise can be defined as unwanted sound that can be found in the environment and the workplace [1]. Furthermore, noise is considered to be one factor contributing to occupational hazards in the workplace [2], [3], [4]. Several studies show that noise pollution is a major concern in many countries [5], [6], [7]. In addition, there are approximately 600 million workers exposed to noise in the workstation worldwide [8]. Furthermore, the WHO reports that workers in developed countries about 15% exposure to noise and potentially harmful to hearing [4].

The relationship between occupational noise and an increase in accidents and injury risk significantly has been the subject of study by several researchers [9], [10]. Several potential consequences arising from noise exposure that contribute to accidents and injury, such as disrupt the concentration [10], increased fatigue and extend the reaction time [9] reduces the ability to hear warning signals [11], increased stress [12], sleeping disorders [13], hypertension [14], and heart disease [15].

Furthermore, research conducted by Moll van Charante and Mulder emphasizes the increased risk of accidents triggered by the presence of hearing loss as an accumulation of exposure to noise [16]. Moreover, the lack of use of hearing protection devices (HPD) is suspected as one of the factors responsible for the increased risk of injury [17], [18], [19]. As a result of the lack of attention of workers in the use of HPD led to various problems such as a decreased ability to hear, interpret the message and a warning signal in the workplace and in order to analyze the ability of votes required in the monitoring machinery and work equipment [11]. In order to solve the problem of minimizing the potential risk to use various approaches. Several considerations are used in applying these approaches such minimal cost and on time. For example, U.S. Department of Health and Human Services has made a practical guide
in order to prevent job loss of hearing [20].

One method that may improve the performance in reducing noise is to apply the Six Sigma method. There were challenges and exciting opportunities in every procedure that may be given by the Six Sigma method. Thus, six sigma method is applied as an approach method in this study to minimize the risk of noise. Six Sigma method has been applied in several areas of research, such as manufacturing [21], [22], health and safety [23], [24], environmental management systems [25], pharmaceutical industry [26], [27].

Six Sigma which applies a variety basic statistical methods and tools of traditional quality management has a huge impact on the quality management approach [28]. Through the application of basic statistics into innovation in quality as an initiative to make Six Sigma business strategy to achieve goals such as increased profitability, increased the market, increase customer satisfaction, reduce material wastage, the waiting time and the risk of accidents. Furthermore, the enhancing company performance is able to achieve by implementing the business strategy using six sigma method [29]. Thus, this study aims to improve the management of health and safety due to the risk of noise by applying six sigma methods.

2. Material and method
The study was conducted in the manufacturing industry, especially in the machinery and automotive divisions. This study analyzed the noise level management to review the factors that most influence on the management of the noise level. Furthermore, the study begins by analyzing and identifying the factors that lead to high levels of noise which exceeds the noise level standard quality standard defined by the Ministry of Labour in Indonesia. In order to address this problem, six sigma method is used to define, measure, analyze, improve and control. Six Sigma methods adopted and modified from US EPA Environmental Professional's Guide to Lean and Six Sigma [30].

In addition, several methods also used in analyzing the causes of problems such as Fishbone diagram, Failure Mode Effect Analysis (FMEA) and 5W1H. Furthermore, this study used observational data and noise level measurements conducted directly by using sound level in the department of construction, assembly and engineering. In addition, the study also conducted brainstorming on several key informants to obtain information related to the causative factors. In addition, the questionnaire used in order to explore the information related to factors that could potentially lead to failure of the noise management process. The questionnaire was distributed to five key people in the company. Primary data obtained from measurements of the noise level will be processed with the aid Minitab software.

In addition, by knowing the value of process capability, then the sigma value will also be determined. Moreover, Fishbone Diagram also used to identify the cause of the noise. Based on the calculation process, then performed an analysis of the factors that cause the problem by applying Fishbone diagram and determine the factors that have the highest number of potential risks by implementing FMEA. Thus, the proposed improvements to the process can be provided based on the ranking of risk factors.

3. Result and discussion
3.1. Define
Determination of the first stage in the current six sigma method is Define. This phase has four major step process that may be considered. For instance, investigation processes and work environment, SIPOC diagram preparation, gathering information and problem establishment. Clarify the issue a priority in the management of noise level. This phase uses SIPOC diagram instruments in order to obtain an overview the process in detail. SIPOC is an abbreviation of Supplier, Input, Process, Output, and Customer. The SIPOC diagram for the noise level management process is given in Table 1 below.
Table 1. SIPOC Diagram

| SUPPLIER       | INPUT                                        | PROCESSES                                      | OUTPUT                                         | CUSTOMER                                               |
|----------------|----------------------------------------------|-----------------------------------------------|-----------------------------------------------|--------------------------------------------------------|
| Engineering    | Material metal                               | Process design and assembly machines          | The noise level more than 85 dB               | Employees feel uncomfortable                            |
|                | standard work                                |                                               |                                               | Employees get tired                                     |
|                | Machinery and                                        |                                               |                                               | Employees easily stressed                               |
|                | Equipment work                                 |                                               |                                               | Employee potential against the risk of deafness.       |
|                | Personal protective equipment                  |                                               |                                               |                                                        |
|                | The company’s physical environment           |                                               |                                               |                                                        |
| Assembly       |                                               |                                               |                                               |                                                        |
| Construction   |                                               |                                               |                                               |                                                        |

3.2. Measure

In order to determine the size and nature of the problem to be solved is required initial data collection history. It is part of the determination of lean six sigma phase. According to the results of direct measurements of noise levels at three different location such as engineering, assembly and construction. Furthermore, the data shows that construction department has the extraordinary level of noise approximately 91.8 dB and the minimum level around 81.4 dB. Moreover, at engineering department has the high level nearly 72.5 dB and the low level around 56.3. In addition, the assembly department provides the high level of noise roughly 86 dB and the small level around 67.1 dB. Therefore, overall it puts construction department with the highest noise levels compared with assembly and engineering departments. Based on this data, the normality test conducted to determine which the data have the normal distribution.

Based on normality test gives information that the value of Kolmogorov-Smirnov (KS) around 0.300 and p-value < 0.010. With the hypothesis that the value of H0 is accepted if the p-value > 0.05, it can be stated that the level of noise on engineering department is a normal distribution. Furthermore, normality test of the data on the assembly department below provides information that the Kolmogorov-Smirnov (KS) is approximately 0.344 and a p-value of about 0.459. With the hypothesis that H0 is accepted if the p-value > 0.05. Thus, can be expressed that the level of noise on the assembly department is a normal distribution. The normality test at the construction department also provide the value of Kolmogorov-Smirnov (KS) around 0.090 and p-value approximately 0.150. With the similar hypothesis that the value of H0 will be accepted if the p-value>0.05. Therefore, it can represent that the level of noise on the construction department is a normal distribution.

![Figure 1. I-MR of noise control chart at The Engineering Department](image-url)
From the normality test is known that all research data were normally distributed. Furthermore, individual moving range control chart (I-MR) were made on each of the test parameters. The control chart is useful to ascertain whether the performance of the process is currently under control (in control) in which the process is running with good stability without the influence of specific causes. The figures of control chart of noise at each engineering department are presented in Figure 1, 2 and 3.

![I-MR Chart of Assembling](image1)

**Figure 2.** I-MR of noise control chart at The Assembly Department

![I-MR Chart of Construction Department](image2)

**Figure 3.** I-MR of noise control chart at The Construction Department

The next step in the measures phase is calculating process capability. The calculation of process capability is intended to determine the extent to which a management process to meet predetermined specifications. Process capability analysis conducted if all the data is in statistical control. The table 2 below represents the results of calculations to determine the value of the Process Capability Analysis of each department. Furthermore, the results show that the Cp values at the entire department were still under the prescribed specifications such as the engineering department around 0.39, the assembly department approximately 0.92 and the construction department roughly 0.71. Similarly, Cpk values
are also under the prescribed specifications, such as the engineering department approximately 0.24, the assembly department around 0.85 and the construction department around 0.56. In addition, Cp and Cpk values on all three departments have a potential failure of the process of managing noise levels around 287,410.98 in the engineering department, the assembly department 6,823.09 and 51,547.65 on the construction department. Furthermore, based on the results of these calculations the average value of Cpk around 0.55 with the potential failure (DPMO) approximately 115,260.6. By using a conversion table DPMO to Sigma Value Based on Motorola Concept was obtained Sigma level around 2.70. Therefore, it can be explained that the process of managing noise levels should be improved.

| Department    | Cp   | Cpk  | Possible process failure (DPMO) |
|---------------|------|------|---------------------------------|
| Engineering   | 0.39 | 0.24 | 287,410.98                      |
| Assembly      | 0.92 | 0.85 | 6,823.09                        |
| Construction  | 0.71 | 0.56 | 51,547.65                        |
| Average       | 0.55 |      | 115,260.6                        |

3.3. Analyze
Analyze is the third operational steps to improve the level of Six Sigma. In addition, the goal to be achieved in the Six Sigma is basically to bring the process under the conditions of stability and have a better capability and achieve zero failure rate. Analyses were performed by collecting the possible causes of the occurrence of out of specification by using the method of brainstorming and classify possible causes by using fishbone diagram.

![Fishbone diagram for noise level management](image)

The next stage determines the root cause of the problem that caused the failure of the dominant noise level management. The method used is the Failure Modes and Effects Analysis (FMEA). Failure Mode and Effect Analysis (FMEA) is a systematic technique for identifying and analyzing and prevent failure. To be able to understand the type of failure, effects and how to make improvements so the next step is to process the results of brainstorming and fishbone diagram into FMEA worksheet. Furthermore, by applying the brainstorming the key informants provide an assessment of potential failure factors are based on the level of severity, occurrence, and detection. The scale of assessment for this calculation is 1-10. Assessment depends on the skills, knowledge, and experience of key informants in understanding the severity, occurrence, and the detection process. Then, calculate the risk priority number (RPN) and prioritize corrective action through the risk level.
Table 3 below shows that the factors that cause deviation dominant in the process of managing the noise level is the material used in the production process and also the rooms were not equipped with a silencer. This is demonstrated in the highest RPN value, such as the use of PPE (Earplug) around 56, the room was no noise reducer around 42 and the tool is not in a normal condition for use approximately 15.

| ID Failure Modes | Potential Failure Modes | Risk Priority Number (RPN) |
|------------------|-------------------------|---------------------------|
| 4.1              | Wear PPE                | 56                        |
| 2.1              | Environment             | 42                        |
| 3.1              | Equipment               | 15                        |
| 1.1              | Material                | 10                        |

3.4. Improve
The improve phases conducted after find out the root cause of noise levels that exceed the value of the noise standard. Thus, it is necessary to the determination of the corrective action plan in order to improve the quality of Six Sigma. At this stage formulated several actions aimed to increase or reduce the factors that can contribute significantly to the process of noise levels management. Therefore, in order to carry out the process of improving the noise level management activities may be carried out as follows:

a. Propose that material labeled as to the level of material hardness. This will provide insights into the working of the working methods of materials having different hardness levels. Thus, with this table will significantly reduce the noise level.

b. Provides a layer of noise reducer on the work area wall that has the potential to cause noise at a high level. Thus, it will be able to reduce the noise level significantly. In addition, employees who are in other rooms do not feel disturbed.

c. Proposed that companies implement workplace health and safety training in order to provide and enhance the knowledge of the workers in order to determine the potential risks arising from work activities. Through this training are expected to arise from employee behavior changes associated with the use of personal protective equipment, safe working methods and a safe working environment.

d. Companies should provide personal protective equipment appropriate for the work performed by employees. In addition, safety equipment must also consider the size of the body of each worker. This is done in conjunction with the comfort level of workers in the use of personal protective equipment. By using appropriate safety equipment will be able to influence the level of productivity of workers.

e. Perform periodically preventive maintenance on all types of equipment used in each production process. Through this activity will provide several advantages for companies and workers, such as reduced levels of machine breakdown, reducing the potential for accidents and improve engine performance. This maintenance activity can be made based on the period of daily, weekly and monthly.

3.5. Control
The final stage of the Six Sigma method is a process control. This activity aims to monitor and evaluates the overall implementation of activities to improve management of the noise level. This stage has a crucial role to Six Sigma approach. This is because the improvement process should be ensured that the repair process on the factors that caused the problems has diminished. In addition, this phase also provides assurance that the proposed changes have been made in order to achieve the targeted goals. Moreover, stakeholders may create a system that is standardized by the modification of policies, regulations, procedures and other management systems. It aims in order to deliver the certainty of continuous improvement. For example, use of statistical control charts to be able to control the noise.
level minimization process. Thus, it will be able to identify whether a statistically controlled process and meet the standard specifications or not. In addition, statistical process control can also observe the consistency of the process and make the process under control.

4. Conclusion
In conclusion, the Cp value at Engineering department around 0.39, Assembling department roughly 0.92 and Construction department approximately 0.71. In addition, the results also showed the average value of Cpk around 0.55 that generate potential failure (DPMO) approximately 115,260.6. This is equivalent to the sigma value is around 2.70. Furthermore, DMAIC method which involves of five phases of the Six Sigma method potentially be applied to the management of noise level. This method may bridge the various efforts in order to reduce the noise level. Moreover, Fishbone diagram shows several factors that cause problems. With the support of FMEA to give priority ranking of the factors that are considered the leading impact on the noise level. Thus, various alternative resolutions may be carried out as a reaction to the problem approach. Goal to condense the ratio of the noise level according to the target of the company will difficult to accomplish. This is because there is no systematic method that is able to support and resolve problems faced. Six Sigma method is a systematic method and is able to solve the problems of a reduction of noise level. The effectiveness and improvement can be achieved by integrating Six Sigma with other methods for the application of the noise level management plan. This study might a starting point in the implementation of six sigma method for designing an investigation into attempts of noise level management.

5. References
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