The Predictable Maintenance 4.0 by Applying Digital Technology: A Case Study of Heavy Construction Machinery

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ABSTRACT

This paper aimed to 1) classify the heavy machinery working process and 2) analyze vibration for the heavy machinery working process (Vibration Monitoring and Analysis) in order to apply the results for future planning of predictable maintenance using heavy machinery. The data was collected from grouping engines through analysis of life expectancy, duties, importance and vibration from 14 heavy machinery pieces, during which value changes were observed that were the causes of deterioration to synthesize the data for predicting maintenance from a smartphone application and analyzing the forecast by finding the appropriate time to inspect heavy machinery. It was discovered that every 15 days and 30 days were the most appropriate times for checking conditions. After preserving machines in good working condition, categorization was carried out by the working processes of different lengths of time, resulting in more accurate preventive schedules that can be constructed by using data checking rather than average number of machine breakdowns. However, the policy was set to maintain heavy machinery as the result of the process from Mean Time between Failure (MTBF) values together with Mean Time to Repair (MTTR) values, which reduce damage by applying 4.0 digital technologies to predict maintenance in heavy machinery.

Keywords: The Predictable maintenance applying 4.0 digital technologies, Heavy machinery, Vibration monitoring and analysis

1. INTRODUCTION

The construction industry is one of many factors that motivate the national economies of countries around the world. Researchers should expect that the industry can drive an economy to be better or worse. In the construction business at present, people use many types of machinery to save time in construction. Because of its efficiency, it also results in less cost for using labor. Some construction should meet standards, e.g. compaction and excavation. Unfortunately, the construction business has faced increasingly higher annual budgets for repairing machinery. Sometimes, projects need to choose reliable and high-quality machinery. Thus, extra services should be available for this possibility. To maintain the efficiency and accuracy of machinery, having a plan to check for conditions can affect the process by making it faster and more cost-effective

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(save time, save cost). When interferences occur in the course of heavy machinery operation, it can put a stop to the entire construction process. To ensure that the machinery and equipment used in production is properly maintained and prepared to respond to current and future needs, providing appropriate management is necessary. This is the reason why researchers apply 4.0 digital technologies to predict needed maintenance.

This paper research is related to the construction industry, where there is a significant amount of heavy construction machinery used. Maintenance in order to prevent and counter deterioration is also considered so that heavy construction machinery can operate continually and effectively for longer periods. However, some problems while processing are still possible. From the evaluation of time, Mean Time between Failure (MTBF), Mean Time to Repair (MTTR) and related studies, the researchers found that predictable maintenance 4.0 by applying digital technology could decrease the interference and deterioration in heavy construction machinery. SM Mortazavi et al.(2017) found that redundancy was a well-known and widely used approach for enhancement of failure-sensitive systems, which are subject to both dependent and independent failures. In most reliability analyses and mean time between failures (MTBF) evaluation models for redundant systems, most dependent failures reduce MTTF and MTBF in redundant systems. Therefore, the frequency of dependent failure events in redundant systems must be minimized and appropriate corrective actions must be taken. The comparison revealed that considering dependent failures in the MTBF function leads to the reduction of MTBF in redundant systems. Obviously, by investigating and integrating dependent failures in MTBF evaluation models for redundant systems, more applicable and realistic MTBF models can be developed. Liu et al. (2011) used bivariate exponential distribution, assuming that components have interdependent lifetimes. In another study by Liu et al. (2010), component lifetime and repair time were modeled by random fuzzy exponential distribution. In addition, system MTBF and mean time to repair (MTTR) were calculated. Goyal et al.(2016) used nonlinear regression to model a degradation process in order to predict mean time to failure (MTTF).

This paper focuses on how to protect the interferences that happen in machines' operations. Lahri (2015) found that the methodology typically adopted for study is direct observation of machines. Here, both primary as well as secondary data has been gathered for the case analysis. After several visits and direct observation of machines as well as analyzing previous machine utilization record problems, it was identified that the machine was not working up to its full load production capacity. Thus, management wants to implement a productivity improvement tool for the organizational environment and management of a "Routine" level of machinery failures and breakdown. Most past studies carried out research on the process in order to predict mean time to failure, but few case studies have researched the case system for heavy machinery in terms of maintenance, which usually misses, but often damages machines, causing low production efficiency. If you look deeper, however, the machine is often damaged by damage to the parts itself, and if it happens to be a piece of machinery that multiple machines (Common Part), it means other machines. It's a chance to lose it, but it's not the time. Therefore, planned maintenance requires both machinery and parts. Both the machine and parts should start with the model equipment and model part. The reason is that the researcher are interested in this study topic. The researcher uses predictable maintenance, which may include categorizing the heavy machinery working process, the vibration of the heavy machinery working process (Vibration Monitoring and Analysis), scheduling for checking engine

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conditions, and maintenance that is not related to the three main variables, including priority, lifetime and duty of heavy machinery.

1.1 Heavy construction machinery working process

Goyal (2016) presented a vibration analysis that proved to be a measure for any cause of inaccuracy in manufacturing processes and components or any maintenance decisions related to machines, as well as a state-of-the-art review of recent vibration monitoring methods and signal processing techniques for structural health monitoring in manufacturing operations. These methods and techniques are used as tools to acquire, visualize and analyze the sampled data collected from machining operations, which can then be used for decision making about maintenance strategies.

Vibration refers to the back and forth movement of objects in comparison to a reference point. Stagnant by backward movement of an object may be free movement or have constant force. For movement, vibration can be found in everyday life and in many engineering aspects. Examples of common vibrations include the vibrations in cars and vibration from the work of heavy construction machinery. Vibration in cars occurs when starting the engine as a result of the operation of the pistons in the engine. Imbalance causes vibration. When a car starts moving, the cogs in the transmission system begin working, causing vibration and noise as well. If the car runs through a rough road, it causes a wave. Running through a xylophone or a hole on the street is similar. The effect of unevenness on road surfaces causes vibration. The vibration from the engine can be resolved by balancing the engine. The least unbalanced force also requires a rubber support platform to reduce the vibration from. Engine to other parts vibration due to the formation of cogs can be reduced by the cog design and increasing the smoothness of the cog. Partial vibration is from the effects of ground conditions. Smooth roads can aid reduced vibration by designing a support system, which consists of springs or tweezers and delays, including shock absorbers (appropriate shock). The researcher analyzed vibration in order to evaluate machines by setting measuring points. The data collection can be applied for analyzing and evaluating machine conditions or abnormalities, e.g. imbalance. Identifying the trend of change in vibration is also possible. Then, the value in each stage will be converted to a graph. Thus, we can find the point which has the value change of vibration, which can be used to predict future failures in heavy construction machines for appropriate times for inspection. Vibration will allow for the enhanced design of machines. Low vibration affects comfort and safety in the use of machinery. In addition, when machines, especially rotary machinery, vibrates and the machinery malfunctions, the vibration will change. Thus, basic understanding of vibration is needed. The signal analysis method must also be very good.

Larizza (2015) stated vibration analysis is the most prevalent method used for monitoring, detecting and analyzing structural conditions in real time or at specified time intervals, due to fast data collection and interpretation. Vibration analysis is a very complex domain that exploits several aspects of testing and diagnosis disciplines, from condition monitoring to defect detection. Improvements in sensor technology now permit the use of vibration analysis methodology within the micro-/meso-world. Vibration analysis methodology can be subdivided into four principal domains:

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1. Time domain
2. Frequency domain
3. Joint domain (time/frequency domain)
4. Model analysis

1.2 The Predictable maintenance

Tsang (1995) found equipment maintenance program to preserve system functions in a cost-effective manner. Surveys using a wide variety of techniques are commonly used to monitor the conditions of mechanical systems. Osborne (1993) presented a preventive maintenance (PM) system in a high volume manufacturing operation with a just-in-time environment. Rolfsen (2012) found that TPM was originally a technologically-based concept, meaning the explanations for success or failure are mainly organizational, pointing to management style, collaboration between maintenance and production. Involvement and teamwork to a high degree of autonomy are also important contributors to success.

Machines are important features for the construction industry. Thus, it needs to be maintained at all times for quality working times. If it is unusable or too incomplete to work, it means the working process is ineffective. It wastes time, which can cause severe loss in business. This problem needs to be fixed in order to improve the quality of engines while avoiding deterioration. There must be ZERO problems. As mentioned, we should plan to maintain our machines for preventing deterioration problems that could cause a break in the working process, resulting in wasted time and budget. The self-maintenance can be done by specifying the scope and type of machines and making employees follow all instructions systematically. Hence, before letting staff take responsibility for maintenance, we should train them for reducing failures during operation. On the other hand, the steps for manual maintenance procedures include personnel preparation, basic cleaning, standard maintenance solutions, general inspection, self-monitoring and self-management. Systematic and effective maintenance planning can prevent the duplication of work, which can affect wasted time and money. Predictable maintenance is maintenance that covers a policy to check machines' working conditions or deterioration with a detector that can analyze the severity of the condition. Because of this, we can predict the chance for failure in heavy construction machineries, and devise a plan to maintain machines before deterioration occurs.

Predictive maintenance uses condition-based indicators and alerts to raise maintenance needs only when assets are at risk of breaking down — optimizing maintenance cadences and maximizing asset availability. By analyzing data generated by machines and sensors, anomalies and issues can be detected early on before they turn into bigger problems. Potential failures can be predicted and prevented by interpreting signals that are unique to individual assets — instead of using uniform maintenance approaches by asset type — to inform about precise, proactive repairs that save time and money. To be clear: these are not a bunch of warnings that are mainly ignored by operators, but rather actionable insight based on individual assets and unique data.

Predictive Maintenance uses data from various sources like historical maintenance records, fault and sensor data from machines, and contextual data such as temperature or humidity to determine when a machine will need to be serviced. By leveraging real-time asset data plus historical data, operators can make better-informed

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decisions about when a machine will need repair. Predictive maintenance takes massive amounts of data. Industrial AI and machine learning translate data into meaningful intelligence and actionable insights.

As digitization continues to transform businesses end to end, optimizing operations by leveraging not only preventive maintenance tools, but predictive maintenance tools as well becoming table-stakes to survive are. Technology is no longer just a luxury; it is needed to remain competitive, reduce downtime, improve safety and increase profits.

1.3 Applying 4.0 digital technology from smartphone application

Falkenreck (2017) used a multi-method approach to outline and test an IoT Business-to-Business (B-to-B) marketing project in a cultural framework. Trust in manufacturer data safety and transfer is a key enabler for IoT dyadic data exchange. Atzori et al.(2012) claim that cooperating with peers to achieve common goals, interacting with their objects, and providing information in real time through standard communication protocols are relevant contributions from the IoT to relationship building and maintenance. Dutta (2014) assessed the mechanics of competition involving perception and reaction to competitor moves. Both incur delays that can be reduced by digital systems. Patluang (2018) Policy adjustments towards these targets are proposed to fulfill the gap existing in the Thailand 4.0 policy.

The pace of entry into the 4.0 industry has led to digital systems, the cornerstone of advanced technology, linking the world to skilled workers. However, it also reduces the use of labor and the economy of the country. The 4th Industrial Revolution will integrate the world of manufacturing into the Internet of Things (IoT) network, as well as all units of the production system. From raw materials to machine tools, automation robots are equipped with networking to enable communication and exchange. Mutual information is freely used to manage all production processes. A highlight of Industry 4.0 is machine automation that can be linked as a part of social networking over the Internet. You can share information with each other. Some resources can also be shared.

The machinery for Industry 4.0 can increase ability significantly in terms of self-employment, flexibility and adaptability to production conditions. It also has the ability to monitor and predict.

Future machines will also have a program to monitor and maintain machine conditions to extend working life. This will be very useful for planning the production and evaluation of the overall efficiency of the machine; that is, the machine will be more intelligent.

In addition to the intelligent machine, the factories for 4.0 are ingenious. Smart Factories can determine the activity conditions, including the production environment. They can communicate freely with other units wirelessly, as well as produce orders according to factors such as time, cost, production, shipping cost, and security reliability. It is the most cost-effective production system available and reduces unnecessary labor costs.

The VibroChecker app turns an iPhone into a vibration checker. VibroChecker is a true innovation and gets the results you need in just three steps: The ACE app can perform ideal measurements when the iPhone is fully placed on the surface to be

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measured. Once the app has been started, four symbols appear on the display of the mobile phone. When the icon 'Measure Vibration' is pressed, a new window opens and the measurement can start.

The result appears within 15 seconds. The resulting values are the starting point for step two, the calculation interface. The most important key data is then entered – machine weight, number of contact surfaces and the desired degree of isolation are defined using the interactive and intuitive fields.

Finally, the program recommends a vibration isolation product from the ACE range, comprising extremely low-frequency isolating air spring elements, ready-to-mount rubber-metal isolators and the tried-and-tested insulation slabs.

2. LITERATURE REVIEW

Advantage Measurement

The competitiveness of enterprises and businesses is consistent with the context of research on the use of this brace. The National Quality Award (Thailand Quality Award, 2012) is the composition of the Dutch activities of interview. The business consists of making commercial loans, added with the racial offloaded without an increase in sales, increased innovation and binders in the event. An award of this quality can also research Sunson (2015), which found how to measure achievement. Business can be measured in 4 aspects: (1) with the customer (2) Internal processes (3) Learning and (4) Financial growth.

The concept refers to the relationship of factors influencing the effect. Business context, business concepts, including Diamond model (Porter, 1990) discuss the factors. The influence of the pump power of the web with: (1) the benefit of the industry. Businesses have components that include domestic demand, including consumer demand and the demand for foreign goods; (2) the elements of composition. Labor, finance, transportation, technology management and natural resources (3) are related to the business component as a wholesaler of goods. Importers and exporters of home goods and manufacturers of goods come from abroad.

This paper aimed to classify the heavy machinery working process as well as analyze the vibration of the heavy machinery working process (Vibration Monitoring and Analysis) in order to apply the results for planning 4.0 digital technologies for predictable maintenance using heavy machinery as a case study. There are many research studies concerning heavy machinery in construction. Mourtzis (2017) studied this topic with an integrated system being developed under the industry 4.0 concept, consisting of a machine tool monitoring tool and an augmented reality mobile application. Nam (2016) identified a method for controlling engine RPM (Revolutions per Minute) for a construction machine. Rasdorf (2015) found that heavy-duty diesel maintenance equipment consumes significant amounts of fuel and consequently emits substantial quantities of pollutants. However, few studies have researched Predictable Maintenance 4.0 by applying digital technology. After reviewing the literature, the researchers found that the vibration measurement result will be different.

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3. METHODOLOGY

The study focuses on specific issues in the process by conducting research ranging from collection and collecting data in the following steps.

3.1 Classify heavy machinery by analyzing and observing the value changes of vibration that cause equipment deterioration. The main variables are divided as mentioned below:

1) Priority

Level A refers to heavy machine operation that stops when the machine is damaged, causing lost opportunity.

Level B refers to heavy machine operation that can continue when the machine is damaged. However, it causes a break in the process, meaning loss of some jobs.

Level C refers to the machine being damaged, but not affecting the working process of heavy machinery.

2) Life expectancy of heavy construction machinery refers to lifetime from registration date, which can be divided into 3 age ranges:

Long lifespan	refers to	10 years or more of life expectancy
Medium lifespan	refers to	5 to 10 years of life expectancy
Short lifespan	refers to	0 to 5 years of life expectancy

3) Workload refers to the number of working hours per day by heavy construction machinery, divided into 3 periods:

Maximum workload	refers to	8 - 10 hours a day
Moderate workload	refers to	5 - 7 hours a day
Minimum workload	refers to	0 - 4 hours a day

By dividing heavy construction machinery into 3 main variables, it can be divided into 27 groups. The example definition of each group is called "group 1 is level A, long lifespan, maximum workload".

3.2 Data Collection

The synthesis from predicting the maintenance by applying 4.0 digital technologies from the smartphone application can reduce the interferences of construction. Nowadays, it is noticeable and accepted that innovation and technology are the important factors that lead to success for businesses. This research collected data from machines' vibration. In a month, data was collected two times. The first period was 1st – 15th of the month, while the second period was collected on the 30th of the month in order to analyze the value, which was taken to find the trend of change in vibration. Then, the value in each stage would be converted to graph form. Consequently, the point where the value changes of vibration occurred could be identified, which could then be used to predict the future failures of heavy construction machines and the appropriate times for inspection. The researcher also took the results to create an inspection plan for each

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category and evaluateก the performance by using the indicators. From doing this, engines are maintained in good condition, allowing them to work more effectively all the time. Even when damaged, they must return to work as soon as possible. To follow a predictable maintenance schedule, we should measure the utilization of the machines caused by deterioration with time to repair (inherent availability). Pati (2015) stated that availability can be defined as the probability of operation of equipment at time 't'. It can also be defined as the ratio of an actual period for which the equipment finds its utility to the total time for which equipment is required to function. It provides the platform for integrating the reliability as well as maintainability parameters, hence depending on the number of failures that occur and the method of quick rectification for faults. Availability is categorized into inherent, achieved and operational availability. The probability of the operation of a system in a content manner, especially in an ideal environment without any maintenance consideration, is called 'Inherent Availability'. It is generally given by:

$$\boxed{\text{Inherent Availability} = \text{MTBF} / (\text{MTBF}+\text{MTTR})}$$

When MTBF refers to Mean Time between Failures
MTTR refers to Mean Time to Repair

Machine utilization rate after being maintained with maintenance time is (Achievement Availability). Achieved availability is nothing more than the mean active maintenance downtime due to preventive and breakdown maintenance, while operational availability is equivalent to mean down time. Both usage rates can be obtained by:

$$\boxed{\text{Achievement Availability} = \text{MTBM} / (\text{MTBM}+\bar{\text{M}})}$$

When MTBM refers to Mean Time between Maintenance

4. RESULTS AND DISCUSSION

To classify the heavy machinery working process:

For predicting maintenance by applying 4.0 digital technologies from a smartphone application based on available data and analysis, it was found that the vibration of heavy machinery occurs in various stages. Vibration can be described as follows:

4.1 For the importance of heavy equipment and construction of a 9-priority task a very moderate workload exists. There is a tendency for vibration values to increase on the 15th of each month. In very young workloads, there is a tendency for vibration values to increase on the 30th of each month.

4.2 In priority group B, 9 heavy construction machinery, priority B very old, heavy load, heavy load, medium load. There is a tendency for vibration values to increase on the 15th of each month. In very young workloads, there is a tendency for vibration values to increase on the 30th of each month.

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4.3 Priority group C did not perform data analysis for use of vibration results of heavy equipment in other groups. Each group will have a time to check for different usage conditions, after which it is created to check the plan and practice by a maintenance technician. The damage is charged after applying the vibration measurement scheme.

Analyze the vibration of the heavy machinery working process (Vibration Monitoring and Analysis) in order to apply the results for planning of predictable maintenance using heavy machineries. Vibration measurement of heavy equipment construction

To bring the results to data synthesis for Predictive Maintenance Planning 4.0, the application of apps is available on smartphones. Reducing the failure of heavy equipment in construction today is understandable and accepted. Innovation and technological advancement are the key factors that will influence the success of a business. In this study, the vibration of heavy machinery over in 1-2 months was examined to assess vibration. Phase 1 ran from the 15th of the month, while phase 2 ran to the 30^{th} day of the month to find the trend of change in vibration. Then the values obtained in each stage were graphed. The point is that the vibration value is likely to change. Using that point is a predictor of heavy machinery downtime at the right time to monitor the groups. The forecasted time period is forwarded to the measurement plan. The vibration of heavy machinery and the performance evaluation uses the indicators. Planned maintenance measurements will keep machines running for long durations. Even when damaged, they must return to work quickly, meaning performance measure is needed. Planned maintenance involves the rate of use of a machine due to damage. The time it takes for repair (Inherent Audibility) and the utilization rate of equipment due to maintenance and maintenance time are significant factors.

5. CONCLUSIONS

The following conclusions were derived from the results of the above case study. Due to the current preventive maintenance plans being unable to reduce the failure of heavy equipment, predictive maintenance is required through analysis of the vibration values for three heavy variables to determine the appropriate time(s) for measurement, as follows:

5.1 Mean time between failure (Mean Time between Failures: MTBF) of each unit process of heavy equipment. The percentage increase is 10-30 percent. Most of them are classified as having high workloads with average of the time during the crash being not very high

5.2 The average time from failure of use (Mean Time to Repair: MTTR) for individual unit processes of heavy equipment is decreased due to the improvement of time for checking the use conditions for more appropriateness as a result of heavy equipment failure.

5.3 In actual use, the period for which vibration is collected to determine the appropriate time to check operating conditions can increase the frequency of vibration collection to obtain more detailed information. The use of technology can help to get the right timing for a more accurate measurement.

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Table 1: Appropriate time for the condition monitoring plan for all heavy equipment construction work

Priority	Lifetime	Work	Group no.	Analysis Group	Appropriate time to check
A	Extremely long	High	1	/	15
		Medium	2	/	15
		Low	3	/	30
	Medium	High	4	/	15
		Medium	5	/	15
		Low	6	/	30
	Low	High	7	/	15
		Medium	8	/	15
		Low	9	/	30
B	Extremely long	High	10	/	15
		Medium	11	/	15
		Low	12	/	30
	Medium	High	13	/	15
		Medium	14	/	30
		Low	15	-	
	Low	High	16	-	
		Medium	17	-	
		Low	18	-	
C	Extremely long	High	19	-	
		Medium	20	-	
		Low	21	-	
	Medium	High	22	-	
		Medium	23	-	
		Low	24	-	
	Low	High	25	-	
		Medium	26	-	
		Low	27	-	

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Priority

Figure 1: Level A refers to heavy machine operation stoppage when a machine is damaged, meaning lost opportunity

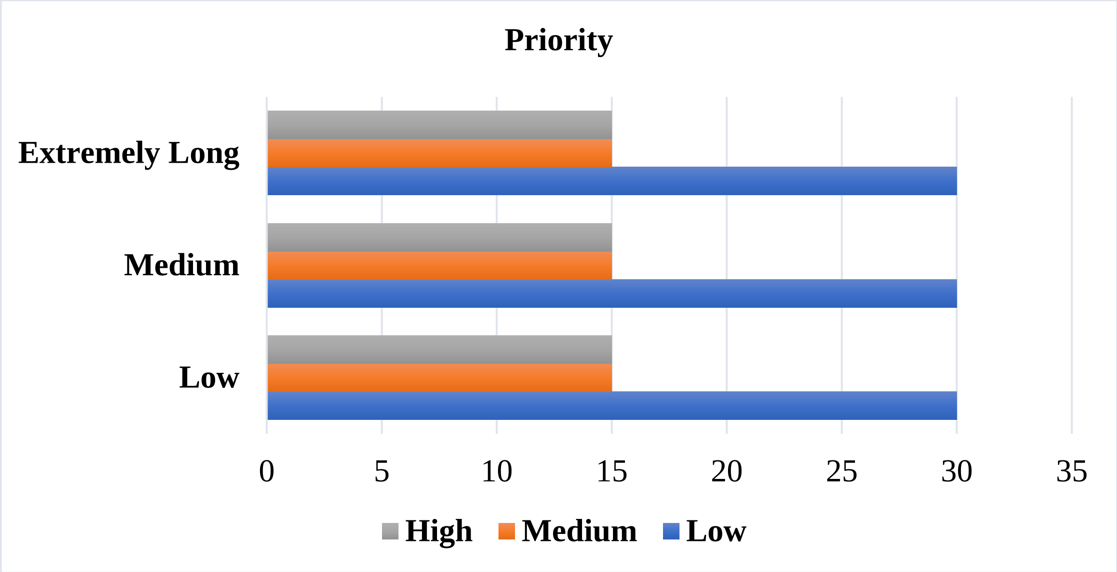
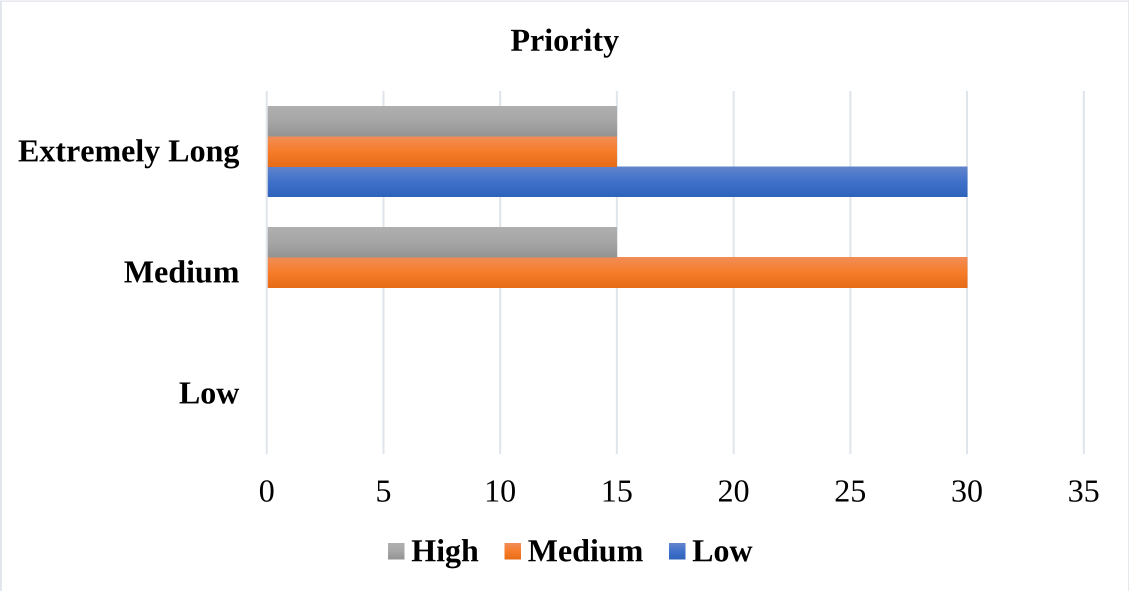


Figure 2: Level B refers to heavy machine operation continuing to operate when the machine is damaged. However, it puts a break in the process, creating loss of some jobs.



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