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# Risk Identification Model for Lean Manufacturing Improvement

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ABSTRACT

*Small- and medium-sized manufacturing enterprises (SMEs) were confronted with a variety of difficulties due to the increasingly complex market environment, and many of them could not make enough profits to proceed with their manufacturing tasks. The objective of this study was to develop a model of risk management by integrating several risk tools at manufacturing companies. This study was also intended to improve the decision making by providing quantitative analysis at each step of risk management and improve lean practices. Risk quantitative analysis methods such as failure modes and effects analysis (FMEA) and multi-objective optimization on the basis of ratio analysis (MOORA) were applied in this study to identify the potential risks. Moreover, the risk assessment was used to categorize risks into different severity levels. The manufacturing data obtained from a case study was utilised to calculate the risk priority number (RPN). The risk mitigation actions were formulated to reduce the original RPN and the final RPN value decreased to a normal standard in the end. Overall, this study optimised the risk management of one case study SME and improved lean manufacturing practices. By establishing the risk identification model and applying common lean manufacturing concepts in reducing wastes at actual manufacturing processes, the manufacturing enterprise could manage to optimize the operations and increase the actual manufacturing productivity. The machining and assembly processes of diesel engines were optimized and improved with the decrease of RPN and the selection of the CK6150 CNC lathe that owns the highest MOORA assessment value.*

*Keywords: Lean manufacturing; SME; FMEA; MOORA; Risk identification*

## INTRODUCTION

Due to the rapid changing business environment, most manufacturers have no alternative but to face a lot of challenges and complexities from business environment changes. According to Palange and Dhatrak (2021), the improvement of productivity is necessary for manufacturing enterprises to sustain business market competency and the concept of lean manufacturing is an essential tool to enhance productivity in manufacturing.

The concept of lean manufacturing origins from Toyota motor corporation in the early 1950s (Ismail et al. 2019). Large-scale manufacturers started to adopt the management concept of lean manufacturing much earlier than the SMEs and most of large corporations own the ability to deal with all kinds of challenges (McKie et al. 2021). In current stage, more and more successful application cases of the lean manufacturing concept in large-scale enterprises such as Volkswagen Group and Toyota motor corporation consistently encourages various manufacturers from all over the world to employ lean manufacturing principles (Paladugu and Grau 2020).

Risk management plays a quite important role in the whole manufacturing sector because proactive and systematic control of risk factors contribute to final realization of lean manufacturing (Hemalatha et al. 2021). What is more, Oduoza (2020) concludes that the risk management for a specific manufacturing process will be successfully implemented when risk factors are identified.

There are two main research motivations. One of them is building risk identification models for lean manufacturing improvement and the other is applying lean manufacturing concepts and lean tools in actual manufacturing processes. FMEA and MOORA are two primary methods to realize these research motivations.

## LITERATURE REVIEW

According to Pojasek (2008), the concept of lean provides manufacturing enterprises with all kinds of effective methods that can be used to eliminate lean wastes from actual manufacturing processes. Jayanth et al. (2020) concludes that the productivity and the quality level of the original manufacturing system will be improved by 23% when the former manufacturing system is replaced by the optimized lean system. The lean technology such as automatic data identification has been widely applied to track assets and inventory in modern industries. At the same time, systematic manufacturing schedules are built in lean implementation frameworks (Rafique et al. 2022).

Mamaghani and Medini (2021) conclude that the early identification and minimization of risks promote effective measures and reasonable response strategies. According to Zimmermann et al. (2019), it is necessary to gain an overview of the manufacturing environment of the investigated firm to determine risks in manufacturing. Oduoza et al. (2017) has identified over 200 risk factors which influence the production performance and Oduoza (2020) finds that integral production performance in the manufacturing sector is commonly measured in terms of cost, time, quality, safety, and other stakeholders. Samuel et al. (2019) finds the risk of time-consuming and generation of wastes in paste production. According to Chand (2021), the most common risks in manufacturing systems consist of operational and supply risks that are caused by inappropriate control of manufacturing processes. Untimely responding to risks which have occurred often leads to the occurrence of supply chain risks (Mustaffa et al. 2018).

Wong et al. (2009) concluded sixteen areas that are responsible for improving the productivity of lean manufacturing and these areas are work processes, scheduling, the inventory, equipment, layout, the material handling, employees, quality, the product design, suppliers, tools and techniques, customers, ergonomics, safety, management, and culture. The substitute machine plays an important role in the construction of flexible production lines and the final increase of productions rates (Kumar and Neeraj 2022). Manufacturing enterprises must make sure that employees are in good health and full of energy since the production quality and efficiency are deeply replied on human resources (Tortorella et al, 2020).

Manufacturing enterprises can make use of risk assessment techniques to identify potential and existing risks as many as possible and specify the reasons and impacts associated with these risks (Ghoushchi et al. 2020). Both quantitative and qualitative risk identification methods that are used by manufacturing companies can control, identify, and mitigate the hazardous consequences (Turskis et al. 2019). What is more, the digitalization of the manufacturing process is perceived to be extremely important for the realization of high productivity and it has not been paid enough attention by the former studies (Schönfuß et al. 2021).

According to Chaudhuri et al. (2018), the importance of risk identification is recognized in practice and theory with much more complicated and dynamic supply chains. Arlinghaus and Rosca (2021) concludes advantages of risk identification are increased productivity and flexibility with the improved process integration and transparency.

## METHODOLOGY

### MOORA

According to Adali and Isik (2017), the first step of the MOORA method is to build the decision matrix. Alternatives and attributes are listed respectively in the column and row of the decision matrix as below.

$$X = [x_{ij}]_{m\times n} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & & x_{2n} \\ \vdots & & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}$$

$x_{ij}$ represents the performance measure of $i$th alternative on $j$th attribute. Meanwhile, $m$ is the total number of alternatives and $n$ is the overall number of attributes.

The next step is to normalize the decision matrix via the equation below.

$$x_{ij}^{*} = x_{ij} / \left[\sum_{i=1}^{m} x_{ij}^{2}\right]^{\frac{1}{2}} (i = 1,2,\ldots,m;\ j = 1,2,\ldots,n)$$

$x^{*}_{ij}$ represents the normalized performance of $i$ th alternative on $j$ th attribute and it is a dimensionless number which belongs to the interval [0,1].

The third step is the estimation of the assessment values $y_i$. The sums for normalized performance values of non-beneficial attributes are subtracted from the sums for normalized performance values of beneficial attributes. Equation for $y_i$ is summarized as below.

$$y_i = \sum_{j=1}^{g} w_j\, x_{ij}^{*} - \sum_{j=g+1}^{n} w_j\, x_{ij}^{*} (j = 1,2,\ldots,n)$$

In the above equation, $g$ is the number of beneficial attributes and $(n - g)$ is the number of non-beneficial attributes. What is more, $w_j$ is the weight of $j$ th attribute. The corresponded value of the attribute could be multiplied with its corresponding weight to give more importance to an attribute (Chakraborty 2011).

### FMEA

There are around eleven steps when completing the whole FMEA method. Figure 1 illustrates specific implementation procedures of the FMEA method. Severity (S), occurrence (O) and detection (D) are three parameters, and each parameter takes values as 1 lowest to 10 highest. The value of 1 indicates ‘none’ in severity (S), ‘extremely remote’ in occurrence (O) and ‘almost certain’ in detection (D). On the contrary, the value of 10 refers to 'hazardous without warning' in severity (S), 'extremely high' in occurrence (O) and 'absolutely uncertainty' in detection (D). The risk priority number (RPN) is calculated by multiplying these three parameters (Bozdag et al. 2015). According to Park et al. (2018), failure modes with high RPN are more crucial and ranked prior to those with low RPN and control measures should be taken for the most crucial failure modes.

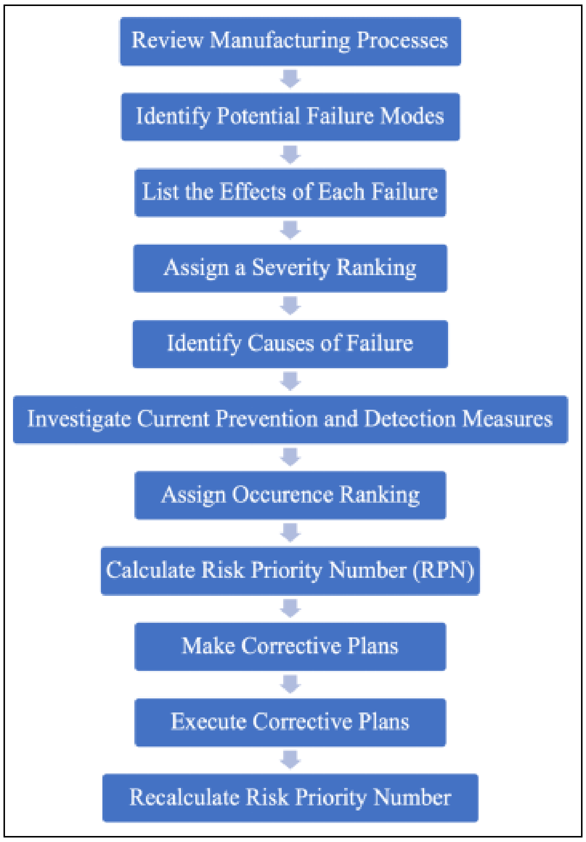


FIGURE 1. Flowchart of FMEA implementation steps

### INTEGRATION OF FMEA AND MOORA

Corrective methods and measures are suggested in the FMEA method with the decrease of calculated RPN and they are realized with the assistance of special lean tools. The selection of lean tools costs much time, which leads to the delay of production. The best lean tool choice or machine is determined by the MOORA method in a quick way. The integration of FMEA of MOORA contributes to the realization of lean manufacturing improvement.

## RESULTS AND ANALYSIS

### MOORA ANALYSIS OF MANUFACTURING PROCESSES

This section will explain the results and discussion based on the MOORA analysis. According to the actual investigation of the case study enterprise, some long-term operated CNC lathes need to be replaced by newly purchased machining equipment such as CNC lathe tools in some workshops. The decision-making problem that how to choose the proper newly purchased machine tool from the different varieties of machines tools in the market will be solved by the MOORA method. There are many factors that ought to be considered when selecting CNC lathes and the commonly considered factors are safety, productivity, flexibility, compatibility, cost, and maintainability (Zaied et al. 2019).

There are six CNC lathe models chosen as comparison alternatives in the final selection of machine tools and they are MAZAK TURN 400, MAZAK TURN 450, DMTG CKA6150, DMTG CKA6163A, SMTCL CK6150 and SMTCL CK6160. Beneficial attributes of these lathe models consist of permitted machining dimension, the spindle speeds, rapid traverse speeds and number of tools on the turret. On the contrary, expenses of CNC lathes are non-beneficial attributes that mainly include selling prices and maintenance cost. On top of this, it can be noticed that some attributes of CNC lathes are more important than others during the evaluation process. Therefore, the weight of attributes of the CNC lathes ought to be determined and they are summarized in Table 1.

TABLE 1. The weight of attributes of the CNC lathes ($w_j$)

| Attributes | Weights ($w_j$) |
|---|---|
| Maximum machining diameter | 0.15 |
| Maximum machining length | 0.15 |
| Maximum spindle speed | 0.1 |
| X-axis rapid traverse speed | 0.075 |
| Z-axis rapid traverse speed | 0.075 |
| Number of tools on the turret | 0.1 |
| Selling Price | 0.25 |
| Annual Maintenance Cost | 0.1 |

Table 2 presents the attribute data of the comparison alternatives, and this table will be regarded as the decision matrix which describes the performance of different CNC lathes with respect to the various attributes. Lathe alternatives are listed in the first column and each of them have eight different attributes. All related data and parameters in Table 2 are collected from CNC lathe supplier websites.

TABLE 2. The attribute data of the comparison alternatives ($x_{ij}$)

| Alternatives | Maximum machining diameter (mm) | Maximum machining length (mm) | Maximum spindle speed (RPM) | X-axis rapid traverse speed (m/min) | Z-axis rapid traverse speed (m/min) | Number of tools on the turret | Selling Price (USD) | Annual Maintenance Cost (USD) |
|---|---|---|---|---|---|---|---|---|
| TURN 400 (MAZAK) | 580 | 1022 | 2500 | 30 | 30 | 12 | 43960 | 1318 |
| TURN 450 (MAZAK) | 580 | 979 | 2000 | 30 | 30 | 12 | 40820 | 1225 |
| CKA6150 (DMTG) | 500 | 930 | 2200 | 4 | 8 | 8 | 16560 | 754 |
| CKA6163A (DMTG) | 630 | 785 | 1000 | 4 | 7.5 | 8 | 15700 | 942 |
| CK6150 (SMTCL) | 500 | 850 | 2200 | 5 | 10 | 4 | 12246 | 613 |
| CK6160 (SMTCL) | 600 | 850 | 2000 | 8 | 10 | 4 | 14758 | 738 |

Table 3 illustrates the assessment value and ranking of lathe alternatives. The CK6150 model owns the highest assessment value. On the contrary, the CKA6163A model obtains the lowest result. Therefore, it can be concluded from Table 3 that the CK6150 model provided by SMTCL company is the best alternative.

TABLE 3. The assessment value ($y_i$) and ranking of the CNC lathes

| Alternatives | $y_i$ | Rank |
|---|---|---|
| TURN 400 (MAZAK) | 0.118954805 | 5 |
| TURN 450 (MAZAK) | 0.121679325 | 4 |
| CKA6150 (DMTG) | 0.124931798 | 2 |
| CKA6163A (DMTG) | 0.09959965 | 6 |
| CK6150 (SMTCL) | 0.127648364 | 1 |
| CK6160 (SMTCL) | 0.124923814 | 3 |

## FMEA ANALYSIS OF MANUFACTURING PROCESSES

Table 4 is the first FMEA analysis form that aims at the machining process of camshafts of the diesel engines and Table 5 is the continuous FMEA form which analyses left processing procedures. Table 6 concentrates on the machining process of the diesel engine blocks and Table 7 is the continuous FMEA form for analysis of the remaining machining processes. Table 8 is the FMEA form that analyses assembly processes of diesel engines and Table 9 is the continuous FMEA form for analysis of the left assembly steps of diesel engines.

TABLE 4. The FMEA form of the machining process of camshafts

| Process Procedure | Failure mode | Effects of failure | Causes of failure | Detection | S | O | D | RPN | Recommended corrective action | S | O | D | RPN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mill terminal faces | Milled terminal faces are not flat enough | Impact positioning accuracy of subsequent process procedures | Milling cutters wear | Check dimensions of milling cutters | 6 | 4 | 5 | 120 | Change milling cutters periodically | 3 | 3 | 4 | 36 |
| Drill center holes of terminal faces | Drilled center holes are out of center | Impact positioning accuracy of subsequent process procedures | Unclamped fixtures | Examine dimensions of fixtures | 7 | 5 | 4 | 140 | Replace fixtures periodically | 3 | 3 | 4 | 36 |
| Turn the cams | The processed cam profile has deviations | Lead to undesirable motion error of the follower | Turning tools wear | Inspect dimensions of turning tools | 5 | 6 | 4 | 120 | Substitute turning tools periodically | 2 | 3 | 4 | 24 |
| Rough turning the cylindric surface | The processing dimension is out of tolerance | Impact subsequent assembly processes | Incorrect installation of lathe tools | Visual checking of the installed lathe tools | 5 | 5 | 5 | 125 | Replace semi-automatic lathes with CNC lathes | 2 | 2 | 3 | 12 |
| Fine turning the cylindric surface | Unqualified cylindric surface roughness | Impact the subsequent process of grinding the cylindric surface | Improper selection of cutting parameters | Observe cutting parameters on display screens of CNC lathes | 4 | 6 | 6 | 144 | Enhance the vocational skills training and cultivate skillful CNC system operators | 2 | 3 | 3 | 18 |
| Drill axial holes | The diameters of processed holes are out of tolerance | Have bad effects on the specific functionality of camshafts which are assembled in engines | Inclined spindles of the drilling machines | Inspect inner structures status of the drilling machines | 6 | 5 | 5 | 150 | Regular maintenance of main structures of the drilling machines | 2 | 2 | 5 | 20 |

TABLE 5. The continuous FMEA form of the remaining machining process of camshafts

| Process Procedure | Failure mode | Effects of failure | Causes of failure | Detection | S | O | D | RPN | Recommended corrective action | S | O | D | RPN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Grind the cams | Fragmentation of grinding wheels | Cause severe injury to operators | Incorrect installation of grinding wheels | Visual checking of the installed grinding wheels | 8 | 4 | 6 | 192 | Enhance the vocational skills training and cultivate skillful grinder operators | 3 | 3 | 3 | 27 |
| Grind the cylindric surface | Unqualified cylindric surface roughness | Impact the matching stability and the sealing performance of the processed camshafts | Unbalanced grinding wheels | Inspect the stationary state of grinding wheels on the balancing frame | 5 | 5 | 5 | 125 | Avoid selecting unbalanced grinding wheels and choose balanced high-quality grinding wheels | 2 | 4 | 3 | 24 |
| Mill the keyway | The processing dimension is out of tolerance | Impact subsequent assembly processes | Milling cutters wear | Check dimensions of milling cutters | 5 | 6 | 5 | 150 | Change milling cutters periodically | 3 | 3 | 4 | 36 |
| Clean manufactured camshafts | Metal scraps and cutting oil are not clean up | Cause damage to internal components of camshafts and impact specific functionality | Cleaning liquid does not meet the requirements | Test both the concentration and temperature of the cleaning liquid | 6 | 5 | 4 | 120 | Change the cleaning liquid periodically and clean manufactured camshafts in a sequence | 3 | 3 | 2 | 18 |
| Final inspection | Failure of crack detection | Lead to low product quality and customer dissatisfaction | Improper selection of detection parameters | Observe magnetization parameters of testing machines | 7 | 4 | 4 | 112 | Enhance the operation skills training of magnetic particle testing machines | 2 | 3 | 2 | 12 |

TABLE 6. The FMEA form of the machining process of engine blocks

| Process Procedure | Failure mode | Effects of failure | Causes of failure | Detection | S | O | D | RPN | Recommended corrective action | S | O | D | RPN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rough milling the upper and bottom face | Unqualified surface flatness | Impact the processing precision of drilling the upper and bottom holes | Wear of milling tools | Check dimensions of milling cutters | 6 | 4 | 5 | 120 | Change milling cutters periodically | 2 | 3 | 3 | 18 |
| Rough milling the lateral and terminal faces | Unqualified surface flatness | Impact the machining accuracy of drilling the upper and bottom holes | Deformation of processed workpieces | Check shape and dimensions of workpieces | 6 | 4 | 5 | 120 | Select appropriate milling cutters | 2 | 3 | 3 | 18 |
| Fine milling the upper and bottom faces | Unqualified surface roughness | Reduce fatigue strength of the upper and bottom faces | Too high processing temperature | Inspect the surface quality of workpieces | 5 | 5 | 6 | 150 | Increase concentration and pressure intensity of the liquid coolant | 3 | 4 | 4 | 48 |
| Fine milling the lateral and terminal faces | Unqualified surface roughness | Reduce abrasion resistance of the lateral and terminal faces | Insufficient precision of milling machines | Precision examination of milling machines | 5 | 5 | 6 | 150 | Regular maintenance of main structures of the milling machines | 3 | 4 | 4 | 48 |
| Expansion of cylinder bores | The drilling bit slips during the hole expansion process | The processing dimension is out of tolerance | Selection of defective drilling bits | Visual checking the quality of the drilling bit | 7 | 5 | 4 | 140 | Perform trial expansion of holes before the actual expansion of cylinder bores | 2 | 3 | 3 | 18 |
| Fine boring cylinder bores | Unqualified surface roughness of cylinder bores | Impact the matching stability of components | Vibration caused by imbalance of boring tools | Check dimensions of boring tools | 5 | 5 | 5 | 125 | Proper adjustment of boring tools to accomplish fine boring of cylinder bores | 2 | 4 | 4 | 32 |

TABLE 7. The continuous FMEA form of the remaining machining process of engine blocks

| Process Procedure | Failure mode | Effects of failure | Causes of failure | Detection | S | O | D | RPN | Recommended corrective action | S | O | D | RPN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Drill the upper and bottom face holes | Fracture of the drilling bit | Cause severe injury to operators | Low rigidity of the drilling bit | Test processing properties of the drilling bit | 8 | 4 | 6 | 192 | Perform trial drilling before the actual drilling process | 3 | 3 | 3 | 27 |
| Drill lateral and terminal face holes | The processing dimension is out of tolerance | Impact subsequent assembly processes | Improper drilling parameters | Check drilling parameters set by drilling machines | 6 | 5 | 4 | 120 | Determine proper drilling parameters through trial processing | 3 | 4 | 2 | 24 |
| Ream lateral and terminal face holes | Insufficient machining accuracy | Have bad effects on wear resistance and leak proofness of the components | Failure to comply with the required processing procedures | Visual checking the actual reaming process procedures | 5 | 5 | 6 | 150 | Enhance the vocational skills training and cultivate skilled reamer operators | 3 | 4 | 4 | 48 |
| Tap screw threads on specific holes | Fracture of screw taps | Impact subsequent assembly processes | Insufficient strength of screw taps | Observe diameters of machined holes | 7 | 5 | 4 | 140 | Replace machine tapping with manual tapping based on actual machining conditions | 3 | 4 | 3 | 36 |
| Clean manufactured engine blocks | Metal scraps and cutting oil are not clean up | Cause abnormal wear of manufactured components and impact the subsequent assembly accuracy | Wash too many workpieces at the same time | Visual checking the quantity of workpieces which are being cleaned | 8 | 5 | 3 | 120 | Set up the maximum allowable quantity of cleaned workpieces and change the cleaning liquid on time | 2 | 3 | 2 | 12 |

TABLE 8. The FMEA form of the assembly process of diesel engines

| Process Procedure | Failure mode | Effects of failure | Causes of failure | Detection | S | O | D | RPN | Recommended corrective action | S | O | D | RPN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Install the camshafts and bearings | Improper tightening torque of fastening bolts of the bearing cap | Cause abnormal abrasion of the camshafts | Insufficient precision accuracy of the torque wrenches | Employ torque sensors of the torque wrench test instrument | 7 | 5 | 4 | 140 | Strengthen regular maintenance of the used torque wrenches | 2 | 3 | 4 | 24 |
| Install the crankshafts | The crankshafts move back and forth during operations | May lead to fracture of crankshafts | Too large axial clearance of the installed crankshafts | Measure the axial clearance of the installed crankshafts | 8 | 4 | 5 | 160 | Take precise measures to adjust the axial clearance of the installed crankshafts | 3 | 3 | 3 | 27 |
| Set up the connecting rods | Loose connection of the connecting rods | May lead to fracture of the connecting rod bolts | The connecting rod bolts and nuts are not fully tightened | Compare actual operations with the assembly instructions | 8 | 4 | 4 | 128 | Set up clear operation reminding slogans in the working position | 3 | 3 | 3 | 27 |
| Mount the piston rings | Incorrect installation direction of rings | Cause complete fracture of the piston rings | Inexperienced assembly workers | Perform skills assessment of employees | 7 | 5 | 4 | 140 | Enhance the vocational skills training of the assembly operators | 2 | 3 | 3 | 18 |
| Install the cylinder heads | Usage of wrong larger or smaller screws | Cannot assemble screws in specified position | Failure to use prescribed screws | Visual checking the selection of screws | 6 | 5 | 5 | 150 | Use toolboxes to sort the model of screws | 2 | 4 | 3 | 24 |
| Install the oil sumps | Random screw assembly sequence | Cannot install screws in the original position | Failure to follow the right sequence | Visual checking the assembly sequence | 6 | 5 | 6 | 180 | Strictly follow the regulated screw assembly sequence | 2 | 4 | 2 | 16 |

TABLE 9. The continuous FMEA form of the remaining assembly process of diesel engines

| Process Procedure | Failure mode | Effects of failure | Causes of failure | Detection | S | O | D | RPN | | S | O | D | RPN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Install the gear sets | Misalignment of installed gears | Cause serious breakdown of diesel engines | Timing marks of paired gears are not aligned | Inspect the alignment of the timing marks | 9 | 4 | 4 | 144 | Enhance the vocational skills training of the assembly operators | 3 | 3 | 3 | 27 |
| Mount the cover plate of gear sets | Loose assembly of the cover plate | Abnormal noises caused by unfixed assembly | The number of screws used is less than the required amount | Visual checking the number of screws used for assembling | 8 | 5 | 5 | 200 | The number of screws used for assembling can be checked by different operators | 2 | 4 | 3 | 24 |
| Install the belt pulleys | The belt pulleys are not put in the same plane | Speed up the abrasion of belts | The belts are not moderately tensioned | Inspect the coplanarity by pulling lines | 7 | 6 | 5 | 210 | Pull lines in more than two different directions to inspect coplanarity | 2 | 4 | 4 | 32 |
| Install the air intake pipes | The connecting face has oil fouling | May cause fracture of screw bolts | The connecting surface is not clean up | Visual checking the connecting face cleanliness | 8 | 6 | 4 | 192 | Employ auto-checking machines to inspect the surface cleanliness | 2 | 4 | 2 | 16 |
| Mount the exhaust pipes | Lack of necessary standard components | Lead to the waiting time and delay the whole assembly process | The delivery of standard components is not in time | The warehouse keeper checks the components delivery list | 6 | 5 | 4 | 120 | The assembly operator and the warehouse keep check the delivery list by each other | 2 | 3 | 3 | 18 |
| Install the cover lids of engine valve chambers | The transportation of cover lids wastes a lot of valuable time | The transportation of cover lids delays the assembly progress | Transportation and motion wastes | Send reports directly out of the detection system | 6 | 5 | 4 | 120 | Reduce components transportation distances by utilizing automated systems | 3 | 4 | 3 | 36 |

## DISCUSSION

Dai et al. (2021) concludes that tens of millions of SMEs were shut down after the outbreak of COVID-19 in January 2020. Based on this above background, research questions and directions are designed for SMEs in this paper. According to Sun et al. (2021), a plenty of manufacturing enterprises are experiencing unprecedented financial pressure and a large percentage of them even cannot make enough profits to proceed with manufacturing tasks. Risk identification models for lean manufacturing are constructed to increase productivity and profits of SMEs in order that normal production processes can be guaranteed.

According to Chand (2021), the operational risks consist of the equipment malfunction, human error, and failure of the control system, which is in line with research findings which indicate that wear of machine tools, incorrect installation of machine tools and inaccurate measurement methods lead to operational risks. According to Oduoza (2020), the labor skill and the equipment maintenance belong to quality related risk factors, which is similar to research findings that illustrate enhancing vocational skills training is a recommended corrective action to insufficient machining accuracy. Simultaneously, maintaining the regular maintenance of machining tools such as milling machines is the recommended corrective measure in this research for the failure mode of unqualified surface roughness, which has a relationship with research findings by Oduoza et al. (2017).

Research questions about how to build risk identification models for lean manufacturing have been solved by FMEA and MOORA forms. Risk identification is accomplished based on the lean principles. Most common risks including improper manufacturing procedures, the lack of experienced operators, wrong choice of machine tools and lack of necessary production regulations do not meet the lean requirements and principles. At the same time, SMEs can use suggested improvement measures in this paper to obtain the aim of lean manufacturing in an effective way. The objective of this study is realized by increasing productivity of SMEs and helping SMEs to make enough profits to maintain normal, efficient, and effective production status and proactively implement preventive maintenance.

Table 3 has suggested that the CK6150 CNC model is the best alternative to be utilized by the SMTCL company, the analyses are further investigated at each of process/procedure to address the potential failure modes, including the effects of failures, causes of failure and the RPN were also determined as the risk mitigation procedure. From the analyses of Tables 4 to 9, the data has offered the following corrective actions that the company can consider. These significant recommendation and corrective actions as the seven potential highest RPNs may include: enhance the vocational skills training and cultivate skillful reamer operators, increase concentration and pressure intensity of the liquid coolant, and regular maintenance of main structures of the milling machines, and periodically change of milling cutters, replace fixtures, replace machine tapping and reduce components transportation distances by utilizing automated systems.

## CONCLUSION

Failure modes and risks are proactively identified with the establishment of risk identification model. FMEA and MOORA are effective risk methods which contribute to the construction of the risk identification model for lean manufacturing improvement. Failure modes that may lead to potential risks are identified by quantitative analysis of manufacturing processes. Lean corrective measures in the context of reducing wastes such as time reduction, effective scheduling, transportation, and periodical maintenance, are concluded in constructed risk identification models, and they are taken to improve the lean manufacturing.

The quantitative analysis of manufacturing processes in company B can be used as a reference for other SMEs. Most failure modes identified in company B belong to most common failure modes and other SMEs can check if their production lines have similar failure modes. The recommended corrective measures are also suitable for other SMEs to take.

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## DECLARATION OF COMPETING INTEREST

None

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