Investigating the Overall Equipment Effectiveness (OEE) of Die Casting Injection Machines using Productivity Analysis

Klint Allen A. Mariñas
Department of Industrial and Systems Engineering
Chung Yuan Christian University
Taoyuan City, Taiwan
klintallen2011@gmail.com

Yung-Tsan Jou
Chairman, Department of Industrial and Systems Engineering
Chung Yuan Christian University
Taoyuan City, Taiwan
ytjou@cycu.edu.tw

Riana Magdalena Silitonga
Department of Industrial and Systems Engineering
Chung Yuan Christian University
Taoyuan City, Taiwan
riana.magdalena@atmajaya.ac.id

Abstract

In industrial applications, specifically in the manufacturing sector, it is essential to know the machine's status. Most companies have advanced machines; however, the data regarding the machine's condition are not highly considered resulting in many problems like low productivity and high rejection rate that constitute cost and environmental impact. This study aims to assess the die casting injection machines of a leading automobile manufacturing company in Indonesia that can be used for manufacturing companies experiencing the same difficulties. Twenty aluminum alloy die casting injection machines were studied in this research. The machine breakdown was summarized, and it turned out that machine 16 was the most problematic among the machines. The results show an Overall Equipment Effectiveness (OEE) of 40.95%. The idling and minor stoppages and breakdown loss was the main contributor to the problem having the abnormal die lock an RPN of 392, with severity (7), occurrence (7), and detection (8) as the leading cause based on the Failure Mode and Effect Analysis (FMEA) results. The findings will provide automobile manufacturing companies and other related industries comprehensive information on properly assessing productivity problems. Therefore, the results can give relevant perspectives on proper procedures integrating productivity analysis in the manufacturing process.

Keywords
Productivity Analysis, Overall Equipment Effectiveness (OEE), Six Big Losses, Failure Mode and Effect Analysis (FMEA)

1. Introduction

1.1 Background of the Study
The use of aluminum alloy in automobile parts continues as industries seek light and high-strength materials for automobiles. The production of aluminum alloys continues to grow over the past years, replacing conventional materials such as iron due to durability and rust resistance features. Aluminum alloys are well-known materials for their machinability and castability, making them more manageable and efficient raw materials for automobile

manufacturing (Gao et al., 2015; Miller et al., 2000). High pressure die casting injection machine is commonly used in manufacturing aluminum alloy-related parts since it is used for diverse and complicated shapes that cannot be made using any other method. In addition, the die casting process is helpful for mass production as it works like a plastic injection machine giving injected parts equivalent to the finished goods (Otarawanna et al., 2009).

Several works of literature have been made to optimize the production process in producing economical and high-quality products. Previous research has identified parameter optimizations as one of the best solutions to product-related problems (Liu et al., 2020). For example, the quality issue is one of the main problems in the die casting process; error and non-conforming products cause much rework that constitutes cost. However, several companies besides the parameter optimization problem have another problem related to machine breakdown since high pressure die casting injection machine uses much pressure, heat, and other factors related to production. The researchers used the Overall Equipment Effectiveness (OEE) method to assess quantitative metrics for measuring individual productivity; literature reveals that it could measure irrelevant costs related to machines (Muñoz-Villamizar et al., 2018). OEE is composed of 3 measures of equipment losses: performance rate, availability, and quality rate. Six Big Losses as aligned to OEE are categorized into six essential categories, namely: breakdown, setup and adjustment, defect and rework, start-up, reduce speed, and idling and minor stoppage (Chikwendu et al., 2020).

The cause-and-effect diagram will determine the machine factor error from the six big losses to determine the internal problems. The failure mode and effect analysis (FMEA) mainly determine the ranking of machine errors from the cause-and-effect diagram and previous analysis from the results of the risk priority number (RPN) (Wang et al., 2021). This research proposes to determine the machine factors that contribute to machine breakdown by identifying vital factors through productivity analysis, including OEE, six big losses, cause-and-effect analysis, and FMEA.

1.2 Motivation of the Study

In a developing country like Indonesia, it is vital to assess the current situation correctly. However, studies regarding production efficiency, especially for the automotive industry, are scarce. In 2018 the Indonesian automotive industry accounted for 10.16 percent of its Gross Domestic Product (GDP) (Anggareni, 2018). The automotive export has a higher value compared to the importation (Amelia, 2014). Indonesia created a milestone entering the top countries producing automobiles landing on the 17th spot producing 0.98 million vehicles (Wright, 2018). Many studies have focused on identifying the optimal parameters of a die casting injection machine (Apparao et al., 2017; Dou et al., 2020), but there is a limited study relating to productivity analysis and machine breakdown. The researchers believe that productivity analysis could solve the longing problem that involves the machine mechanisms related to machine breakdowns. Furthermore, the research finds a need to address this gap since die casting efficient production is one of the main problems of many companies, not only for the parameter issue but also for machine problems.

1.3 Objectives of the Study

The purpose of this research is to comprehensively investigate the productivity of the Injection Die Casting Machine by using the Overall Equipment Effectiveness (OEE) metrics of an automotive manufacturing company. Moreover, it provides automotive companies and other related industries information on the factors that need to be addressed when encountering low manufacturing productivity. This research evaluated one aluminum alloy injection die casting machine to represent the other machines in the production plant. The experiment was conducted in an automotive manufacturing plant to enrich the literature about OEE and Productivity Analysis that could also help the automotive manufacturing sector improve profit, efficiency and increase the plant OEE.

2. Methodology

2.1 Data Collection

The research was conducted in the production department of one of the leading automobile manufacturing companies from January 13, 2020, to February 13, 2020. The researchers also conducted interviews, observations, and historical data collection. Data collection was carried out based on the department's current problem; historical data from August 2019 to December 2019 was used to analyze the current problem. Moreover, it focused on problems that affect production performance.

2.2 Conceptual Framework

This study uses a machine productivity analysis approach to detect the causes of production process obstruction on the production floor. Furthermore, investigating the machine effectiveness using the Overall Effectiveness Equipment

(OEE) method. Then the total machine breakdown was computed to see the machine with the highest total breakdown. The types of losses and their calculations are determined based on the six big losses method. After determining the four types of causes based on company data, a cause-and-effect diagram was made. The cause-and-effect information is analyzed, and FMEA calculations are carried out based on the previous analysis processes. FMEA will then determine which one must be satisfied first so that the effective performance value increases. To understand the process flow, the researchers created a conceptual framework, as shown in Figure 1.

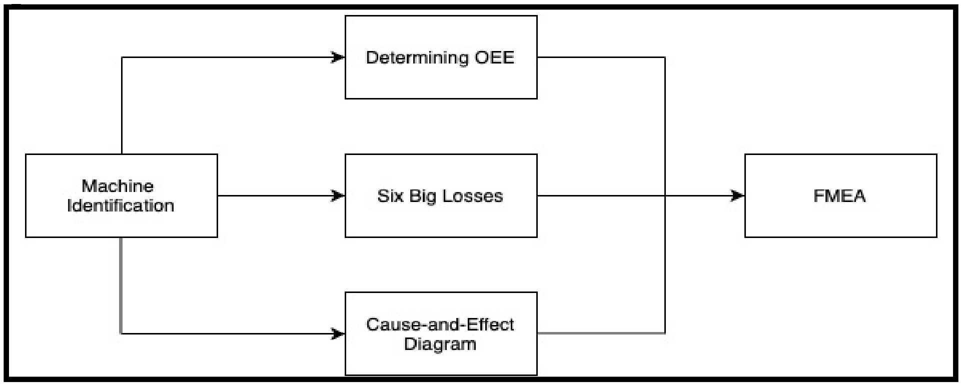

Figure 1. Conceptual Framework

2.3 Formulas
The researchers used formulas in computing the OEE of the machine derived from Nakajima's formula for equipment effectiveness. The availability, performance, and quality rate were computed first before computing the OEE. After computing the OEE, the researchers computed the six significant losses: breakdown loss, setup loss, idling, and minor stoppages, reduced speed, defect loss, and reduced yield. The computation helped the researchers to conduct the preliminary assessment in investigating the internal problem.

2.3.1 OEE Formulas
The study used OEE to compute the machine's productivity performance; the formulas were adapted from the Nakajima (1988) study, as shown on equations 1,2,3 and 4.

$$Availability\ Rate = \frac{Operation\ Time}{Loading\ Time}\ x\ 100\% \tag{1}$$

$$Performance\ Rate = \frac{Ideal\ Cycle\ Time\ x\ Process\ Amount}{Processing\ Time}\ x\ 100\% \tag{2}$$

$$Quality\ Rate = \frac{Process\ Amount - Defect\ Amount}{Process\ Amount}\ x\ 100\% \tag{3}$$

$$OEE = Availability\ Rate\ x\ Performance\ Rate\ x\ Quality\ Rate \tag{4}$$

2.3.2. Six Big Losses Formulas
A bottom-up approach known as the Six Big Losses have been conducted after computing the OEE to see the negative factors that should be eliminated from the manufacturing process (Muñoz-Villamizar et al., 2018). The six big losses formulas used in the study can be seen in equations 5, 6, 7, 8, 9, and 10.

$$Breakdown\ Loss = \frac{Breakdown\ Time}{Loading}\ x\ 100\% \tag{5}$$

$$Setup\ or\ Adjustment\ Losses = \frac{Setup\ or\ Adjustment\ Losses}{Loading\ Time}\ x\ 100\% \tag{6}$$

$$Idling\ and\ Minor\ Stoppages = \frac{(Target\ Production - Total\ Production)\ x\ Cycle\ Time}{Loading\ Time}\ x\ 100\% \tag{7}$$

$$Reduced\ Speed = \frac{(Actual\ Cycle\ Time - Ideal\ Cycle\ Time)\ x\ Total\ Product\ Processed}{Loading\ Time}\ x\ 100\% \tag{8}$$

$$Defect\ Losses = \frac{Total\ Reject\ x\ Ideal\ Cycle\ Time}{Loading\ Time}\ x\ 100\% \tag{9}$$

$$Reduced\ Yield = \frac{Scrap\ x\ Cycle\ Time}{Loading\ Time}\ x\ 100\% \tag{10}$$

3. Results and Discussion

3.1 Results

3.1.1 Machine Breakdown

The study was conducted using actual data from a leading Indonesian automobile company. Moreover, to determine which machine affects the production process significantly, it is necessary to collect data related to each machine's breakdown time. The most significant machine representing each manufacturing process problem is the die casting injection machine 16, as shown in Table 1. Therefore, machine no. 16 was chosen to be investigated that includes the data on rest time, work time, number of trials, production capacity, defective products, the good product produced are also recorded to find the OEE value that could resolve the six big losses.

Table 1. Breakdown times of all machines in minute

Machine No.	Month					Total Breakdown
	August	September	October	November	December	
1	2530.00	1730.00	2750.00	2625.00	2330.00	11965.00
2	3280.70	1875.00	6960.00	3005.00	1720.00	16840.70
3	2175.00	2010.00	7415.00	3930.00	2315.00	17945.00
4	3705.00	2814.00	6459.00	3270.00	1335.00	17583.00
5	1995.00	2095.00	5260.00	3710.00	1060.00	14120.00
6	1495.00	430.00	3195.00	1560.00	235.00	6915.00
7	2225.00	1540.00	2540.00	1100.00	360.00	7765.00
10	3090.00	2250.00	6576.70	2530.00	2085.00	16531.70
11	3120.00	2465.00	4901.00	2865.00	1290.00	14641.00
12	2870.00	3012.00	7954.00	3105.00	1735.00	18676.00
13	3175.00	2168.00	4120.00	3160.00	1875.00	14498.00
14	3555.00	2110.00	8415.00	2885.00	1435.00	18400.00
15	2590.00	1356.00	7620.00	4020.00	1945.00	17531.00
16	3535.00	1630.00	7510.00	4775.00	1600.00	19050.00
17	2205.00	1420.00	7399.00	3965.00	1440.00	16429.00
18	2000.00	2995.00	5525.00	2309.00	1390.00	14219.00
19	3159.00	1545.00	7005.00	3970.00	2555.00	18234.00
20	3655.00	2493.00	5230.00	2960.00	1720.00	16058.00

3.1.2 Overall Equipment Effectiveness (OEE)

Based on OEE calculations from equations 1, 2, 3, and 4, the average OEE value is 40.95%, as shown in Table 2. The OEE value is significantly lower than the world-class standard of 85% (Muñoz-Villamizar et al., 2018); therefore, it is necessary to improve the manufacturing process. However, the problem can be fixed if the root problem can be determined. Therefore, the researchers compute the six big losses for error classification that affects the machine performance.

Table 2. OEE Calculation

Period	Availability Rate (%)	Performance Rate (%)	Quality Rate (%)	OEE (%)
August	84.94	58.18	88.18	45.58
September	85.85	60.94	83.52	43.69
October	69.14	67.81	80.81	37.89
November	78.20	61.70	83.32	40.20
December	85.89	54.54	84.11	39.40
Average	80.80	60.64	83.99	40.95

3.1.3 Six Big Losses

Six Big Losses is representing the six classifications of losses. Furthermore, based on the computation result, the six big losses show that idling and minor stoppages were the highest cost of losses, followed by breakdown loss, reduced speed, setup or adjustment losses, reduced yield, and defect losses. With an average of 35.25, 13.03, 9.75, 6.17, 6.17, and 1.62, respectively, as shown in Table 3.

Table 3. Six Big Losses Calculation

Period	Breakdown Loss (%)	Setup or Adjustment Losses (%)	Idling and Minor Stoppages (%)	Reduced Speed (%)	Defect Losses (%)	Reduced Yield (%)
August	10.38	4.68	34.57	9.88	1.16	4.68
September	6.95	7.20	31.64	10.46	1.42	7.20
October	24.38	6.48	37.12	9.38	2.52	6.48
November	15.53	6.26	35.76	9.65	1.79	6.26
December	7.89	6.23	37.18	9.37	1.22	6.23
Average	13.03	6.17	35.25	9.75	1.62	6.17

3.1.4 Fishbone Analysis

As shown in Figure 2, several types of errors were identified in the Fishbone diagram as idling errors, minor stoppage errors, and machine time breakdown loss. The category includes the Machine, Section, Die, and other factors contributing to the problem. The categories were determined based on the error data classification recorded in the company's historical data based on the engine factors as it is the focus of the research.

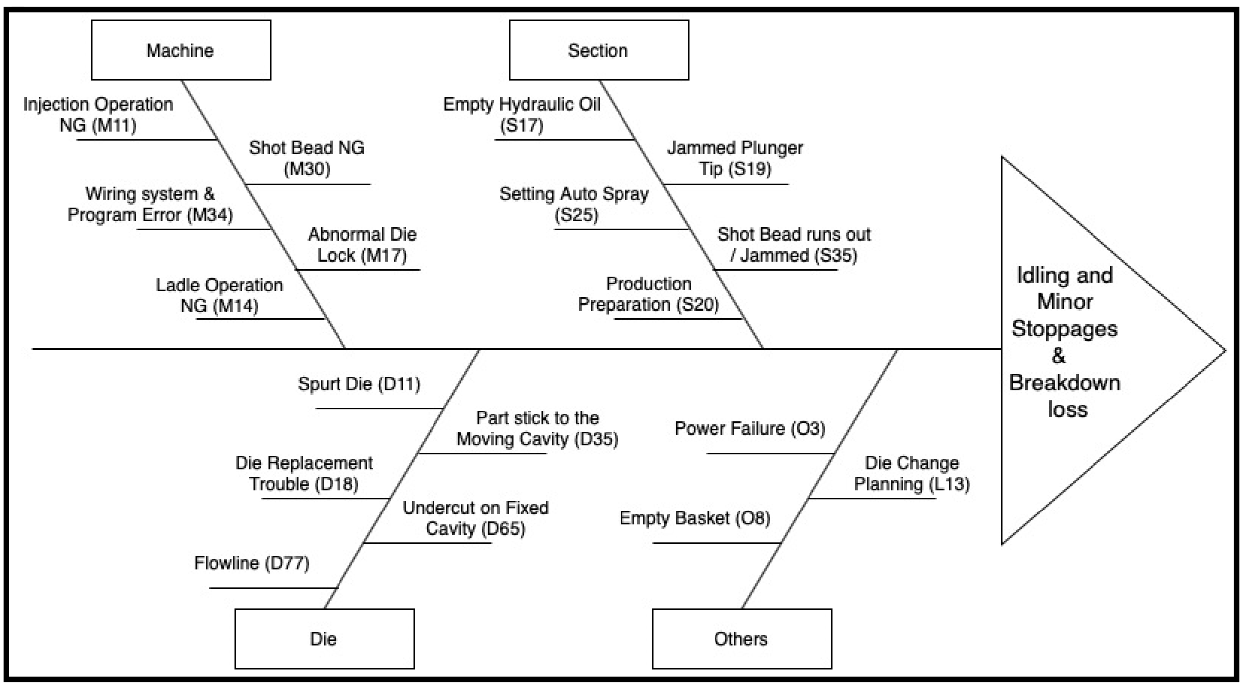

Figure 2. Fishbone diagram of Idling and Minor stoppage error and Breakdown loss

3.1.5 Machine Errors

The top five machine errors were determined to examine the relationship between the machine error and the idling and minor stoppages and breakdown loss and the fishbone analysis. As shown in Table 4, the types of damage are M17 (abnormal dies lock), M14 (ladle operation not good), M30 (Shot bead not good), M6 (Head spray not good), M24 (safety operation not good). The table also includes the total repair time and the amount of damage for five months. Moreover, based on the analysis, M17(abnormal die lock) occurs more often and takes the longest time to repair, followed by M14 (ladle operation not good), M30(shot bead not good), M6(head spray not good), and M24(safety operation not good).

Table 4. Machine errors summary

Month	M17 (abnormal die lock)		M30 (shot bead NG)		M14 (ladle operation NG)		M6 (head spray (NG)		M24 (safety operation NG)	
	Repair Time (min)	Amount of Damage (no.)	Repair Time (min)	Amount of Damage (no.)	Repair Time (min)	Amount of Damage (no.)	Repair Time (min)	Amount of Damage (no.)	Repair Time (min)	Amount of Damage (no.)
August	12000	5	5100	3	6000	6	7200	4	0	0
September	0	0	0	0	600	1	27600	11	15000	7
October	6000	4	28800	15	22200	13	6600	5	600	1
November	27600	14	8100	7	17400	8	4200	4	3000	2
December	16200	14	17100	5	5400	6	1200	1	600	1
Total	61800	37	59100	30	51600	34	46800	25	19200	11

3.1.5 Failure Mode and Effect Analysis (FMEA)

The FMEA calculation output can be seen from the RPN results from the computation (RPN = Severity x Occurrence x Detection), as shown in Table 5. The bigger the RPN, the worse it means. The most significant RPN result is the type of error that has the most impact and is the priority to be resolved, which is the abnormal die lock having an RPN of 392 followed by ladle operation not good, head spray not good, shot bead not good, and safety operation not good with RPN of 336, 245, 70, and 42 respectively. FMEA was made subjectively and based on interviews with factory foreman, quality control, the operators concerned. The current controls to the problem were also indicated on the table. The recommended action was based on the current situation and the researchers' interview of the persons directly involved in the operations.

Table 5. FMEA

Process Function	Failure Mode	Effect of Failure	Severity	Causes	Occurrence	Current Controls	Detection	RPN	Recommended Action
Injection Process	The Machine cannot Inject	Production time stops, the number of good products decreases, rework decreases machine productivity	7	Abnormal die lock	7	Manual lock force setting, plunger tip replacement every 8000-10000 shots	8	392	Plunger tip replaceable 4000-5000 shot, Operator training to use lock force automatically
				Ladle operation Not Good	6	Not replaced unless it is problematic	8	336	Running the SOP that has been created
				Shot bead Not Good	5	Checked every shift change	2	70	Preventive system maintenance is carried out
				Head Spray Not Good	5	Centralized flow system	7	245	Preventive flow system maintenance is established
				Safety Operation Not Good	3	Manual operator monitoring	2	42	Training for operators regarding safety

3.2 Discussion

The present study shows that Productivity Analysis is an essential method in manufacturing companies, especially when dealing with machine productivity. OEE measurements play an essential part in determining whether the equipment is doing what it is supposed to do. The company will be responsible for interpreting OEE's underlying factors; the availability, performance, and quality rate will be the key points in determining the particular cause of the system's problems (Hedman et al., 2016).

The result shows that machine 16 has availability, performance, and quality rate all below the world-class standards having 80.80%, 60.64%, and 83.99%, respectively. It shows that performance has the lowest rank among the three factors and is a vital indication of a problem with the machine engine. The availability and quality have a higher rate than the performance; however, it is still below the set standards. It should also be noted that machine 16 runs the same product for five months; thus, there is enough evidence for investigating the selected machine. In our view, likely, the company does not measure the OEE of the machines; accordingly, it is evident not only with the investigated machine but also with the remaining machines. Previous research states that under certain factors, the quality rate of 100% is not realistic to achieve; however, the present study is far from the 99% standard (Jonsson and Lesshammar, 1999). Kuhlang et al. (2014) state that many companies do not measure the product cycle time or have a basic understanding of the productivity analysis and theoretical maximum performance.

The result of the six big losses shows that idling and minor stoppages as the top contributor, followed by breakdown loss, reduced speed, reduce yield, setup or adjustment loss, and defect loss with an average percentage of 35.25, 13.03, 9.75, 6.17, 6.17, and 1.62, respectively. The result shows that Idling and Minor stoppages and Breakdown loss are the top contributors; therefore, further analysis was focused on these factors. Machine error summary was investigated to profoundly see the cause of the problem, and based on the results, abnormal die lock got the highest time of repair of 61,800 minutes and frequency damage at 37. The remaining problems are shot bead not good, head spray not good, and safety operation not good all the identified machine errors are related to the injection process. The last part of the productivity analysis was the FMEA, based on the interview with the people involved in the manufacturing process and the industry experts. It shows that Abnormal die lock got the highest RPN of 392 followed by ladle operation not good, head spray not good, shot bead not good, and safety operation not good. The summary of the results of the research analysis is shown in Table 6.

Table 6. Results Summary

Productivity Indicators	Results
1. OEE	It shows that the OEE of the company was 40.95%, having an availability rate of 80.80%, a performance rate of 60.64%, and a quality rate of 83.99%, below the world-class standards of 85%.
2. Six Big Loses	Among the identified six big losses, the idling and minor stoppages (35.25%) were the highest contributors of the losses, followed by the breakdown loss having 13.03% loss contribution.
3. FMEA	The abnormal die lock got the highest RPN of 392 from the five identified sources of OEE losses that include ladle operation not good, head spray not good, shot bead not good, and safety operation not good.

Although our study reports several significant findings, there are inevitably some noteworthy limitations. First, the sample size for the investigated machine was small; there might be an improvement in the OEE results by including more machines in the study. Furthermore, due to the limited time, the researchers were allowed to conduct experiments and investigations with the company; only the machine factors were considered in the study. As a result, the study did not include other factors, such as the manufacturing systems, parameter optimization, and other production-related problems that could give significant results.

Future studies could increase the number of machines to be investigated to widen the span of results. Moreover, to incorporate other techniques like the Taguchi method to help the system design, parameter design, and tolerance design on the manufacturing systems. Several literatures used Taguchi to optimize process parameters in a wide range of manufacturing industries (Shanmugasundar et al., 2019; Yizong et al., 2017). Therefore, it proves that the proposed method can enhance the quality of the results and give more depth to the study that future research might explore in extending this study.

4. Conclusion

The research presented in this paper identified the critical factors that directly affect machine productivity, specifically machine engine errors, and the applicability of OEE measures in measuring and identifying losses in the manufacturing process. It has been found that when calculating the machine's productivity, it is essential for the companies and management not to distance themselves from managing complicated machines. An obvious coordination error from the production to the maintenance department affects the machines' maintenance process.

It is concluded that the die casting injection machine 16 engine has the most number of breakdowns among the 20 machines investigated in the research. The machine's availability, performance, and quality rates have a lower value than the world standard of 90%, 95%, and 99%, respectively. The OEE value is 40.95%, far from the world's OEE standard of 85%. The Idling and Minor Stoppages and breakdown losses are the most dominant among six big losses. The fishbone diagram results with the machine breakdown summary point out that Abnormal die lock (M17) error should be prioritized, having an RPN of 392 based on the FMEA results. The outcome of this research could help the company and other automobile companies in Indonesia and other countries experiencing the same problems. Manufacturing companies can incorporate the methods and results to fully utilize the study's potential and the importance of productivity analysis through OEE and FMEA.

References

Amelia, V. R. (2014, September 18). *Industri Otomotif Indonesia Untung 2,5 Miliar Dolar AS*. Warta Kota. https://wartakota.tribunnews.com/2014/09/18/industri-otomotif-indonesia-untung-25-miliar-dolar-as.

Anggraeni, K. (2018, February 29). *Menperin: Industri Otomotif Sumbang 10,16 Persen ke PDB*. Tempo.Co. https://bisnis.tempo.co/read/1074289/menperin-industri-otomotif-sumbang-1016-persen-ke-pdb/full&view=ok.

Apparao, K. C., & Birru, A. K. (2017). QFD-Taguchi based hybrid approach in die casting process optimization. *Transactions of Nonferrous Metals Society of China*, *27*(11), 2345–2356. https://doi.org/10.1016/s1003-6326(17)60260-7

Chikwendu, O. C., Chima, A. S., & Edith, M. C. (2020). The optimization of overall equipment effectiveness factors in a pharmaceutical company. *Heliyon*, *6*(4). https://doi.org/10.1016/j.heliyon.2020.e03796

Dou, K., Lordan, E., Zhang, Y. J., Jacot, A., & Fan, Z. Y. (2020). A complete computer aided engineering (CAE) modelling and optimization of high pressure die casting (HPDC) process. *Journal of Manufacturing Processes*, *60*, 435–446. https://doi.org/10.1016/j.jmapro.2020.10.062

Gao, H., Zhao, B., Zhao, Z., & Liu, C. (2015). A cluster of inclusions on Al–Si–Cu die casting cylinder block. *Engineering Failure Analysis*, *55*, 370–375. https://doi.org/10.1016/j.engfailanal.2015.07.015

Hedman, R., Subramaniyan, M., & Almström, P. (2016). Analysis of Critical Factors for Automatic Measurement of OEE. *Procedia CIRP*, *57*, 128–133. https://doi.org/10.1016/j.procir.2016.11.023

Jonsson, P., & Lesshammar, M. (1999). Evaluation and improvement of manufacturing performance measurement systems - the role of OEE. *International Journal of Operations & Production Management*, *19*(1), 55–78. https://doi.org/10.1108/01443579910244223

Kuhlang, P., Erohin, O., Krebs, M., Deuse, J., & Sihn, W. (2014). Morphology of time data management - systematic design of time data management processes as fundamental challenge in industrial engineering. *International Journal of Industrial and Systems Engineering*, *16*(4), 415. https://doi.org/10.1504/ijise.2014.060652

Liu, W., Peng, T., Tang, R., Umeda, Y., & Hu, L. (2020). An Internet of Things-enabled model-based approach to improving the energy efficiency of aluminum die casting processes. *Energy*, *202*, 117716. https://doi.org/10.1016/j.energy.2020.117716

Miller, W. S., Zhuang, L., Bottema, J., Wittebrood, A. J., De Smet, P., Haszler, A., & Vieregge, A. (2000). Recent development in aluminium alloys for the automotive industry. *Materials Science and Engineering: A*, *280*(1), 37–49. https://doi.org/10.1016/s0921-5093(99)00653-x

Muñoz-Villamizar, A., Santos, J., Montoya-Torres, J. R., & Jaca, C. (2018). Using OEE to evaluate the effectiveness of urban freight transportation systems: A case study. *International Journal of Production Economics*, *197*, 232–242. https://doi.org/10.1016/j.ijpe.2018.01.011

Otarawanna, S., Gourlay, C. M., Laukli, H. I., & Dahle, A. K. (2009). Microstructure formation in high pressure die casting. *Transactions of the Indian Institute of Metals*, *62*(4-5), 499–503. https://doi.org/10.1007/s12666-009-0081-2

Shanmugasundar, G., Karthikeyan, B., Ponvell, P. S., & Vignesh, V. (2019). Optimization of Process Parameters in TIG Welded Joints of AISI 304L -Austenitic Stainless Steel using Taguchi's Experimental Design Method. *Materials Today: Proceedings*, *16*, 1188–1195. https://doi.org/10.1016/j.matpr.2019.05.213

Wang, L., Yan, F., Wang, F., & Li, Z. (2021). FMEA-CM based quantitative risk assessment for process industries—A case study of coal-to-methanol plant in China. *Process Safety and Environmental Protection*, *149*, 299–311. https://doi.org/10.1016/j.psep.2020.10.052

Wright, M. (2018, November 20). *World's Top 20 Largest Passenger Car-Producing Countries In 2017 (Million Units)*. CEOWORLD magazine. https://ceoworld.biz/2018/11/20/worlds-top-20-largest-passenger-car-producing-countries-in-2017-million-units/.

Yizong, T., Ariff, Z. M., & Khalil, A. M. (2017). Influence of Processing Parameters on Injection Molded Polystyrene Using Taguchi Method as Design of Experiment. *Procedia Engineering*, *184*, 350–359. https://doi.org/10.1016/j.proeng.2017.04.105

Biography

Klint Allen A. Mariñas is a Ph.D. student at the Industrial and Systems Engineering Department, Chung Yuan Christian University in Taiwan. He earned his bachelor's degree in Industrial Engineering at Adamson University, Manila, Philippines, and his master's in Industrial Engineering degree at Mapua University, Manila, Philippines. He previously worked as a process engineer in a plastic manufacturing company in the Philippines for three years and eventually taken his graduate studies focusing on production planning, human factors, ergonomics, and quality engineering. He is currently under the CIM and Smart Manufacturing laboratory working on ergonomics and production improvement studies.

Yung-Tsan Jou received his Ph.D. degree in Integrated (ME, ISE) engineering from Ohio University, Athens, OH, in 2003. He is an Associate Professor of Industrial and Systems Engineering at Chung Yuan Christian University, Taiwan. His research has made contributions in green design, human–system interface design, senior assistive devices, and usability or quality evaluation by using virtual reality tools, smart manufacturing, machine learning, and data analysis.

Riana Magdalena Silitonga received her bachelor's degree in Mathematics in 2001 and her Master's Degree in Management Technology in 2003 from Bandung Institute of Technology. Currently, she is a Ph.D. student in the Department of Industrial and Systems Engineering of Chung Yuan Christian University, Taiwan. Her research interest is in management technology, information system, product design, and innovation.