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Proposed Application of OEE and FMEA Methods and Dynamic Simulation in Laser Machine Maintenance

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Abstract

This study aims to provide suggestions for improving the laser machine maintenance system at PT. Nosa Jaya Karya, through the application of Overall Equipment Effectiveness (OEE), Failure Mode and Effects Analysis (FMEA), and dynamic simulation methods. The primary issue is sudden damage to the laser machine, resulting in high downtime and reduced production quality. The OEE analysis in 2024 shows an average of 85.01%, meeting World Class Manufacturing standards, but the performance efficiency (88.02%) and quality rate (98.87%) remain below the ideal standard. Through FMEA, five main failure modes were identified, such as long setup times and problematic cooling systems. Dynamic simulations show that preventive maintenance can consistently improve production performance and quality over the next five years. As a recommendation, daily check sheets to support regular machine inspections are proposed to reduce the risk of failure and improve operational efficiency on an ongoing basis..

Keywords:Overall Equipment Effectiveness, FMEA, Udapi Laser Machine, Preventive Maintenance, Acrylic Production.

INTRODUCTION

The acrylic manufacturing industry continues to grow along with increasing demand from various sectors, encouraging PT. Nosa Jaya Karya is to maintain precision, quality, and efficiency in the production of motor vehicle accessories (Putri & Ismail (2020). Laser machines, as the primary tool, play a crucial role but often experience sudden breakdowns, leading to high downtime and reduced product quality. This study proposes the application of the Overall Equipment Effectiveness (OEE) method to measure overall machine performance Gozali et al. (2020), as well as Failure Mode and Effects Analysis (FMEA) to identify and prioritise potential failures based on risk value (Apriyan et al. (2017); Al Hazza et al. (2021); Salah et al. (2023)). Additionally, dynamic simulation is used to project the long-term impact of maintenance strategies on machine quality and performance (Heizer & Render (2001); Yuan et al. (2025)). The combination of these three approaches is expected to help companies develop more proactive maintenance policies, reduce the risk of machine damage, increase production efficiency, and maintain operational stability sustainably (Levitt (2013); Guste et al. (2024)).

A Scopus search using the keywords Maintenance, FMEA, and System Dynamics yielded eight related papers. These eight papers include: Automatic Train Operation, Safety Analysis for Hoists, Reliability Systems with Markov Models, Degradation Degree Based on Simulation Data for Propellant, and Investment Planning for Power System Transmission.

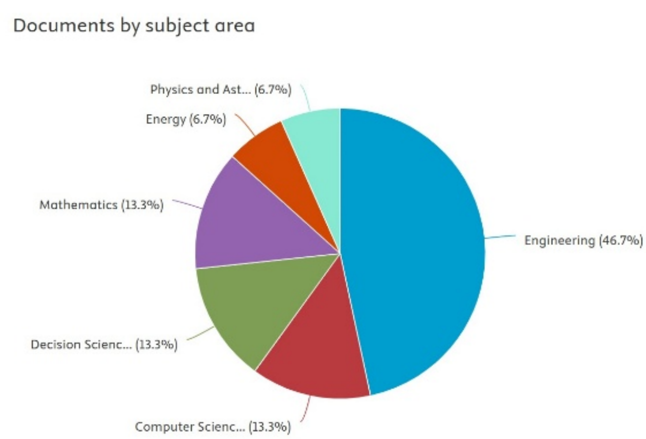

Figure 1: Scopus Publication in Maintenance, FMEA and Dynamic Systems

Figure 2: The FMEA Maintenance and system dynamics research publications in the years

Only one paper addresses Maintenance System Dynamics but uses Monte Carlo simulation (Chemweno et al. (2017)). This paper, which combines maintenance research using FMEA and system dynamics, presents a novel and state-of-the-art approach. Figure 1 shows the results of Maintenance, FMEA, and Dynamics Systems topics.

LITERATURE REVIEW

Overall Equipment Effectiveness (OEE)

Overall Equipment Effectiveness (OEE) is a method used to assess the performance of machines and equipment across several key aspects, including availability, machine performance, and product quality level or quality rate (Gasperz (2004); Prabowo et al. (2020)). Every company expects machines to operate optimally without wasting time, although in reality, this is difficult to achieve (Mobley (2002); Choi et al. (2022)). Therefore, measuring the value of Overall Equipment Effectiveness (OEE) on machines is crucial, and limits are necessary to determine the ideal OEE value (Pasra & Ruswandi (2016); Van De Ginste et al. (2022)). Based on the opinion of Seichi Nakajima, as quoted in the book "Integrated Maintenance System" by Ansori & Mustajib (2013), the World Class Manufacturing condition standards for a company's OEE are shown in Table 1.

Table 1: World-Class Manufacturing Standars

Description	Score(%)
Availability	$> 90\%$
Perfformance	$> 95\%$
Quality Yield	$> 99\%$
OEE	$> 85\%$

Failure Modes and Effects Analysis (FMEA)

Failure Mode and Effect Analysis (FMEA) is an analytical method used to identify, trace, and eliminate potential failures, errors, or problems that may occur in a system, design, process, or service, before they have an impact on customers (Babazadeh et al. (2016);Laurensia & Gozali (2021)). In this study, FMEA was applied to assess the potential risks associated with the operation of acrylic production machines, particularly laser machines (Wu et al. (2021)).

Severity (S) measures how serious the consequences are when a failure occurs, focusing on the impact on safety, machine performance, product quality, or system downtime. Occurrence (O) reflects how frequently the failure mode is expected to happen based on historical data or expert judgment. Detection (D) indicates how likely the current controls are to detect the failure before it causes an impact—the lower the detectability, the higher the score. These three scores (S, O, D) are multiplied to form the Risk Priority Number (RPN), which helps prioritize the most critical failure modes (Gozali et al. (2019)).

Severity Rate

Severity is an indicator used to assess the impact of a failure. This rate means that each type of failure is evaluated based on its consequences for the system or process (Fitriyan & Syairudin (2016); Filz et al. (2021)). There is a direct relationship between the level of impact (effect) and the severity value. R. Babazadeh, M. Kermanshahi, and A. Raeisian Babazadeh et al. (2016) state, as an illustration, that if the impact is classified as critical, the severity value will be high. Conversely, if the effect is not very significant, the severity value will also be low.

Occurrence Rate

Occurrence is the likelihood that a failure cause will occur and result in a failure during a product's lifecycle (Zhu et al. (2021)). The occurrence value reflects the estimated failure frequency, calculated from predicted occurrence rates or from accumulated historical data on similar failures Molęda et al. (2023).

Detection Rate

Detection is the extent to which a control mechanism or system can detect the cause or mode of failure before it reaches the user or impacts the process (Rojek et al., 2023). The lower the probability of a failure being detected before it occurs, the higher the detection value, indicating that the risk is not being adequately detected and requires greater attention in its control (Abdallah et al. (2022).

Risk Priority Number (RPN)

The Risk Priority Number (RPN) is obtained by multiplying the severity, occurrence, and detection levels of a failure (Liu, Li & Deng, 2023). The RPN serves to determine the priority of failures that require increased attention and resources (Wu & Wu (2021); Karek et al. (2025)). Although the RPN value itself has no absolute meaning, it is used to rank potential failures by risk level Sharma & Srivastava (2018). The equation used to calculate the RPN is as follows:

$$RPN = SeverityOccurrenceDetection \quad (1)$$

Dynamic Simulation

Dynamic simulation is a modelling method used to understand and analyse systems that change over time (Pidd (2004); Wang et al. (2022)). Unlike static simulations, which describe a system's condition at a single point in time, dynamic simulations account for the cause-and-effect relationships among variables in a time-dependent system (Schünemann et al. (2024)). Dynamic systems methods can provide valuable insights in dealing with the complexity of dynamic systems, estimating aspects that are difficult to measure directly, identifying delays within the system, understanding the relationship between short-term and long-term impacts, and assisting in determining appropriate organisational boundaries in the strategic planning process (Chen (2023); Cheng et al. (2023)).

RESEARCH METHODOLOGY

The research methodology outlines the steps to be taken in this research. This research began with the identification of problems in the maintenance system of acrylic laser production machines, followed by the determination of the topic and scope to focus the research. After that, a field study and a literature review on machine maintenance theory, OEE, FMEA, and dynamic simulation were conducted to provide a strong analytical basis. The next stage was to define the problem boundaries to maintain the research direction, followed by the process of collecting essential data such as machine data, failures, maintenance, performance, and production quality through interviews, observations, and historical data; this process continued until the data was deemed sufficient. The collected data was then processed using FMEA to identify failure modes and determine improvement priorities, followed by OEE calculations to measure machine effectiveness, and dynamic simulations with the Powersim application to predict the impact of various maintenance strategies on long-term performance. The results of the FMEA, OEE, and simulations were interpreted to yield practical recommendations to reduce failures and improve maintenance effectiveness. Finally, the research concluded with a summary that summarised the entire process, key findings, and implications for improving machine maintenance management in the company. The research methodology flowchart is shown in Figure 3.

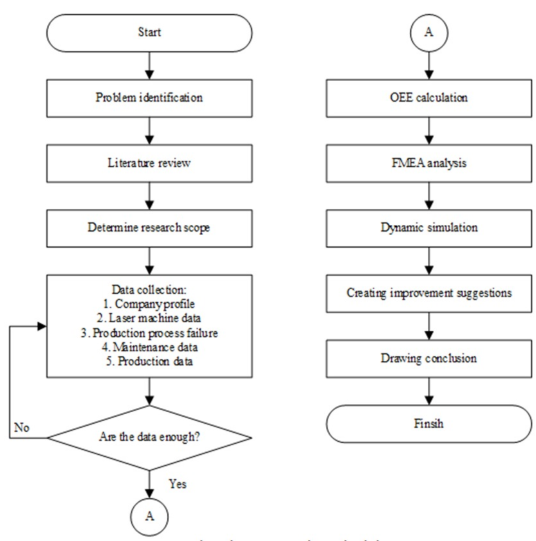

Figure 3: Flowchart Research Methodology

DATA COLLECTION
Data collection was conducted through interviews. The interview method involved several parties asking questions and answering them regarding the required data, including interviews with laser machine operators and production managers. During the interviews, the author explained the purpose of the interviews.

Table 2: Production Data in the Company

Period (2024)	Ideal Production (pcs)	Actual Production (pcs)	Defect (pcs)
Jan	62351	61553	798
Feb	58002	57345	657
Mar	62213	61444	769
Apr	60139	59434	705
May	62007	61366	641
Jun	60000	59377	623
Jul	62554	61855	699
Aug	62070	61269	801
Sep	60087	59446	641
Oct	62008	61368	640
Nov	60154	59576	578
Dec	62094	61396	698

Table 3: Data of Machine Time Operation

Period (2024)	Available Time (Min)	Planned Downtime (Min)	Unplanned Downtime (Min)
Jan	11520	60	81
Feb	11520	60	44
Mar	11520	120	101
Apr	11520	60	90
May	11520	60	50
Jun	11520	60	112
Jul	11520	60	116
Aug	11520	60	104
Sep	11520	120	104
Oct	11520	60	117
Nov	11520	60	53
Dec	11520	120	32

Table 2 above shows data on laser machine production volumes for 2024. Interviews also provided machine operation data, including machine operating time, planned downtime, and unplanned downtime. PT Nosa Jaya Karta's laser machine operation data are presented in Table 3

RESULT AND ANALYSIS

This project focuses on applying Overall Equipment Effectiveness (OEE) methods, Failure Mode and Effects Analysis (FMEA), and dynamic simulation to improve the effectiveness of laser machine maintenance at PT. Nosa Jaya Karya. The primary objective of this activity is to minimise the risk of failure in the laser machine used in the acrylic production process, ensuring that the production flow runs more stably and efficiently, and that it follows established targets. The implementation plan is systematically prepared to provide a real impact on improving machine performance (Bagaskara et al. (2020)).

Availability Rate
Availability is a ratio that indicates the time a machine is available to operate. Availability is the ratio between operating time and loading time. The higher the availability value, the better. Data on laser machine availability through 2024 are presented in Table 4.

Table 4: Data on Laser Machine Availability

Period (2024)	Planned Downtime (Min)	Loading Time (Min)	Downtime (Min)	Operating Time (Min)	Availability (%)	Available Time (Min)
Jan	60	120	81	11259	97.73	11520
Feb	60	100	44	11316	98.22	11520
Mar	120	110	101	11189	97.12	11520
Apr	60	90	90	11280	97.91	11520
May	60	130	50	11280	97.91	11520
Jun	60	100	112	11248	97.63	11520
Jul	60	110	116	11234	97.51	11520
Aug	60	90	104	11266	97.79	11520
Sep	120	100	104	11196	97.18	11520
Oct	60	120	117	11223	97.42	11520
Nov	60	110	53	11297	98.064	11520
Dec	120	130	32	11238	97.55	11520
97.67						

Table 5: Data of Laser Machine Performance

Period (2024)	Operation Time (Min)	Actual Production (Pcs)	Cycle Time (Min)	Performance) Efficiency (%)
Jan	11259	62351	0.162	89.71366906
Feb	11316	58002	0.162	83.03573701
Mar	11189	62213	0.162	90.07512736
Apr	11280	60139	0.162	86.36984043
May	11280	62007	0.162	89.05260638
Jun	11248	60000	0.162	86.41536273
Jul	11234	62554	0.162	90.20605305
Aug	11266	62070	0.162	89.25386118
Sep	11196	60087	0.162	86.94260450
Oct	11223	62008	0.162	89.50633520
Nov	11297	60154	0.162	86.26137913
Dec	11238	62094	0.162	89.51083823
Average	–	–	–	**88.03**

Performance Performance calculations are based on actual production volume, ideal cycle time, and adequate machine time. Laser machine performance calculations for 2024 are presented in Table 5.

Quality Rate

The quality rate reflects the proportion of products produced in accordance with quality standards relative to total production output. The quality rate indicates the number of products successfully produced without defects or requiring rework (Salekha & Apriliani (2024). The higher the quality rate, the more reliable the production process is in delivering products that meet specifications. This component is a key indicator for measuring the effectiveness of the quality control process within the overall production system. The calculation of the laser machine quality rate for 2024 is presented in Table 6.

OEE Calculation

After obtaining the Availability, Performance, and Quality Rate values, the next step is to calculate the OEE. The OEE value for the laser machine is shown in Table 7.

Table 6: Data of Laser Machine Quality Rate

Period (2024)	Ideal Production (Pcs)	Defect (Pcs)	Quality Rate (%)
Jan	62351	798	98.72014883
Feb	58002	657	98.86728044
Mar	62213	769	98.76392394
Apr	60139	705	98.82771579
May	62007	641	98.96624575
Jun	60000	623	98.96166667
Jul	62554	699	98.88256546
Aug	62070	801	98.70952151
Sep	60087	641	98.93321351
Oct	62008	640	98.96787511
Nov	60154	578	99.03913289
Dec	62094	698	98.87589783
Average	–	–	**98.89045808**

Table 7: OEE Calculation

Period (2024)	Availability (%)	Performance Efficiency (%)	Quality Rate (%)
Jan	97.73	89.71	98.72
Feb	98.22	83.03	98.86
Mar	97.12	90.07	98.76
Apr	97.91	86.36	98.82
May	97.91	89.05	98.96
Jun	97.63	86.41	98.96
Jul	97.51	90.20	98.88
Aug	97.79	89.25	98.71
Sep	97.18	86.94	98.93
Oct	97.42	89.50	98.96
Nov	98.064	86.20	99.04
Dec	97.55	89.51	98.87
Average	**97.67**	**88.02**	**98.87**
Standard	**90**	**95**	**99**

FMEA Analysis

FMEA analysis is used to identify, track, and eliminate failure modes in laser machines. The steps involved in this method are as follows:

1. Determining the machine components to be analysed.
2. Performing and determining the failure modes present in the machine.
3. Identifying the potential causes of failures.
4. Identifying the causes of failure modes occurring during the process.
5. Determining severity, occurrence, and detection values.
6. Determining the RPN value, which indicates the severity of the failure mode.

Failure modes in PT. Nosa Jaya Karya's laser machines are designed based on machine performance, work methods, and workforce. Failure modes with the highest RPN values are prioritised for corrective action. The FMEA analysis is presented in Table 8.

Table 8: FMEA Analysis

Failure Mode	Potential Effect	Potential Cause	S	O	D	RPN	Solution
Cutting speed decreases	Low output	Nozzle worn/dirty	7	6	4	180	Standard SOP, setup training
Long setup time	Downtime increases	Operators are not trained	6	5	6	168	Routine nozzle maintenance, SOP cleaning
Delay in replacing raw materials	High idle time	Logistics delays	5	4	5	100	Driver check and system control
Long preheat time	Production-ready time is slow	Engine has not pre-started	5	3	6	90	Schedule regular optical cleaning
Head vibration during cutting	Inaccurate cut	Loose bolts/mechanical components	8	3	5	120	Validation system before cutting
Blurry lens/mirror	Cut quality decreases	Dust/oil sticks	7	5	5	175	Vibration daily checklist
Error in software nesting	Wasted material	Bug or incorrect file	6	2	6	72	Periodic sensor calibration
Chiller failure	Engine overheating	Coolant pump stuck	9	3	4	108	Real-time temperature monitoring, chiller maintenance
Machine false alarm	Process stopped for no reason	Sensor error/dirty	6	4	5	120	Logistic scheduling and stock buffer
Inconsistent cutting speed	Fluctuations in production results	Problematic motorbike driver	7	4	6	168	Auto warm-up system
Program input error	Wrong cutting dimensions	Operator input data incorrectly	8	3	5	120	Nesting validation and software update
Uneven (curved) material	Imperfect cutting	Poor raw material quality	6	3	4	72	Quality control of incoming materials
Auxiliary gas runs out during production	Machine stops suddenly	No gas level sensor	7	3	5	105	Automatic gas sensor and gas filling SOP

After ranking the RPN values from the FMEA analysis results, the next step is to provide improvement suggestions for each failure mode, which have been sorted by priority level, as visualised in Table 8. The purpose of this proposal is to enhance the quality control system and improve the reliability of production machines, which are currently suboptimal. In this case, improvements are not focused solely on high-RPN failure modes but also encompass all identified failure modes, providing a comprehensive evaluation and strategic consideration for PT. Nosa Jaya Karya's laser machines.

Causal Loop Diagram

Based on the causal loop diagram, the system illustrates a balancing (negative) feedback loop related to machine maintenance and performance. Increased Maintenance effort leads to reduced Machine Problems, which in turn decreases downtime and improves machine performance. Better Machine Performance is associated with higher machine reliability and, potentially, improved Quality Maintenance. Crucially, the loop connecting Machine Problem, Downtime, Machine Performance, machine reliability, and Quality Maintenance appears to have a positive influence on the system; however, the overall loop is self-regulating: the presence of a Machine Problem drives (or necessitates) maintenance, creating the negative link. The core dynamic is that maintenance corrects or suppresses machine problems, stabilising overall machine performance and reliability, as shown in Figure 4.

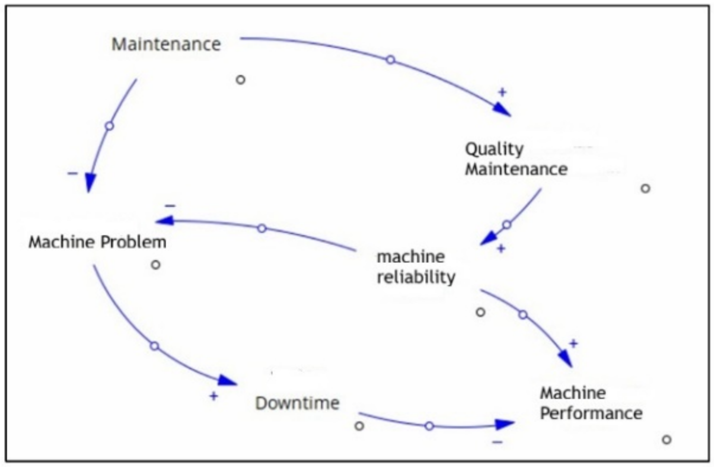

Figure 4: Causal Loop Diagram

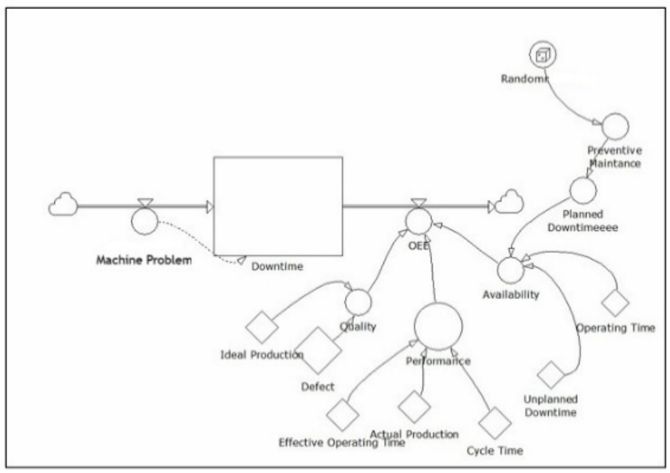

Figure 5: Stock Loop Diagram

Stock Flow Diagram
The stock flow diagram process is used to determine the dynamic flow of the laser machine maintenance system at PT. Nosa Jaya Karya. This Stock Flow Diagram aims to visualise how the flow of key variables is influenced by factors such as machine constraints, preventive maintenance activities, and operational performance. The laser machine stock flow diagram is shown in Figure 5.

Dynamic Simulation
After the stock-flow diagram process was completed, a dynamic simulation was conducted to project the development of system performance variables based on the previously designed stock-and-flow model. This simulation analysed two leading indicators: Quality and Performance, which showed improvements in quality control and performance over five years. The dynamic simulation graph for the laser machine is shown in Figure 6 and 7

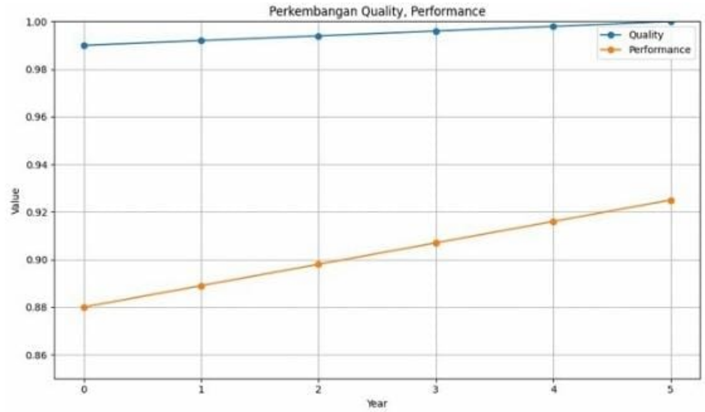

Figure 6: Quality and Performance Dynamic Simulation Result

year	Quality (First)	Performance (First)
0	0,99	0,88
1	0,992	0,889
2	0,994	0,898
3	0,996	0,907
4	0,998	0,916
5	1,00	0,925

Figure 7: Dynamic Simulation Graph of A Laser Machine

Based on the simulation results graph in Figure 4, the Quality value shows a steady upward trend from year to year, starting from around 0.98 in the first year and reaching nearly 1.00 in the fifth year. This result indicates that process or product quality is improving over time due to the system interventions.

Meanwhile, the Performance indicator also shows a positive growth pattern, albeit with a lower initial value than Quality. The Performance value increased from 0.88 in the first year to around 0.92 in the fifth year. This increase reflects that the system's effectiveness and efficiency are continuing to improve, although it will take longer to match the quality level.

The implementation of a preventive maintenance strategy plays a crucial role in improving these two indicators. By systematically performing regular maintenance, machine failures can be detected early, which directly impacts consistent product quality and smooth machine operation.

Preventive maintenance also minimises unplanned downtime, thereby reducing downtime. This simulation shows that the developed model, using the preventive maintenance method, gradually has a positive impact on the system.

CONCLUSION

This study demonstrates that applying Overall Equipment Effectiveness (OEE), Failure Mode and Effects Analysis (FMEA), and dynamic simulation methods can deliver measurable, strategic solutions to improve the effectiveness of laser machine maintenance at PT. Nosa Jaya Karya. The average OEE of 85.01% meets world-class standards, but the performance efficiency and quality rate remain below the ideal threshold. Through FMEA, five main failure modes with the highest RPN values were identified, including long setup times, cloudy lens conditions, disturbances in the cooling system, and variations in cutting speed. Proposed improvements focused on operator training, SOP implementation, and routine maintenance. The results of the dynamic simulation demonstrated that consistent preventive maintenance improved machine performance and product quality over five years. Thus, integrating these three methods has proven effective in designing a more proactive, sustainable maintenance system to improve the efficiency and reliability of laser machine production at PT. Nosa Jaya Karya.

Dynamic simulation is needed because it provides behavior-level insights that standard OEE–FMEA cannot capture. In maintenance FMEA, OEE–FMEA only gives static, snapshot-type assessments—such as severity, occurrence, detection, and overall equipment performance at a fixed point in time. However, real production and maintenance systems behave dynamically, with failures, repairs, delays, resource constraints, and machine interactions that change over time. Dynamic simulation allows you to model these time-dependent behaviors and see how failure modes actually influence system performance under realistic operating conditions. It reveals hidden effects such as bottleneck shifts, cumulative downtime impacts, maintenance resource overload, failure propagation, and variability in cycle times—insights that OEE–FMEA alone cannot quantify. As a result, dynamic simulation helps validate which failure modes truly matter in real operations, tests "what-if" maintenance strategies, and predicts long-term performance outcomes, making the maintenance FMEA more accurate, realistic, and decision-ready.

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