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Valuation of The Cable Harness TPM Program on The HASS Burn-In Chamber Machine to Improve MAU Module Productivity in An Aerospace Manufacturing Company

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Abstract

Cable harness degradation during aerospace environmental testing can cause false failures, repeated testing, and hidden productivity losses. This study evaluated cable harness maintenance in highly accelerated stress screening (HASS) chambers and developed total productive maintenance (TPM) recommendations to improve avionics module testing productivity. A case study examined three years of operational records from five chambers, supplemented by field observations, maintenance documentation, and technician questionnaires. The analysis combined overall equipment effectiveness (OEE), adjusted using first-pass yield (FPY), with reliability indicators, Pareto analysis, fishbone diagrams, and cost of poor quality (COPQ) calculations. The actual OEE was 77.05%, compared with the internally reported value of 94%, revealing substantial productivity losses obscured by retesting practices. The first-pass yield was 91.01%. Cable failures had a mean time between failures (MTBF) of 236.81 hours and a mean time to repair (MTTR) of 9.09 hours. False failures affected 592 modules, consumed 2,368 machine hours, and generated total costs of IDR 2,356,160,000. Connector degradation, restricted workspace, and installation time pressure contributed to maintenance and setup difficulties. These findings supported recommendations that integrated autonomous inspection, planned cable replacement every eight operating days, and visual installation aids. The study concluded that reliability-informed TPM and first-pass performance measurement could support productivity improvements, although the proposed interventions require implementation and validation.

INTRODUCTION

The aerospace manufacturing industry was compelled to substantially restructure its operating costs because of the decline in global aviation activity during the COVID-19 pandemic, including workforce reductions to maintain business continuity (Dube et al., 2021; Nguyen Jr, 2021; Nhamo et al., 2020). However, post-pandemic recovery has introduced additional challenges, particularly the global semiconductor supply shortage caused by a sudden surge in demand (Johan et al., 2022). The unavailability of these critical components resulted in cumulative financial losses exceeding US$5.6 million. Workforce reductions also affected the effectiveness of equipment maintenance, limiting the ability of production equipment to achieve its optimal capacity. Previous suboptimal

maintenance practices contributed to quality deterioration, highlighting the need for a comprehensive evaluation of production asset performance. The MAU unit experienced invalid production failures at the highly accelerated stress screening (HASS) test station, primarily because of prolonged equipment downtime associated with degradation of the cable harness used as a data transmission interface. Exposure to extreme temperatures and vibration caused frictional wear on the microconnector pins, a common failure mechanism in the automotive and aerospace industries under physical stress. Retesting following these false functional failures consumed substantial machine time because data transmission was disrupted by physical degradation of the gold plating on the cable connectors (Lampman et al., 2022; Ojala, 2024; Song et al., 2025).

This study demonstrated the limitations of conventional overall equipment effectiveness (OEE) reporting systems in capturing repeated product repair and retesting incidents (Bujna et al., 2022). Consequently, the company's reported equipment effectiveness of 94% contrasted with the actual first-pass yield (FPY) of approximately 90%. This hidden factory phenomenon created an illusion of efficiency because operational inefficiencies were obscured by products that eventually passed after repeated testing (Gisi, 2024; Lampland, 2023). Traditional efficiency calculations that treated reworked or retested products as successfully completed output contributed to distorted performance measurements. Therefore, more accurate measurement of equipment productivity was necessary to identify capacity losses that had become normalized in high-technology manufacturing environments (Bujna et al., 2022). Such hidden losses contributed to declining reliability performance at the test facility by obscuring setup-time losses and reductions in equipment utilization. The novelty of this study lies in integrating maintenance management with technical reliability metrics, including mean time between failures (MTBF), mean time to repair (MTTR), and mean time to failure (MTTF), and adjusting OEE calculations using FPY to identify latent productivity losses. The OEE calculation was adjusted using first-pass performance to distinguish genuine product defects from false failures caused by data transmission problems. Reliability indicators such as MTBF provided quantitative measures for evaluating maintenance performance and estimating component replacement requirements (Ben, 2022). Root cause analysis was conducted using a fishbone diagram to classify potential failure factors related to personnel, methods, materials, machines, the environment, and measurement. The research framework systematically progressed from identifying operational problems to formulating continuous improvement recommendations for equipment maintenance strategies intended to reduce false failures and support sustainable manufacturing in the aerospace sector.

Personnel competence and work practices are important determinants of operational performance in high-technology manufacturing and are directly associated with efficiency and productivity (Di Luozzo & Schiraldi, 2023). Time constraints during product installation may cause technicians to perform tasks hastily, increasing the risk of bent connector pins because of improper force application. Inadequate lighting conditions, combined with time pressure, can further increase the likelihood of human

error and subsequent damage to test components. Financial losses associated with these quality issues, including liquid nitrogen consumption and validation labor costs, reached IDR 2.35 billion. A visual assistance system designed to reduce operators' cognitive load when determining cable connector orientation was proposed to improve setup-time efficiency. Visual guidance can also serve as an error-proofing mechanism to reduce installation errors and maintain the integrity of electronic components during the testing and assembly processes.

The implementation of autonomous maintenance and planned maintenance pillars, supported by visual technical aids, was proposed as an operational optimization strategy within the total productive maintenance (TPM) program. Under autonomous maintenance, operators were assigned responsibility for conducting initial inspections of cable and connector conditions before test preparation by technical personnel. A reliability-centered preventive maintenance approach included scheduled cable harness replacement every eight operating days to reduce the likelihood of unexpected failures that could disrupt production. Fluorescent visual cues were proposed as an error-proofing measure to assist operators in correctly orienting and installing connectors, thereby reducing the potential for physical damage. Establishing proactive and continuous maintenance practices was expected to improve testing equipment readiness and support the timely completion and delivery of products.

METHOD

The research was conducted in five stages, from identifying operational problems to formulating strategic improvement recommendations aligned with the facility's standard operating procedures. The analysis focused on identifying the causes of high operational downtime at environmental testing stations and developing sustainable measures to improve productivity in high-technology manufacturing facilities operating under extreme environmental conditions (Bujna et al., 2022). Historical machine performance data were collected and analyzed using relevant reliability indicators (Ben, 2022). Maintenance improvement strategies were subsequently developed based on the operational data and supported by literature and field investigations (Toke, 2023). The overall research process included establishing evaluation criteria, analyzing equipment performance and reliability, identifying root causes, and formulating a proactive maintenance strategy (Hardt et al., 2021).

Primary and secondary data were collected through direct observations on the production floor and reviews of internal company documents. Historical records of unplanned downtime associated with critical cable harness failures were obtained from internal quality databases and maintenance reports. Technical data included cable specifications, engineering bulletins, and component cost information used for financial analysis. Field observations were conducted to identify ergonomic constraints, workspace limitations, and equipment density within the test chambers. Technician perceptions of potential failure factors were collected using a Likert-scale questionnaire administered to production and maintenance personnel. Visual documentation of component damage was

also examined to support the assessment of material failures associated with extreme environmental conditions in the test chambers.

Equipment effectiveness was evaluated using overall equipment effectiveness (OEE), based on availability, performance, and quality (Tonny et al., 2023). Availability and performance were calculated using operational records collected during the three-year observation period (Priyono et al., 2019). The quality component was adjusted using first-pass yield (FPY) to account for units that passed testing on the first attempt without requiring retesting or rework (Bujna et al., 2022). Units requiring retesting because of signal transmission failures were incorporated into the loss assessment to identify productivity losses that could otherwise be obscured by repeated testing.

Cable harness reliability was evaluated using mean time between failures (MTBF), mean time to repair (MTTR), and mean time to failure (MTTF) based on three years of historical failure and operating data (Ben, 2022). These reliability indicators were used to assess failure frequency, maintenance performance, and component service life (Chauhan & Pancholi, 2013). The results provided a quantitative basis for determining an appropriate preventive replacement interval for critical cable harness components.

The primary sources of productivity loss were identified using Pareto analysis (Bujna et al., 2022). Root causes of cable harness degradation were subsequently examined using a fishbone diagram covering six categories: personnel, methods, materials, machines, environment, and measurement. These factors were analyzed to determine their contribution to cable harness failures in the aerospace testing facility (Di Luozzo & Schiraldi, 2023). Cost of poor quality (COPQ) analysis was used to quantify the financial impact of productivity losses associated with false failures and retesting. The root cause analysis was further supported by questionnaire responses concerning ergonomic and visual constraints experienced by technicians. The combined results were used to formulate total productive maintenance (TPM) recommendations focused on proactive failure prevention (Sahoo & Yadav, 2020).

The results were interpreted by integrating equipment effectiveness, reliability, root cause, financial, and field assessment findings with relevant maintenance literature (Toke, 2023). Relevant data were selected and organized according to the research objectives (Dieste et al., 2021). The proposed maintenance improvements were assessed against applicable TPM principles (Hardt et al., 2021), while maintenance planning was used to establish equipment productivity targets and estimate production capacity (Zennaro et al., 2019). The findings subsequently provided the basis for developing facility maintenance improvements and supporting a transition from reactive maintenance toward a proactive, reliability-informed maintenance strategy (Mubaricky et al., 2026).

RESULTS AND DISCUSSION

The total actual operating hours of the five machines in the environmental test facility, according to the company's records and effective work calendar as outlined in Table 1., amounted to twenty-nine thousand forty per year.

Table 1. Parameters of Machine Operating Time Availability *HASS Chamber (*Per Year*)*

Operational Parameters	Determination Value	Units	Company Standard Description
Total days in a year	365	Day	Annual standard calendar.
Total Official Holidays	18	Day	Determination of national holidays and replacement *days*.
Total Weekends	105	Day	52 weeks x 2 days (Saturday and Sunday).
Effective Weekdays	242	Day	Calculated from the total days minus holidays and weekends.
Number of Shifts	3	Turn	Fully operational non-stop on weekdays.
Duration of Work Per *Shift*	8	Hours	Normal work time limits outside of overtime work.
Total Operating Machines	5	Units	Chamber ID: 143, 144, 145, 146, 151.
Total *Factory Loading Time*	29.04	Hours	242 days x 24 hours x 5 units of machinery.

The data in Table 1. indicate the use of very massive assets, demanding 24-hour non-stop operation of the machine every day to meet the surge in market demand. The operational imbalance is highlighted by the fact that management provides only four hours of planned maintenance per year for each machine handling a load of five thousand eight hundred and eight hours. The workload review confirmed that the test unit was at high risk of sudden failure, due to the lack of adequate preventive maintenance during the machine's operating hours. The implication of this neglect of routine maintenance was the acceleration of material fatigue in all signal transmission components due to exposure to radical and continuous temperature fluctuations in the production area.

An in-depth description of the technical and financial aspects of the cable harness components, whose functions are vital to securing the integrity of data transmission in the testing process, can be found in Table 2.

Table 2. Technical and Financial Specifications of Cables *Harness HASS Chamber*

Type	***Part Number***	***Spect Temp***	***Mating Cycle***	***Estimation Cost (Rp)***
PCI Cable (Red)	T336597-9001_E	-55°C to +125°C	500 Siklus	72 Million
PCI Cable (Blue)	T336596-9026	-55°C to +125°C	500 Siklus	72 Million
PCI Cable (Green)	T336596-9038	-55°C to +125°C	500 Siklus	72 Million
Input / Output Cable	T336625-200	-55°C to +125°C	Unspecified	100 Million

As shown in Table 2, the connector assembly utilizes a precision gold protective layer with a thickness of fifty microns, which in practice is only capable of sustaining reliability for up to five hundred connection cycles. Empirical evidence regarding physical decay, such as the deterioration of insulation material and bending of the microconnector pins, is presented visually in the technical documentation in Fig 1.



Figure 1. Visual Evidence of Insulation Degradation and Bending of Harness Cable Connector Pins

As illustrated by Fig. 1, exposure to high-intensity vibrations and drastic temperature changes in the chamber can cause micro-cracks in the heat shrinkage layer, which further inhibits signal transmission. This physical damage is believed to be the main cause of false failures that confuse the test algorithm, so the avionics module unit requires a retest process.

The validation of the total effectiveness of the equipment at the environmental test station was recorded at seventy-seven point zero five percent, as detailed in Table 3. through mathematical calculations.

Table 3. Calculation Nilai Overall Equipment Effectiveness (OEE) Actual Station HASS

OEE Calculation Parameters	Year D-3	Year D-2	Year H-1	Total Accumulation
Planned Production Time (Hours)	29.020,00	29.020,00	29.020,00	87.060,00
Unplanned Unplanned Unemployed Time (Hours)	3.443,80	3.240,57	4.296,57	10.980,94
Actual Operating Time (Hours)	25.576,20	25.779,43	24.723,43	76.079,06
Availability Level	88,13%	88,83%	85,19%	87,38%
Performance Level	96,87%	97,08%	96,96%	96,97%
Quality Level (*Quality/FPY)*	87,52%	93,23%	91,41%	91,01%
Actual OEE Value	74,66%	80,41%	75,44%	77,05%

Findings of Table 3. show that the actual performance of the facility is far from the gold standard of world manufacturing efficiency, which requires the achievement of a minimum of eighty-five percent on a sustainable basis. This significant decrease in performance was analyzed as a result of the adjustment of the calculation method that adopted the passing criteria in the first test, which led to the elimination of the product from retesting due to problems with the wiring function. The significant difference between the company's internal reports and the real operational data revealed the existence of the phenomenon of "hidden factories" as well as unintentional manipulation of efficiency in the production area. By applying stricter quality indicators, these efficiencies bring clarity to the loss of production capacity due to retest activities that do not add value to product quality.

The Pareto principle is applied to sequence the distribution of accumulated operational time losses over a three-year period based on their significance, as evidenced by the historical data contained in Table 4.

Table 4. Distribution *Six Big Losses* and Pareto Accumulation (H-3 - H-1)

No	Category *Six Big Losses*	Total Time Loss (Hours)	Percentage Loss (%)	Cumulative Percentage (%)
1	Production Rejects (True Defect)	7.764,00	32,47%	32,47%
2	Setup and Adjustment	5.996,24	25,07%	57,54%
3	Equipment Failure (Breakdown Losses)	5.485,97	22,94%	80,48%
4	Startup Rejects (Rework/False Fail)	2.368,00	9,90%	90,38%
5	Reduced Speed (Slow Cycles)	1.500,00	6,27%	96,65%
6	Idling and Minor Stoppages	800,00	3,35%	100,00%
Total	Overall Waste	23.914,21	100,00%	

Figure 2 graphically presents the dominance of three crucial elements that contribute to the decline in operational capacity, namely rework, adjustment, and engine breakdown.

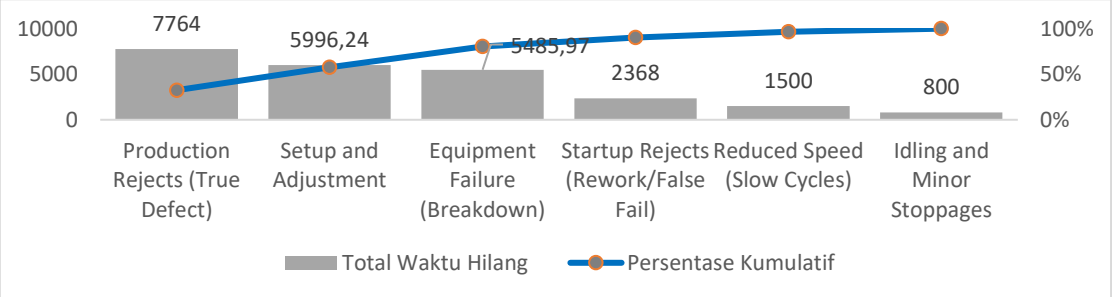


Figure 2. Pareto Distribution Diagram *Six Big Losses* (H-3 – H-1)

According to the eighty-by-twentieth Pareto Law, the data in Fig 2 indicates that the solution to the three main root problems will quickly negate most of the time waste. The analysis shows that the most significant inefficiencies come from the adjustment time swelling up to five thousand nine hundred and ninety-six hours. This is due to ergonomic constraints when connecting a large number of cables in the test area. Therefore, this mapping mathematically validates that the improvement in the reliability of the harness cable is fundamental to restore the stability of production capacity and maximize the

utilization of valuable machine operating time.

The identification of the root cause of the failure of the harness cable in the testing machine is categorized into six key pillars, where the detailed mapping is shown in its entirety through the fishbone diagram in Figure 3.

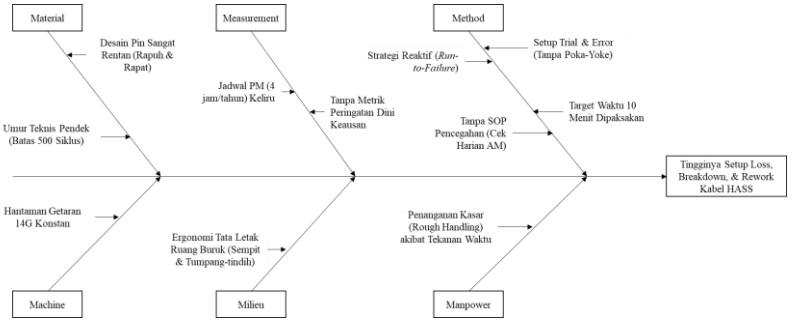


Figure 3. Fishbone 6M Diagram of Harness Cable Failure on HASS Machine

A review of Fig 3 shows that this is a manifestation of destructive stress accumulated across the pillars, with dysfunction in methodology and measurement aspects as the main root of systemic failure. Quantitative details regarding the contribution of each category of the main cause of cable downtime, which are dominated by reasonable wear and combined factors, are presented in Table 5.

Table 5. Identify the Root Cause of Cable Harness Idle Time (H-3 – H-1)

Root Problem Category (*Root CaX'use*)	**Duration of Unemployed Time (Hours)**	**Percentage of Contribution (%)**
Normal Wear and Tear (NWT)	1.421,68 Jam	42,71%
Multiple Causes (MC)	1.395,86 Jam	41,93%
Operator Handling (OH)	511,38 Jam	15,36%
Total Cable Damage	3.328,92 Jam	100,00%

Based on the data in Table 5, it is known that eighty-four points of sixty-four percent of the damage to the cable was caused by natural factors in the form of material wear and tear due to exposure to undetected extreme temperatures. These findings confirm that the absence of the implementation of a proactive maintenance system forces the cable to work beyond its technical operational duration, resulting in gradual damage to physical materials.

The financial impact that must be borne by business entities due to the failure of a faulty cable transmission has been detailed through the data contained in Table 6.

Table 6. Calculation of COPQ due to False Cable Failure PCI/I.O (Period H-3 – H-1)

Operational Cost Component (*Re-test*)	Charging Per Hour Fee (Rp)	Total Rework Hours (Hours)	Total Financial Loss (Rp)
Liquid Nitrogen Utility (LN2)	750.000	2.368	1.776.000.000
HASS Electric Power Utilities	75.000	2.368	177.600.000
Labor Cost	170.000	2.368	402.560.000
Total *Cost of Poor Quality*	995.000	2.368	2.356.160.000

Significant monetary loss, amounting to Rp 2.35 billion, is interpreted from the figures shown in Table 6, which is only intended for retesting activities. FIg 4. presents a visualization of the false failure history record on the test software interface, which is clear evidence of waste of utility resources.

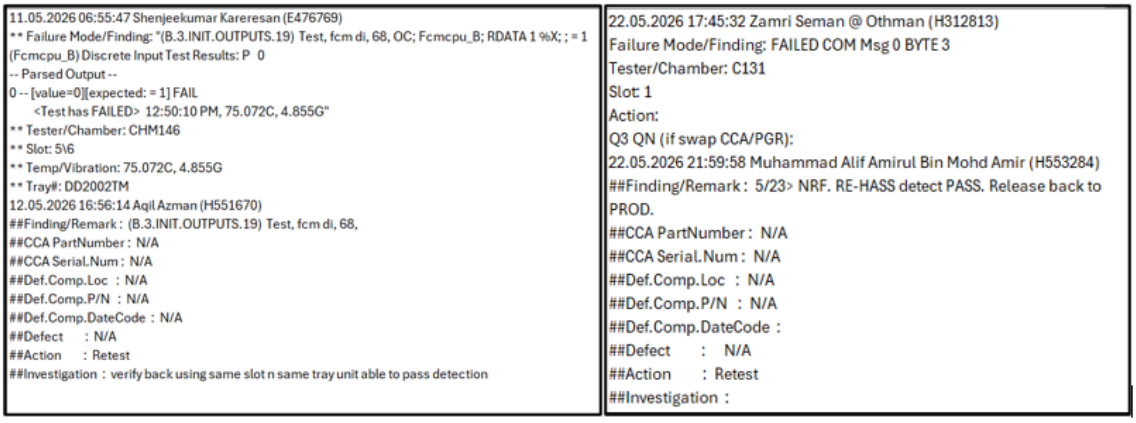


Figure 4. False Failure History on the HASS Test System Interface

The assertion of the inefficiency of the utilization of liquid nitrogen and the waste of technician manpower hours for the revalidation of the problematic avionics module is seen in the visualization in Fig 4. All these mathematical calculations related to the cost of poor quality provide an irrefutable argument for the immediate restructuring of the total productive maintenance system.

The striking difference between the reported administrative efficiency of 94% and the effectiveness of real equipment of 77.05% indicates a *hidden factory phenomenon* that disrupts manufacturing production. The CH145 and CH151 engine units were identified as the main source of problems, with cumulative downtime accounting for 54.76% of the total technical incidents. The actual effectiveness rate that is well below the standards of the global manufacturing industry (85%) demands a more structured and proactive maintenance approach. This inaccuracy in the delivery of operational data is at the root of the problem of management failure in identifying waste of machine energy and utility. Neglect of time-consuming configuration time and a drastic increase in the frequency of machine failures in production areas are the causes of accidental data

manipulation.

A 91.01% product quality failure was caused by signal transmission being interrupted due to a physically damaged harness cable due to exposure to extreme heat. A total of 592 avionics modules experienced false failures due to resistance spikes in the micro-D connectors, which were triggered by wear and tear due to continuous friction. The test algorithm misinterpreted these systemic failures as malfunctions, triggering inefficient retesting. Microvibration anomalies were identified as the main cause of contact reliability loss in the aerospace industry operating under high physical pressure. The accumulation of these false failures consumes thousands of hours of production capacity and interferes with the achievement of international quality standards.

The average time between crucial events of the harness cable of 236.81 hours indicates a failure of reactive maintenance in maintaining the operational stability of the high-tech testing facility. The low operational endurance is exacerbated by an average recovery duration of 9.09 hours for each incident of unexpected cable failure. Significant ergonomic problems due to the dense placement of 27 cable units in a confined working area, which inhibits the mobility of technicians, are the main cause of the high recovery time. Based on the analysis of the reliability of the irreparable components, it is necessary to immediately adopt a preventive replacement schedule based on the technical life of the components to prevent degradation of the operational integrity of the machine and the accumulation of downtime that is detrimental to the productivity of the aerospace industry as a whole.

The root of the technical problem that triggered the contact resistance spike and operational data transmission failure was the erosion of the 50-micron-thick protective gold layer on the connector pins. Mathematically, the operation of the harness cable components exceeding the reliability limit of 500 connection cycles was confirmed as the dominant trigger of oxidative corrosion in the copper core. Random vibrations of 14 G and temperature fluctuations from -55°C to 125°C accelerate the formation of microcracks in the heat shrinkage insulation of the test instrument. This absolute fatigue condition of the material inherently impairs the integrity of the data reading and causes significant capacity losses for aerospace manufacturing. The absence of a monitoring system that can detect microscopic degradation before the machine fails in the field of total failure exacerbates the damage to this material pillar.

Operators experience a significant increase in cognitive load and mental fatigue due to the 10-minute time demands of stringing 27 wiring units in a tight space. Extremely limited visual conditions and mobility in the hull of the thermal simulation engine prompt technicians to perform low-precision and rush connector fitting to fit the target. The occurrence of twisted connector pins is confirmed as a result of forced component suppression, aligning time targets that are out of line with the limited ergonomics of the workspace. This mental overload empirically lowers the psychomotor accuracy of technicians, magnifying the likelihood of human error resulting in damage to data transmission instruments in the factory. The lack of visual aids to prevent errors results in a heavy reliance on *trial and error*, which systematically reduces the time efficiency and

operational stability of the equipment.

Poor quality has resulted in financial losses of Rp 2,356,160,000, which are mainly sourced from liquid nitrogen wastage and inefficient retesting activities. During the observation period, the plant's productive capacity was eroded by 348.51 effective working days due to the rework of avionics modules triggered by cable transmission failures. Critical environmental testing stations that experience critical constraints cause chain effects, disrupt production balance, and lead to material shortages on the final assembly line. The application of constraint theory shows that workstations with the longest cycle times become bottlenecks that sacrifice the accuracy of global delivery schedules. The need to transform from reactive maintenance to a predictive strategy of technical reliability is reinforced by this high cost of internal failure.

CONCLUSION

The results showed that the validated overall equipment effectiveness (OEE) of the environmental testing station was only 77.05% after adjustment using first-pass yield (FPY), revealing the presence of hidden factory losses within the production process. A substantial gap was observed between the 94% OEE reported by management and the actual operational performance, primarily because repeated testing of avionics modules was not adequately reflected in the conventional performance measurement. The actual FPY was 91.01%, partly because signal transmission anomalies were interpreted by the test system as functional product failures. These findings provided a more accurate representation of equipment productivity and highlighted the need to improve the maintenance system to reduce capacity losses associated with false failures and repeated testing. The operational performance results also indicated that the environmental testing station operated below the targeted equipment effectiveness level, supporting the need for improvements in maintenance practices.

Further analysis revealed that cable harness failures accounted for 84.64% of the identified test-related failures, primarily because of frictional wear and oxidation of the connector pins. The cable harnesses had a mean time between failures (MTBF) of 236.81 operating hours, equivalent to approximately 10 operating days, while the mean time to repair (MTTR) was 9.09 hours per failure. The relatively long repair time was associated with ergonomic constraints and limited workspace caused by the dense arrangement of test equipment within the chamber. The existing reactive maintenance approach allowed critical components to remain in service until failure, thereby increasing the risk of unplanned equipment downtime. Human factors also contributed to component degradation, particularly the cognitive and time pressures associated with the 10-minute setup requirement, which increased the risk of physical damage such as bent connector pins.

The cost of poor quality (COPQ) associated with these failures reached IDR 2,356,160,000 during the three-year observation period, including losses related to liquid nitrogen consumption and testing activities. A total of 592 avionics modules experienced false failures, resulting in 2,368 hours of additional machine utilization for retesting.

These disruptions also affected production flow and potentially contributed to material availability constraints at the final assembly stage. In addition, repeated setup activities accounted for 5,996.24 labor hours, further reducing productive capacity. Collectively, these losses adversely affected equipment utilization, quality performance, and operational productivity within the aerospace manufacturing facility.

Improvement strategies were formulated through a total productive maintenance (TPM) program integrating autonomous maintenance and planned maintenance based on critical-component reliability indicators. Visual error-proofing aids were proposed to reduce setup time by facilitating the correct identification and orientation of cable connectors. Autonomous maintenance through routine operator inspections using standardized inspection sheets was proposed to identify cable and connector degradation before the equipment entered the testing cycle. Based on the reliability analysis, preventive cable harness replacement every eight operating days was recommended to reduce the risk of unexpected failures and maintain the continuity of avionics module testing.

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