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Operational Readiness Improvement in Make-to-Order Carton Packaging Systems: An Applied Industrial Engineering Study

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***Abstract*— Make-to-order manufacturing systems are highly dependent on operational readiness to ensure that available production time is effectively converted into output. In practice, many production facilities experience idle production days, where scheduled production time is available but no output is realized, leading to inefficiencies that are not fully captured by machine-based performance indicators alone. This study aims to analyze operational readiness in a carton packaging production system by examining the relationship between available production time, execution readiness, and output realization. A quantitative case study approach was applied using daily operational data from a carton packaging workshop, including planned production time, downtime, output records, and production execution status. The analysis differentiates between active production days and idle production days to identify readiness-related gaps affecting production utilization. The results show that high machine availability does not necessarily guarantee effective production execution, as a significant proportion of available production time remains unutilized due to readiness issues related to scheduling, material availability, and setup preparedness. This study provides applied insights into operational readiness improvement and offers practical recommendations to enhance production time utilization in make-to-order manufacturing environments.**

***Key Words* : applied industrial engineering; operational readiness; make-to-order manufacturing; production execution; carton packaging**

I. INTRODUCTION

Make-to-order manufacturing systems require a high level of coordination between planning and execution to ensure that available production time is effectively converted into output. Unlike make-to-stock systems, make-to-order environments are characterized by high product variability, frequent setup changes, and dynamic production scheduling, which increase operational complexity and execution risk. (Rajagopalan, 2002; Upadhyay et al., 2023). In such conditions, production performance is not determined solely by machine capability but is strongly influenced by the readiness of operational elements that support production execution. In applied industrial engineering practice, production inefficiency has traditionally been associated with technical issues such as machine breakdowns, reduced speed, and quality defects. These issues are commonly evaluated using machine-centered performance indicators that focus on equipment utilization and reliability. (Chikwendu et al., 2020; My Abdelbar et al., 2019). While these indicators remain important for diagnosing technical performance, they do not fully capture execution-related inefficiencies that occur when machines are technically available, but production activities are not executed as planned. As a result, significant portions of available production time may remain unutilized without being classified as technical losses.

Empirical evidence from applied manufacturing studies indicates that high machine availability does not necessarily lead to high production output, particularly in systems with complex execution requirements (Tayal et al., 2021; Wasesa & Jumali, 2020). In many cases, production delays and idle time originate from organizational and operational factors rather than from equipment failure. These

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factors include delayed release of production orders, material unavailability, incomplete setup preparation, and misalignment between production planning and shop-floor execution (Bokrantz et al., 2016; Rakyta et al., 2024). Research in Indonesian manufacturing contexts has consistently highlighted the importance of system-level coordination in determining production performance. Applied studies by Jumali and colleagues demonstrate that production inefficiencies are often rooted in operational misalignment rather than machine limitations. Jumali et al. (2019) showed that inadequate capacity planning and execution coordination led to underutilized production time despite sufficient machine availability. In subsequent applied studies, Jumali et al. (2023) reported that improvements in material flow and layout organization significantly enhanced production performance without requiring changes to machine specifications. These findings emphasize the need to examine production systems as integrated operational entities.

Operational readiness provides a useful concept for understanding execution-related inefficiencies in manufacturing systems. Operational readiness refers to the condition in which all prerequisites required for production execution, such as released production orders, available materials, completed setups, and ready operators, are fulfilled prior to scheduled production time. When operational readiness is incomplete, production execution may be delayed or absent, resulting in idle production time even though machines are available and capable of operating. (Parra et al., 2024; Tortora et al., 2025). In make-to-order environments, operational readiness is particularly critical due to the dependency on timely information flow and coordination. Rajagopalan (2002) noted that make-to-order systems are inherently sensitive to execution delays because production activities are initiated only after customer orders are confirmed. Similarly, Upadhyay et al. (2023) found that variability in order release and material preparation significantly affects production continuity in customized manufacturing systems. These characteristics increase the likelihood of idle production days, where scheduled production time exists but no output is realized.

Applied industrial engineering studies have shown that idle production time represents a substantial source of inefficiency that is often underestimated. Jumali et al. (2025) demonstrated that in printing and packaging industries, minor setup delays and material handling issues accumulated into significant execution losses over time. In another applied case study, Utomo et al. (2022) found that production execution gaps were frequently caused by delayed coordination between planning and shop-floor activities, rather than by technical machine problems. These findings suggest that execution-related losses should be analyzed explicitly rather than being implicitly attributed to equipment performance. Despite these insights, many manufacturing performance evaluations continue to prioritize machine-based indicators as the primary measure of effectiveness. While such indicators are useful for monitoring equipment condition, they may obscure readiness-related losses that occur before production actually starts. (My Abdelbar et al., 2019; Tayal et al., 2021). Consequently, organizations may focus improvement efforts on maintenance and technical optimization while overlooking execution-level inefficiencies that have a direct impact on production utilization.

The distinction between machine readiness and production execution readiness is therefore critical. Machine readiness refers to the technical availability and functional capability of equipment, whereas production execution readiness encompasses organizational and operational conditions that enable machines to be used productively. When these two forms of readiness are misaligned, production systems may exhibit situations where machines are available, but output remains low. (Bokrantz et al., 2016; Zhong et al., 2023). Such conditions are commonly observed in applied manufacturing environments with high operational variability. Carton packaging production systems offer a relevant context for examining operational readiness issues. These systems typically operate under make-to-order conditions, producing customized packaging designs with varying dimensions and specifications. Frequent setup changes, dependence on custom cutting tools, and coordination with customer orders increase the risk of readiness-related disruptions. (Joachimiak-Lechman et al., 2019;

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Klemenčić et al., 2023)). Applied studies in packaging industries indicate that execution losses are often dominated by setup-related delays and material mismatches rather than by machine breakdowns. (Wasesa & Jumali, 2020).

In public service production units, such as government-operated technical workshops, operational readiness challenges may be further intensified by administrative procedures and resource constraints. Jumali et al. (2023) noted that production execution in public manufacturing units is frequently affected by delayed order approval, procurement lead times, and coordination across organizational units. These conditions increase the probability of idle production days and reduce overall production utilization. From a quantitative perspective, production utilization can be defined as the proportion of available production time that is actually converted into output. Idle production days have a direct and significant impact on this metric, regardless of machine availability or technical performance. (Fragapane et al., 2022; Goyal et al., 2022). Therefore, distinguishing between active production days and idle production days is essential for accurately diagnosing production system performance in make-to-order environments.

Several studies emphasize the importance of analyzing production data at a daily or shift-level resolution to capture execution-related inefficiencies. (Petropoulos et al., 2025; Ruiz-Rojas et al., 2024). Aggregated monthly indicators may conceal substantial variability in daily production behavior, particularly in systems with fluctuating readiness conditions. By examining daily operational records, applied industrial engineers can identify patterns of idle time that are directly linked to readiness gaps rather than to equipment failure. This study adopts a quantitative, applied industrial engineering approach to analyze operational readiness in a make-to-order carton packaging production system. The analysis focuses on daily production data to distinguish between days with realized output and days where production time was available but not executed. This approach enables a clearer identification of readiness-related inefficiencies that contribute to idle production time. Machine performance indicators are considered as supporting information, but the primary emphasis is placed on production execution behavior and operational readiness conditions.

The objective of this research is to quantitatively assess operational readiness and its impact on production execution in a real manufacturing environment. By identifying the extent and characteristics of idle production time, the study aims to provide practical insights for improving production utilization through enhanced scheduling alignment, material preparation, and setup readiness. Through this applied focus, the research contributes to industrial engineering practice by highlighting execution-level improvement opportunities that can be implemented without major capital investment.

II. Research Method

a. Result

Research Approach and Positioning

This study is designed as applied quantitative industrial engineering research with a focus on diagnosing operational problems and generating practical improvement insights. The research does not aim to build theoretical models or test abstract hypotheses; instead, it seeks to quantitatively examine how operational readiness affects production execution in a real make-to-order manufacturing system. This positioning is consistent with applied industrial engineering principles, where empirical operational data are used to support decision-making and continuous improvement initiatives. (Dwivedi et al., 2022; Tayal et al., 2021). The methodological focus of this study differs from conventional machine-centered performance evaluations. While machine availability and reliability remain important, this research emphasizes production execution behavior, particularly the occurrence of scheduled production days in which available production time does not result in output. Such conditions are treated as indicators of operational readiness gaps, rather than as purely technical machine failures.

Case Study

The empirical setting of this research is a make-to-order carton packaging production system characterized by customized products,

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variable order sizes, and frequent setup changes. The production process involves several core operations, including cutting, slotting, die-cutting, and laminating, which together form the main production flow. Due to the make-to-order nature of the system, production execution depends heavily on the timely release of production orders, material availability, and setup readiness prior to scheduled production time. Previous applied studies have shown that packaging and printing industries operating under make-to-order conditions are particularly vulnerable to execution-related inefficiencies when coordination between planning and shop-floor activities is weak (Wasesa & Jumali, 2020).

Data Type, Period, and Sources

This study uses quantitative operational data obtained from routine daily production records. These records are generated as part of normal production control activities and provide objective information on planned production time, downtime, and output realization. The use of operational records enhances data validity by reflecting actual execution conditions rather than subjective assessments.(Petropoulos et al., 2024). The analysis covers a continuous one-month production period, selected based on data completeness and consistency. Daily-level data are used to capture short-term execution variability that may not be visible in aggregated monthly indicators .

Unit of Analysis and Operational Classification

The unit of analysis in this research is the daily production day for each major machine. Each production day is classified based on execution outcome into one of two categories:

a. Active production day, where scheduled production time results in realized output.
b. Idle production day, where scheduled production time is available, but no output is produced.

This execution-based classification is essential for distinguishing operational readiness problems from technical machine failures. Idle production days are interpreted as indicators of readiness gaps, such as unavailable production orders, incomplete setup, or material unavailability.

Operational Variables and Measurement

To ensure transparency and replicability, all variables used in the analysis are operationally defined and measured using objective production data. Operational readiness is not measured through perception-based instruments; instead, it is inferred from observable execution outcomes recorded in daily production data. Table 1 presents the operational variables, their definitions, and measurement units. Machine-based performance indicators are included only as supporting diagnostics to help distinguish execution-related losses from technical losses, and they are not treated as primary outcome variables.

Table 1. Operational Variables and Measurement

Variable Category	Indicator	Operational Definition	Measurement Unit
Production Time	Planned Production Time	Total scheduled production time allocated per machine per day	Minutes/day
Production Time	Downtime	Total recorded downtime during scheduled production time	Minutes/day
Execution Time	Operating Time	Planned production time minus recorded downtime	Minutes/day
Execution Outcome	Production Output	Total quantity of products produced per machine per day	Units/day
Execution Quality	Defect Quantity	Number of defective products recorded per day	Units/day
Execution Status	Production Day Status	Output > 0 classified as active day; output = 0 classified as idle day	Binary
Supporting Indicator	Machine Availability	Ratio of operating time to planned production time	Percentage (%)

Classification of Production Days

Production days are classified based on execution outcome to identify operational readiness gaps. This classification avoids conflating idle production time with machine breakdowns and allows a more accurate diagnosis of execution-related inefficiencies.

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Table 2. Classification of Production Days Based on Execution Outcome

Production Day Type	Classification Criteria	Operational Interpretation
Active Production Day	Daily production output > 0	Scheduled production time successfully executed
Idle Production Day	Daily production output = 0 with available production time	Production was not executed due to an operational readiness gap

Data Analysis Procedure

The data analysis follows a structured quantitative procedure designed to support applied industrial engineering diagnosis. The analysis begins with data validation to ensure internal consistency between planned production time, downtime, and output records. Production days are then classified as active or idle, enabling the quantification of idle production time and production utilization. Subsequently, a comparative analysis across machines is conducted to identify differences in execution sensitivity and readiness-related behavior. The analysis focuses on identifying operational patterns that can inform practical improvement actions related to scheduling, setup preparation, and coordination between planning and execution.

Table 3. Data Analysis Procedure

Step	Analysis Activity	Output
1	Data validation and cleaning	Consistent daily operational dataset
2	Classification of production days	Active vs. idle production days
3	Production utilization calculation	Utilization rate and idle time proportion
4	Comparative analysis across machines	Execution sensitivity per operation
5	Contextual interpretation	Identification of readiness-related losses

Validity, Reliability, and Ethical Considerations

Internal validity is supported by the use of actual operational records generated during routine production activities. The daily resolution of the data allows the study to capture execution variability and readiness-related disruptions with sufficient detail. (Slater & Hasson, 2024). Reliability is ensured through the consistent use of standardized production records across the observation period. Because the methodology relies on commonly available operational data, it can be replicated in other make-to-order manufacturing environments with similar characteristics. All data are analyzed at the system level without reference to individual performance. No proprietary or sensitive organizational information is disclosed, ensuring ethical compliance.

III. RESULT AND DISCUSSION

a. RESULT

Monthly Machine Performance Including Idle Production Days

Table 1 presents the average monthly performance of the main carton packaging machines calculated using all scheduled production days, including days with available production time but zero output (idle production days). The results show that machine availability remained relatively high across all machines, with values exceeding 91%. However, the overall equipment effectiveness (OEE) values were considerably low. The monthly OEE ranged from 18.75% to 32.39%, indicating substantial underutilization of available production capacity. The lowest OEE value was observed for the slotter machine (18.75%), while the highest was recorded for the die-cutter (plong) machine (32.39%). These results indicate that the inclusion of idle production days significantly reduced monthly effectiveness values despite high machine availability. Monthly values are calculated using all scheduled production days, including idle production days.

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Table 1. Monthly OEE Performance Including Idle Production Days

Machine	Active Production Days	Avg. Availability (%)	Avg. Performance (%)	Avg. Quality (%)	Avg. OEE (%)
Board-to-Board Laminator	7	91.78	29.86	43.67	28.53
Die-Cutter (Plong)	6	91.59	34.49	36.77	32.39
Slitter	5	92.04	22.78	31.25	21.57
Slotter	4	92.56	19.88	24.69	18.75

Machine Performance on Active Production Days

To isolate execution-related losses from technical performance, OEE was recalculated using only active production days, defined as days with realized output. The results are shown in Table 2. When idle production days were excluded, all machines exhibited a substantial improvement in performance indicators. Average availability values exceeded 94%, while quality rates approached 100%. Notably, the die-cutter (plong) machine achieved an average OEE of 86.38%, exceeding the commonly referenced world-class benchmark of 85%. Values are calculated using only production days with output greater than zero.

Table 2. OEE Performance on Active Production Days

Machine	Active Production Days	Avg. Availability (%)	Avg. Performance (%)	Avg. Quality (%)	Avg. OEE (%)
Board-to-Board Laminator	7	96.17	68.26	99.82	65.22
Die-Cutter (Plong)	6	95.83	91.98	98.06	86.38
Slitter	5	94.52	72.89	100.00	69.02
Slotter	4	95.24	79.53	98.77	75.01

Comparison of Monthly and Active-Day OEE

Figure 1 compares average OEE values calculated using all scheduled production days with those calculated using only active production days. The figure clearly illustrates the magnitude of execution-related losses caused by idle production days. Comparing average OEE values (%) for each machine under two conditions: (1) monthly calculation including idle production days, and (2) calculation using only active production days. That shows a pronounced gap between monthly and active-day OEE values for all machines, confirming that low monthly effectiveness is primarily driven by execution gaps rather than by technical machine limitations.

b. DISCUSSION

Operational Readiness and Production Execution Gaps

The results demonstrate that idle production days are the primary contributor to low monthly effectiveness in the observed make-to-order carton packaging system. Although machine availability remained consistently high, a large proportion of scheduled production time did not result in output, indicating significant operational readiness gaps. This finding supports applied industrial engineering research showing that production execution failures often stem from organizational and coordination issues rather than equipment malfunction. (Jumali & Utomo, 2019; Wasesa & Jumali, 2020). When production orders are not released on time, materials are unavailable, or setups are incomplete, production execution may not occur even though machines are technically ready.

Implications for Production Utilization Assessment

The contrast between Tables 1 and 2 highlights the importance of distinguishing between technical performance and execution performance. Monthly OEE values underestimated the true technical capability of machines by conflating idle production days with machine-related losses. By separating active production days from idle production days, this study provides a more accurate diagnosis of utilization losses. Similar approaches have been recommended in applied manufacturing research, particularly for make-to-order systems where execution variability is high. (Goyal et al., 2022; Tayal et al., 2021).

Execution Sensitivity Across Machines

Differences in OEE improvement between machines suggest varying sensitivity to execution readiness constraints. The die-cutter machine exhibited the largest improvement when idle days were excluded, indicating that its low monthly OEE was not caused by technical

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inefficiency but by limited execution opportunities. Machines with higher setup complexity and greater dependence on material preparation, such as slotter and slitter machines, showed greater vulnerability to execution disruptions. These findings are consistent with prior studies in packaging industries, which identify setup readiness and material availability as dominant factors affecting execution continuity. (Joachimiak-Lechman et al., 2019; Klemenčić et al., 2023).

Applied Industrial Engineering Implications

From an applied industrial engineering perspective, the findings suggest that improvement initiatives should focus on enhancing operational readiness rather than solely improving machine performance. Practical actions include implementing daily readiness checklists, improving coordination between planning and execution, and standardizing setup preparation procedures. Additionally, performance evaluation systems should incorporate execution-based indicators, such as the proportion of idle production days, alongside conventional machine metrics. This integrated approach enables more targeted and cost-effective improvement strategies in make-to-order manufacturing environments.

IV. CONCLUSION

This study analyzed production execution in a make-to-order carton packaging system using a quantitative, applied industrial engineering approach. By distinguishing between active production days and idle production days, the study identified that low monthly production effectiveness was primarily driven by execution-related issues rather than by technical machine limitations. Although machine availability consistently remained high, a significant portion of scheduled production time did not result in output, indicating substantial underutilization of available capacity. The comparison between monthly performance indicators and performance calculated only on active production days revealed a clear execution gap. When production execution occurred, machines demonstrated high availability and quality levels, and one machine achieved effectiveness values consistent with commonly referenced world-class benchmarks. These results confirm that machine capability was not the dominant constraint; instead, the absence of production execution during scheduled time played a decisive role in reducing overall effectiveness.

From an applied industrial engineering perspective, the findings emphasize the importance of separating execution-related losses from technical losses in make-to-order manufacturing environments. Aggregated performance indicators that include idle production days may obscure the true sources of inefficiency and lead to incorrect conclusions regarding machine performance. An execution-based analysis at the daily level provides a more accurate diagnosis of production utilization losses. The study concludes that improving production performance in make-to-order systems requires greater attention to operational readiness. Ensuring timely production order release, material availability, and setup preparedness before scheduled production time is essential to reducing idle production days. Practical, low-cost interventions—such as daily readiness checks, standardized setup preparation, and improved coordination between planning and execution—can significantly enhance production utilization without major capital investment. Overall, this research demonstrates that execution-based quantitative analysis using existing operational data offers a practical and effective approach for diagnosing and improving production performance in applied manufacturing settings. The approach and findings are directly applicable to similar make-to-order production systems seeking to improve utilization and operational effectiveness.

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