

Integration of Critical Path Method (CPM) and Material Requirement Planning (MRP) for Optimizing Production Scheduling and Material Procurement in Hull Block Fabrication

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ABSTRACT

Shipbuilding production systems involve complex and interdependent operational activities that require effective coordination between production scheduling and material procurement processes. In hull block fabrication, production delays frequently occur because scheduling activities and material procurement are often managed separately, resulting in material shortages, waiting time, and extended project duration. This study aimed to develop an integrated framework using the Critical Path Method (CPM) and Material Requirement Planning (MRP) to optimize production scheduling and material procurement in hull block fabrication processes. A quantitative approach with a case study design was employed in this research. Data was collected from operational records, including production activity durations, bill of materials, inventory status, supplier lead times, and production schedules. CPM analysis was used to identify critical activities affecting project duration, while MRP analysis was applied to determine material requirements and procurement schedules. The results showed that all production activities belonged to the critical path sequence with a total production duration of 27 days under existing conditions, where the welding process represented the longest activity with a duration of seven days. The proposed integrated framework reduced production lead time from 27 days to 23 days, reduced production delays from four days to one day, decreased waiting time from three days to one day, increased material availability accuracy from 82.4% to 96.2%, and improved on-time completion rate from 85.2% to 95.1%. The findings indicate that integrating CPM and MRP successfully improved production synchronization and operational efficiency in hull block fabrication processes.

1. Introduction

The shipbuilding industry represents one of the most complex manufacturing environments because it operates under an engineer-to-order production system characterized by low production volume, high product customization, large structural components, extensive material requirements, and long production lead times [1], [2]. In shipyard operations, hull block fabrication constitutes a critical production stage because it directly influences subsequent assembly and erection activities. Hull block fabrication involves a sequence of interdependent processes, including drawing release, material procurement, cutting, fitting, welding, grinding, inspection, and block completion. Since these activities are highly dependent on one another, disruptions occurring in a single process can immediately affect downstream operations and reduce overall production

performance. Furthermore, hull block fabrication requires the timely availability of numerous structural materials, including steel plates, profiles, stiffeners, and welding consumables, making material availability a critical factor in maintaining production continuity.

Recent advancements in manufacturing systems have highlighted the need for cohesive planning and decision-making to enhance operational efficiency and competitiveness [3], [3]. Manufacturing businesses are progressively transitioning from discrete operational systems to integrated frameworks that enable the synchronization of production planning, resource allocation, and material management. In contemporary manufacturing environments, increasing variability in customer demand and operational uncertainty further necessitates adaptability and agility in production systems. Consequently, manufacturing systems must not only optimize production processes but also ensure the timely availability of supporting resources required for execution [3], [4]. Moreover, intelligent manufacturing systems and advanced production management strategies have become increasingly important for improving manufacturing performance and reducing operational inefficiencies [5]. These developments indicate that manufacturing performance is determined not only by production scheduling decisions, but also by the effective synchronization of supporting functions, particularly material planning and procurement activities.

Unlike conventional manufacturing systems, hull block fabrication involves large-scale engineered-to-order products, extensive material consumption, complex activity dependencies, and strict sequence constraints among fabrication stages [6], [7]. Each hull block requires hundreds of structural components that must be available at specific stages of production, making material availability a critical factor in maintaining production continuity [8]. Consequently, disruptions in material procurement directly affect cutting, fitting, welding, and assembly activities because alternative processing routes are generally unavailable within block fabrication operations [9]. Despite advancements in manufacturing systems, production scheduling and material procurement processes are frequently managed separately across various industries, including shipbuilding [10], [11]. This separation often creates mismatches between production requirements and material availability, causing fabrication activities to wait for materials that have not yet been procured or delivered [11], [12]. In practical situations, production activities are frequently scheduled to start according to planned timelines even when the required materials remain unavailable because of procurement delays, inventory shortages, or supplier lead-time variability. Therefore, fabrication processes may experience idle labor time, machine underutilization, schedule revisions, and extended production lead times. Furthermore, delays in material availability may generate cascading effects that disrupt downstream activities and reduce overall production performance.

In the studied shipyard, production continuity is highly dependent on the timely availability of steel plates, profiles, stiffeners, and welding consumables required for hull block fabrication. Preliminary observations and historical production records indicated that procurement activities were often planned independently from production schedules, resulting in several operational disruptions. Material shortages generated approximately three days of waiting time and contributed to production delays of up to four days beyond the planned schedule. In addition, material availability accuracy reached only 82.4%, while the on-time completion rate remained at 85.2%. These operational symptoms demonstrate insufficient synchronization between production scheduling and material procurement activities and indicate the need for a more integrated planning approach.

Previous studies have extensively investigated manufacturing process improvement and production efficiency through various optimization approaches. Research on manufacturing system development shows that adaptable and reconfigurable systems enhance manufacturing competitiveness by enabling firms to respond more effectively to changing operational requirements [13]. Similarly, process optimization techniques have demonstrated significant improvements in quality and operational performance across manufacturing environments [14]. Furthermore, systematic process improvement and production system optimization have been widely recognized as effective approaches to increasing productivity and reducing operational inefficiencies in manufacturing industries [15]. However, despite these contributions, most existing studies focus on individual aspects of manufacturing systems and provide limited consideration of the synchronization between production scheduling and material procurement activities, particularly in complex shipyard manufacturing environments.

Previous studies have investigated production scheduling optimization using the Critical Path Method (CPM) and other scheduling approaches to improve manufacturing performance. Other studies have focused on inventory planning and Material Requirement Planning (MRP) to enhance material availability and procurement efficiency. Several researchers have also examined integrated production planning systems in manufacturing environments. However, these studies generally treat production scheduling and material planning as separate decision-making functions and are predominantly conducted in discrete manufacturing industries. Existing research primarily focuses on scheduling optimization, inventory management, or procurement planning independently, with limited studies proposing a mechanism that explicitly synchronizes critical production activities with material procurement schedules [16], [17]. Consequently, the relationship between production schedules and material procurement remains insufficiently explored, particularly in shipyard manufacturing environments where production continuity is highly dependent on timely material availability and where disruptions in material procurement can immediately affect activities located on the production critical path.

This limitation is particularly significant in hull block fabrication processes because production activities are highly interdependent and possess limited scheduling flexibility. The fabrication process requires the timely availability of steel plates, structural profiles, stiffeners, and welding consumables at specific production stages. Consequently, delays in material procurement can directly disrupt activities on the production critical path, resulting in waiting time, schedule revisions, and extended production lead times [18], [19]. Despite the critical relationship between production scheduling and material availability, studies that specifically investigate their integration within hull block fabrication environments remain scarce. To address this gap, this study proposes an integrated decision-support framework that combines the Critical Path Method (CPM) and Material Requirement Planning (MRP) for hull block fabrication operations. The novelty of this study lies not in the separate application of CPM or MRP, which are well-established methods for production scheduling and material planning [20], [21], [22], but in their integration mechanism that links critical production activities identified through CPM with material procurement schedules generated through MRP. This integration enables procurement priorities and material release schedules to be determined based on critical-path requirements, allowing better synchronization between production planning and material availability.

This study adopts a quantitative case study approach using operational data collected from hull block fabrication activities in a shipyard environment. The analysis is based on production activity durations, bill of materials, inventory records, procurement data, and supplier lead-time information to evaluate the effectiveness of the proposed CPM–MRP integration framework. Optimization in this study refers to measurable improvements in operational performance, including reductions in production lead time, production delays, and material waiting time, as well as improvements in material availability accuracy and on-time completion rate. Practically, the proposed framework provides decision-support guidance for production planners and procurement personnel by synchronizing production schedules with material procurement activities, thereby reducing disruptions caused by material shortages. Theoretically, this study contributes to the industrial engineering literature by proposing an integrated CPM–MRP framework for hull block fabrication and extending existing research on the relationship between production scheduling and material procurement in shipbuilding systems.

2. Method

2.1 Research Design

This research utilized a quantitative methodology with a case study design to provide a cohesive framework for production scheduling and material procurement in hull block fabrication operations within a shipyard manufacturing context. The quantitative technique was used due to the study's reliance on numerical operational data, including production activity duration, material amounts, inventory availability, supplier lead times, and schedule information. The numerical data were rigorously analyzed to discern correlations between production operations and material planning requirements.

The case study design was deemed suitable as it enables comprehensive examination of operational phenomena within a particular industrial context and promotes practical problem-solving grounded in actual

production settings [23]. The application of a case study methodology facilitates the direct assessment and implementation of the suggested framework in real industrial operations.

2.2 Research Object and Scope

This study focused on the hull block construction process in a shipyard manufacturing system. The manufacture of hull blocks is a critical phase in shipbuilding, as it profoundly impacts later assembly and erection processes. The procedure typically comprises multiple interrelated processes, including design release, material acquisition, cutting, assembly, welding, grinding, inspection, and finalization of the block.

This research focused only on production scheduling and material procurement planning related to hull block fabrication procedures. The research concentrated on the integration of Critical Path Method (CPM) and Material Requirement Planning (MRP) to align production schedules with material availability. Additional operational aspects, including manufacturing cost analysis, labour productivity, maintenance systems, and quality management activities, were omitted to concentrate on the proposed framework.

2.3 Data Collection Techniques

The research employed both primary and secondary data sources acquired from operational activities and corporate documentation.

Primary data were obtained via direct observations and structured interviews with individuals involved in production scheduling and material procurement, including personnel from Production Planning and Control (PPC), purchasing staff, warehouse employees, and production supervisors. Observations were performed to comprehend actual manufacturing operations and pinpoint operational concerns including scheduling and material availability.

Secondary data were sourced from company operational records and ancillary documentation, encompassing production schedules, duration records of production activities, bill of materials (BOM), inventory reports, purchase order records, supplier lead-time data, and historical production records.

The application of CPM and MRP in this study was based on several assumptions commonly adopted in production planning research. For CPM analysis, activity durations were assumed to be deterministic and represented by average durations obtained from historical production records [20]. Activity precedence relationships were assumed to remain fixed throughout the hull block fabrication process. For MRP analysis, bill of materials (BOM), inventory records, and supplier lead times were assumed to be accurate and available during the planning horizon [21], [22].

Although CPM and MRP are deterministic planning tools, shipyard production environments are inherently subject to uncertainties, including supplier delivery delays, weather conditions, equipment breakdowns, labor availability, and engineering changes. These factors may affect both activity durations and material availability. However, to ensure analytical consistency, the study utilized verified historical operational data collected from completed hull block fabrication projects. Activity durations and supplier lead times were determined based on average values derived from historical records rather than single observations. Therefore, the study adopted average historical values as planning parameters and treated unexpected operational disruptions as external factors outside the deterministic CPM–MRP calculations.

To reduce the influence of data uncertainty, information obtained from company documents was cross-checked with interview results and validated through discussions with production supervisors, Production Planning and Control (PPC) personnel, and procurement staff. Consequently, the CPM and MRP calculations represent planned operational conditions and provide a baseline framework for evaluating production scheduling and material procurement synchronization. The influence of dynamic uncertainties was recognized as a limitation of the study and is discussed in the limitations section.

Purposive sampling was utilized to choose a hull block production unit, as the chosen unit exemplified typical production features and had comprehensive operational data necessary for analysis [24]. Purposive sampling is frequently employed when samples are chosen based on qualities pertinent to research aims.

2.4 Research Instruments and Supporting Tools

The research instruments principally comprised operational records and ancillary data collection forms utilized during the analysis process. The instruments comprised production activity records, bill of materials, inventory reports, purchase order data, supplier lead-time information, and analytical scheduling templates.

Data processing and analytical tasks were facilitated by Microsoft Excel software. Microsoft Excel was utilized to execute Critical Path Method calculations, Material Requirement Planning calculations, schedule development, and performance assessment of the suggested model. The software was chosen for its sufficient analytical capabilities in scheduling and material planning, as well as its effective visualization of computation outcomes.

2.5 Research Procedure

The study technique commenced with the identification of production scheduling and material procurement challenges within hull block fabrication operations. Initial observations were conducted within the hull block fabrication area to examine production workflow, material receiving activities, inventory handling procedures, and the implementation of production schedules. In addition, structured consultations were carried out with Production Planning and Control (PPC) personnel, production supervisors, purchasing staff, and warehouse personnel to obtain a comprehensive understanding of scheduling and procurement practices. The problem identification process was supported by the review of historical production reports, procurement records, and schedule performance data. The analysis revealed recurring production delays caused by material shortages, procurement lead-time mismatches, and insufficient synchronization between production schedules and material procurement activities.

Following the discovery of the problem, operational data and ancillary information were gathered and systematically organized for subsequent study. Following the identification of the problem, operational data and supporting information were collected and systematically organized for analysis. For CPM analysis, the collected data included activity codes, activity descriptions, activity durations, and predecessor–successor relationships among production activities involved in hull block fabrication. These data were used to construct the project network and determine the critical path, earliest start (ES), earliest finish (EF), latest start (LS), latest finish (LF), and slack values.

For MRP analysis, the collected data included bill of materials (BOM), gross material requirements, current inventory levels, scheduled receipts, supplier lead times, and procurement records. These data were used to calculate net material requirements, planned order receipts, and planned order releases required to support production activities according to the schedule generated through CPM analysis.

Data verification was conducted through a combination of document checking, expert confirmation, and data triangulation. Operational records obtained from production schedules, inventory reports, purchase orders, and historical production documents were first reviewed for consistency and completeness. The collected information was subsequently confirmed through discussions with Production Planning and Control (PPC) personnel, production supervisors, purchasing staff, and warehouse personnel. In addition, selected activity duration data and supplier lead-time records were compared with historical production records to ensure their representativeness and reliability before being used in CPM and MRP calculations.

A Critical Path Method analysis was performed to ascertain activity interdependencies and pinpoint activities that substantially influence overall production time. CPM has been extensively utilized in production and scheduling contexts due to its ability to identify key tasks and enhance scheduling efficiency [20], [25]. The outcomes derived from CPM analysis encompassed activity sequences, critical routes, and production time frameworks.

The scheduling data produced from CPM analysis was later utilized as input for Material Requirement Planning analysis. An MRP analysis was performed to ascertain material requirements and procurement timelines based on production schedules, inventory levels, and supplier lead times [12], [21], [23]. Material Requirements Planning (MRP) is frequently utilized in manufacturing systems to align production needs with material availability.

The outputs from CPM and MRP analyses were integrated to generate synchronized production scheduling and material procurement plans for hull block fabrication activities.

An evaluation stage was subsequently conducted to assess the effectiveness of the proposed CPM–MRP integration framework. The performance of the proposed system was compared with the existing

production scheduling and procurement practices using several operational performance indicators, including production lead time, production delay, waiting time caused by material shortages, material availability accuracy, and on-time completion rate. The evaluation results were used to determine the extent to which the integrated framework improved production performance and operational coordination within the shipyard environment. Figure 1 illustrates the complete research framework employed in this study.

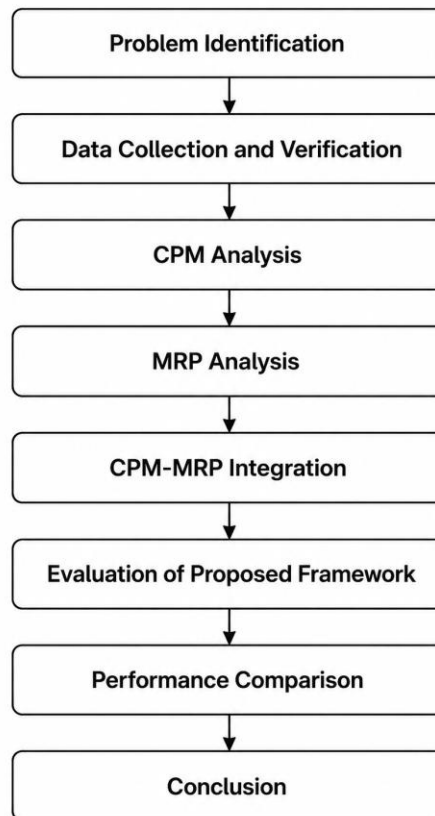


Fig. 1. Research framework of the proposed CPM–MRP integration model

2.6 Data Analysis Techniques

The analysis in this study was performed by integrating the Critical Path Method with Material Requirement Planning techniques.

An analysis using the Critical Path Method was conducted to ascertain the production scheduling framework by computing the earliest start (ES), earliest finish (EF), latest start (LS), latest finish (LF), slack values, and critical activities influencing the overall production timeline. Activities with zero slack values were designated as critical activities.

A study of Material Requirement Planning was performed to ascertain material needs and procurement timelines by computing gross requirements, net requirements, planned order receipts, and planned order releases.

The efficacy of the proposed integrated model was assessed by contrasting operational performance metrics between the current and suggested systems [26]. The assessment metrics were reductions in production lead time, production delays, waiting times, and material availability accuracy, which are frequently employed in the evaluation of manufacturing system performance.

3. Results and Discussion

3.1 Presentation of Research Results

The proposed integrated Critical Path Method (CPM) and Material Requirement Planning (MRP) framework was implemented to evaluate its capability in improving production scheduling and material

procurement performance within hull block fabrication processes. The analysis was conducted using production activity data, bill of material information, inventory availability, and supplier lead-time records collected during the study.

The first stage of the analysis involved the implementation of Critical Path Method to identify activity relationships and determine activities affecting overall production duration. CPM is commonly applied in manufacturing and scheduling environments because of its capability to determine activity dependencies and identify activities with significant influence on completion time [20], [25]. The activity scheduling results are presented in Table 1.

Table 1. CPM Scheduling Calculation Results

Activity	Duration (Days)	ES	EF	LS	LF	Slack
A (Drawing Release)	2	0	2	0	2	0
B (Material Procurement)	5	2	7	2	7	0
C (Material Receiving & Inspection)	1	7	8	7	8	0
D (Cutting Process)	3	8	11	8	11	0
E (Fitting Process)	4	11	15	11	15	0
F (Welding Process)	7	15	22	15	22	0
G (Grinding Process)	2	22	24	22	24	0
H (Quality Inspection)	2	24	26	24	26	0
I (Block Completion)	1	26	27	26	27	0

The CPM calculation results showed that all activities possessed zero slack values, indicating that each activity belonged to the critical sequence. Activities with zero slack values indicate that no scheduling flexibility exists and any delay occurring within these activities directly affects overall production completion time [20], [25]. The critical path generated from network analysis was identified as:

A → B → C → D → E → F → G → H → I

The total project duration under existing scheduling conditions was determined to be 27 days. Among all activities, the welding process demonstrated the highest duration with a processing time of seven days. The result indicates that welding activities represented the major contributor to total production duration and therefore possessed substantial influence on overall production performance.

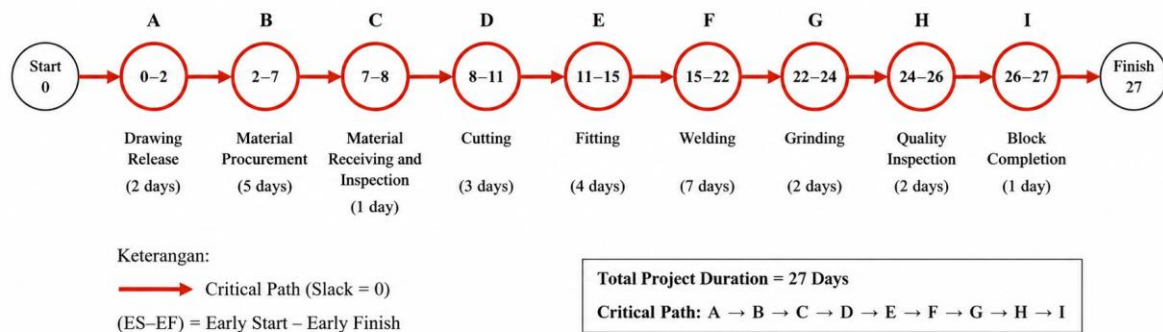


Fig. 2. Critical Path Network Diagram

After identifying production activity relationships through CPM analysis, Material Requirement Planning calculations were performed to determine procurement schedules based on material demand timing and supplier lead times.

The MRP analysis focused on the principal materials required for hull block fabrication, including steel plates, structural profiles, stiffeners, and welding consumables. Material quantities were expressed according to the units commonly used in shipyard procurement and inventory management practices. Steel plates were measured in sheets, flat bars and angle bars were measured in pieces, stiffeners were measured in pieces, and welding electrodes were measured in boxes. These materials were selected because they represent the primary components required throughout the fabrication process and directly influence production continuity when shortages occur. The MRP results are presented in Table 2.

Table 2. Material Requirement Planning Results

Material	Gross Requirement	Inventory	Net Requirement	Planned Order Receipt	Lead Time (Days)	Planned Order Release
Steel Plate 10 mm	60	24	36	36	5	Day 2
Steel Plate 12 mm	42	18	24	24	5	Day 2
Flat Bar	80	36	44	44	4	Day 3
Angle Bar	70	30	40	40	4	Day 3
Stiffener	100	45	55	55	5	Day 2
Welding Electrode E7018	40	14	26	26	3	Day 5

The MRP results demonstrated that existing inventory levels were insufficient to satisfy production requirements for several materials. Consequently, additional procurement activities were required before fabrication activities could proceed according to the planned schedule.

The production schedule was first established using CPM calculations based on activity durations and predecessor–successor relationships among fabrication activities. The CPM analysis generated the critical path sequence and identified the planned start and finish times for each activity. Because all fabrication activities were located on the critical path, the timing of each activity became the primary reference for determining when materials would be required during production execution.

The scheduling information generated through CPM analysis was subsequently used as an input for procurement planning calculations. The proposed CPM–MRP framework synchronized production scheduling and procurement planning by linking material requirements to the activity schedule generated through CPM analysis. Material demand dates were determined according to the planned start times of the corresponding fabrication activities. Subsequently, supplier lead times and existing inventory levels were incorporated into MRP calculations to determine planned order release dates. Procurement orders were therefore scheduled sufficiently in advance to ensure that materials became available before the commencement of the activities requiring them. Through this mechanism, procurement planning was no longer performed independently from production scheduling but was directly aligned with critical production requirements.

The synchronization process allowed procurement schedules to be released before materials were required within production activities, thereby minimizing waiting time resulting from material shortages. The performance comparison between the existing system and the proposed integrated framework is presented in Table 3.

The reduction in production lead time from 27 days to 23 days occurred primarily because procurement activities for critical materials were released before fabrication activities started. Under the existing system, material shortages generated approximately three days of waiting time and one day of procurement-related delay. Through synchronization between scheduling and procurement planning, these non-value-added activities were substantially minimized.

Table 3. Existing and Proposed System Performance Comparison

Performance Indicator	Existing System	Proposed System	Improvement (%)
Production Lead Time	27 days	23 days	14.81
Production Delay	4 days	1 day	75.00
Waiting Time	3 days	1 day	66.67
Material Availability Accuracy	82.4%	96.2%	16.75
On-time Completion Rate	85.2%	95.1%	11.62

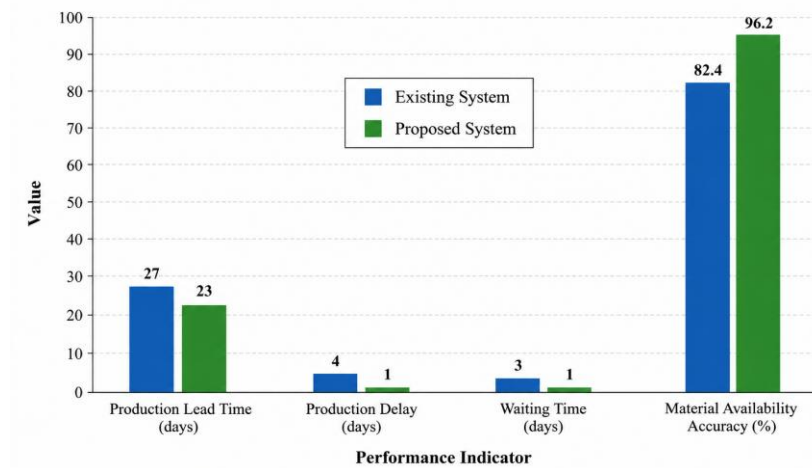


Fig. 3. Performance Comparison Between Existing and Proposed Systems

3.2 Analysis of Findings

The first research question addressed how Critical Path Method can identify activities significantly affecting production duration within hull block fabrication processes. The findings indicate that all production activities belonged to the critical path sequence and possessed zero slack values. This condition demonstrates that the hull block fabrication process exhibits high interdependency among activities, where delays occurring in one stage immediately affect subsequent activities and total project completion time.

The identified critical path sequence consisted of Drawing Release, Material Procurement, Material Receiving and Inspection, Cutting Process, Fitting Process, Welding Process, Grinding Process, Quality Inspection, and Block Completion. The results indicate that the production system possessed no scheduling flexibility because all activities directly contributed to total production duration.

Among the identified activities, the welding process demonstrated the highest processing duration with a total of seven days. The longer processing time associated with welding activities can be attributed to several operational factors including preparation time, execution complexity, joint alignment requirements, and quality verification procedures. Welding processes generally require extensive operational resources and therefore frequently become bottlenecks within manufacturing systems. Consequently, delays occurring during welding operations significantly affect downstream activities and overall production completion performance.

The results further indicate that procurement activities played a significant role in determining production continuity [10], [11]. Although fabrication activities such as cutting and welding physically contribute to production processes, procurement-related activities directly influenced material availability and production readiness. Under the existing scheduling condition, material procurement activities were not fully synchronized with production schedules, resulting in waiting periods and interruptions within fabrication processes.

The second research question examined whether integrating Critical Path Method and Material Requirement Planning could improve production scheduling and material availability. The findings demonstrated that the proposed framework successfully improved operational performance indicators.

Production lead time was reduced from 27 days to 23 days, representing an improvement of 14.81%. The reduction occurred because procurement activities were scheduled according to production requirements generated through CPM calculations. Under previous conditions, material shortages generated unnecessary waiting periods before fabrication activities could begin. Through integration between CPM and MRP, procurement schedules were established before material demand occurred, allowing materials to become available at the required time.

The reduction of production delays from four days to one day also indicates a substantial improvement in scheduling reliability. Delays occurring in manufacturing systems are frequently associated with poor coordination between operational functions and inadequate material planning processes. The

implementation of integrated planning approaches minimizes uncertainty and improves production continuity.

Waiting time caused by material shortages decreased from three days to one day. This result demonstrates that the proposed model successfully reduced non-value-added activities occurring within production processes. Waiting activities do not contribute to value creation and generally reduce production efficiency and resource utilization [27]. Therefore, minimizing waiting time contributes directly to improving overall manufacturing performance.

Material availability accuracy demonstrated the highest improvement among all performance indicators, increasing from 82.4% to 96.2%. The improvement indicates that procurement planning became substantially more responsive to actual production requirements after implementing MRP calculations. Improved material availability subsequently reduced operational interruptions and supported smoother production flow [28].

The improvement in on-time completion rate from 85.2% to 95.1% further confirms the effectiveness of integrating scheduling and procurement planning activities. Similar studies in manufacturing systems suggested that synchronized planning mechanisms significantly improve production stability, reduce operational disruptions, and enhance manufacturing performance [29].

Overall, the findings demonstrate that integrating CPM and MRP does not merely optimize production scheduling activities independently but also creates a coordinated planning mechanism between production and material procurement functions. The results indicate that effective synchronization among operational activities can significantly improve production performance within shipbuilding environments [30].

Beyond the observed performance improvements, the proposed CPM-MRP framework provides practical decision-support capabilities for both production planners and procurement personnel. From the production planning perspective, CPM enables planners to identify activities located on the critical path and determine which fabrication stages require strict schedule adherence. The integration with MRP allows material requirements associated with critical activities to be prioritized over non-critical procurement items. For example, materials required for cutting, fitting, and welding activities can be identified and scheduled according to their planned start dates, reducing the risk of production interruptions. From the procurement perspective, MRP calculations generate planned order release dates by considering supplier lead times, inventory availability, and production schedule requirements. This enables procurement staff to initiate purchasing activities before materials are required in production. In addition, the framework assists decision makers in identifying potential material shortages at the planning stage, allowing corrective actions such as early purchasing, supplier coordination, or inventory adjustment to be implemented before fabrication activities begin. Consequently, the integrated CPM-MRP approach functions not only as a scheduling tool but also as a proactive planning mechanism that supports more reliable production and procurement decision making.

3.3 Implications of the Results

The findings of this study provide practical implications for shipyard production management and industrial engineering applications. From an operational perspective, the proposed framework can support production planning departments in improving decision-making related to scheduling and procurement activities. Synchronization between production schedules and material availability enables production managers to anticipate material shortages earlier and reduce unnecessary waiting periods.

The implementation of the integrated framework may also contribute to improving operational efficiency within shipyard environments through reductions in production delays and improvements in production continuity. Reduced lead times and increased on-time completion performance may contribute to improved project delivery reliability and operational responsiveness. Although these improvements may potentially support customer satisfaction, customer-related outcomes were not directly measured in the present study and therefore no direct conclusion regarding customer satisfaction can be drawn.

From an academic perspective, this study contributes to industrial engineering literature by demonstrating an integrated application of Critical Path Method and Material Requirement Planning within shipbuilding production environments. Previous studies have frequently discussed scheduling optimization

and material planning separately; however, this study provides a more comprehensive perspective by integrating both approaches into a single framework.

The findings additionally provide opportunities for future development through integration with additional operational variables such as workforce allocation, production cost optimization, machine utilization, and uncertainty factors within dynamic manufacturing systems.

3.4 Limitations of the Study

Several limitations should be considered when interpreting the findings obtained in this study. First, the research focused specifically on hull block fabrication processes and therefore may not fully represent operational characteristics associated with other shipbuilding activities such as assembly, outfitting, and erection processes. Different operational environments may possess distinct activity structures and resource requirements.

Second, deterministic activity durations and supplier lead times were used during analytical procedures. In actual industrial environments, production activities and procurement processes are often affected by uncertainties including supplier delays, machine failures, labor availability, weather conditions, and unexpected operational disruptions.

Third, the proposed framework focused primarily on scheduling and material planning factors and did not include additional variables such as production cost, workforce productivity, machine utilization, and quality-related factors. Including these variables could potentially improve the comprehensiveness and applicability of the proposed framework.

Future research may extend the proposed model through the integration of simulation approaches, optimization algorithms, and uncertainty analysis methods to improve decision-making capabilities in complex manufacturing environments.

4. Conclusion

This study addressed the issue of production delays and material procurement inefficiencies in hull block fabrication processes by proposing an integrated framework combining the Critical Path Method (CPM) and Material Requirement Planning (MRP). The research aimed to improve coordination between production scheduling and material availability in order to reduce operational interruptions and enhance production performance within shipyard manufacturing environments.

The findings demonstrated that the application of CPM successfully identified critical activities affecting overall production duration and revealed that hull block fabrication processes possessed high interdependency among activities. The welding process was identified as the activity with the longest processing duration and therefore contributed significantly to overall production performance. Furthermore, the integration between CPM and MRP enabled synchronization between production schedules and procurement activities, ensuring that required materials became available according to production requirements.

The implementation of the proposed framework showed improvements across several operational performance indicators, including reductions in production lead time, production delays, and waiting time, while simultaneously increasing material availability accuracy and on-time completion performance. These findings indicate that integrating production scheduling and material planning provides a more coordinated decision-making mechanism compared with treating both functions independently.

From a practical perspective, the proposed framework can support production planning and procurement departments in shipyard environments by improving scheduling reliability and reducing disruptions caused by material shortages. From an academic perspective, this study contributes to industrial engineering literature by demonstrating the application of integrated scheduling and material planning approaches within shipbuilding production systems.

Future studies may extend the proposed framework by incorporating additional operational factors such as workforce allocation, production cost analysis, machine utilization, and uncertainty variables associated with supplier performance and production disruptions. The integration of optimization algorithms and simulation-based approaches may further improve decision-making capabilities in complex manufacturing environments.

Declarations

Author contribution. The contribution or credit of the author must be stated in this section.

Muhammad Destri Sahputra Hardi: Conceptualization, methodology, data collection, data analysis, and write original draft.

Hery Irawan: Evaluation, Manuscript review, and editing

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