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# Contractor Mobilization Process Improvement Using the DMAIC Framework in a Large-Scale Mining Company in Indonesia

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**Abstract**

**Background:** Contractor mobilization plays a critical role in ensuring workforce readiness and supporting the timely execution of large-scale industrial projects. However, complex administrative requirements, extensive compliance procedures, and coordination among multiple stakeholders often create inefficiencies that affect project performance.
**Objective:** This study analyzes and improves the contractor mobilization process within one of divisions of a large-scale mining company in Indonesia during a major overhaul project. Although the project was planned for 35 calendar days, actual completion required 84 days, indicating substantial deviation from the planned project schedule.
**Methods:** The study employs the Define–Measure–Analyze–Improve–Control (DMAIC) framework using qualitative and quantitative data obtained from interviews, document reviews, and internal performance records. Process performance was assessed using four indicators Mobilization Lead Time (MLT), Mobilization Fulfillment Ratio (MFR), Readiness Compliance (RC), and Delay Frequency (DF), all of which were defined at first use in the text.
**Results:** The findings reveal an average Mobilization Lead Time (MLT) of 57 days, exceeding the 30-working-day service-level target. The overall Mobilization Fulfillment Ratio (MFR) was 82.1% (270 of 329 planned contractors mobilized); however, only 48.6% of contractors were available at project commencement (initial fulfillment rate), while Readiness Compliance (RC) was 27.8% and Delay Frequency (DF) was 40.7%.
**Conclusion:** These improvements are expected to reduce mobilization lead time, enhance workforce readiness, strengthen cross-functional coordination, and improve the overall effectiveness of contractor mobilization management.

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## INTRODUCTION

In large-scale industrial projects, success is commonly measured by a company's ability to deliver projects on time, within budget, and in compliance with quality and safety standards. Among these indicators, timely completion remains one of the most critical because project delays can disrupt operations, increase costs, reduce productivity, and negatively affect overall organizational performance. Previous studies have highlighted that successful project execution depends on several factors, including technical capability, effective planning, clear scope definition, and robust control mechanisms that ensure project objectives are achieved (Datta et al., 2025; Gunduz & Yahya, 2018). Likewise, workforce readiness has been identified as a key determinant of project success, particularly in industrial and energy-related sectors where project activities are highly dependent on manpower availability and coordination (Komarudin & Nugroho, 2022).

Timely project completion is closely linked to the readiness and availability of manpower. Projects cannot be executed as planned without enough competent personnel available at the required time. Workforce readiness encompasses not only manpower availability but also technical competence, certifications, medical fitness, and safety compliance necessary to support project execution. Abeysinghe and Jayathilaka (2022) identified labor shortages and inadequate workforce preparedness as major contributors to project delays, highlighting the importance of effective workforce mobilization in achieving project performance targets.

These challenges are particularly relevant in large-scale mining operations, where business continuity depends on uninterrupted support from critical infrastructure and supporting facilities. Within such environments, power generation and transmission functions play a vital role in ensuring operational reliability by supplying electricity to mining, processing, residential, and supporting areas. In addition to routine operational responsibilities, these functions frequently execute maintenance and reliability improvement projects that require specialized contractor personnel. Consequently, contractor mobilization becomes a critical process for ensuring that qualified manpower is available when required to support project execution.

To ensure compliance with organizational and regulatory requirements, contractor personnel must complete various administrative, competency, medical, and safety-related requirements before deployment. These requirements often involve multiple stakeholders, extensive documentation, and several approval stages. Although such controls are necessary to maintain safety and governance standards, the complexity of the mobilization process can create coordination challenges and operational inefficiencies when activities are not properly synchronized (Bhatta et al., 2026; Yiu et al., 2019). This condition reflects the organizational challenge of balancing operational control with process flexibility, as discussed by De Leeuw and Volberda (1996) and (Khan et al., 2025).

The significance of this issue became evident during a major power plant overhaul project conducted within a large-scale mining company in Indonesia in 2025. Although the project was originally scheduled to be completed within 35 calendar days, actual completion required 84 days, resulting in a delay of 49 days beyond the planned schedule and 54 days beyond the online target. Mobilization records also revealed a substantial workforce readiness gap, with only 160 of the planned 329 contractor personnel (48.6%) successfully mobilized and available on-site by the scheduled shutdown date. These conditions reduced workforce availability during critical execution periods and contributed to the prolonged project duration. From a business perspective, the consequences extended beyond schedule performance, as contractor service expenditures increased by approximately 25–30% above the planned allocation due to extended manpower utilization and the prolonged outage duration. All data presented in this study including project duration, mobilization readiness, and cost estimates were obtained from internal mobilization records, project schedule documents, and financial performance reports maintained by division and were validated during the data collection process.

These findings indicate that contractor mobilization should not be viewed merely as an administrative process but as a critical operational capability that directly influences project readiness and execution performance. Although the mobilization delays observed in this study coincided with the overall project delay, this research does not argue that mobilization was the sole cause of the 49-day delay. Instead, the evidence suggests that inadequate workforce readiness at the commencement of the project was one of the major contributing factors to the extended project duration and increased operational costs. Despite its strategic importance, contractor mobilization remains relatively underexplored in the mining and heavy industrial sectors, where previous studies have primarily focused on construction execution, procurement efficiency, or contractor performance after deployment rather than on the pre-deployment mobilization process itself.

Based on these issues, this study aims to analyze and improve the contractor mobilization process within the power generation and transmission function of a large-scale mining company in Indonesia using the DMAIC (Define–Measure–Analyze–Improve–Control) framework. Specifically, the study seeks to evaluate the effectiveness of the existing contractor mobilization process during a major overhaul project, identify process inefficiencies and non-value-added activities (waste), determine critical bottlenecks affecting workforce readiness, and develop improvement initiatives to enhance coordination and workflow efficiency. In addition, the study proposes expected performance improvements in terms of workforce readiness, coordination effectiveness, mobilization lead time, and overall project performance based on the redesigned process.

Organizations continuously seek structured approaches to improve operational performance, reduce inefficiencies, and enhance process reliability. Among the most widely adopted methodologies is the DMAIC (Define–Measure–Analyze–Improve–Control) framework, originally developed within Six Sigma and subsequently applied across various industries to support continuous improvement initiatives. DMAIC provides a systematic and data-driven approach for identifying operational problems, analyzing process inefficiencies, implementing corrective actions, and sustaining long-term improvements (Banerjee & Akhila, 2026; Gupta et al., 2018). The Define phase establishes a clear understanding of the problem, project objectives, stakeholders, and process boundaries. The Measure phase develops performance baselines through quantitative data collection and evaluation. The Analyze phase identifies bottlenecks, sources of variation, and non-value-added activities that contribute to process inefficiencies. The Improve phase focuses on designing and implementing solutions to address identified causes, while the Control phase ensures that improvements are sustained through monitoring mechanisms, standardization, and continuous evaluation. Previous studies have demonstrated that DMAIC effectively improves process performance by integrating analytical rigor with practical problem-solving techniques. Wang et al. (2022) highlighted that DMAIC enables organizations to systematically identify inefficiencies and develop sustainable improvement initiatives. Due to its structured nature and adaptability, DMAIC is particularly suitable for administrative and coordination-intensive processes characterized by multiple stakeholders, complex approval requirements, and significant workflow dependencies.

The successful implementation of DMAIC often relies on supporting analytical tools that facilitate process understanding, performance measurement, bottleneck identification, and risk prioritization. This study employs a SIPOC diagram, performance measurement indicators, an I-MR control chart, waste identification analysis, and Failure Mode and Effects Analysis (FMEA) to support the improvement process.

The SIPOC (Suppliers–Inputs–Process–Outputs–Customers) diagram is a high-level process-mapping tool used to define process boundaries and identify key stakeholders involved in a workflow. According to George et al. (2005), SIPOC provides a structured overview of process interactions by identifying suppliers, required inputs, major process activities, expected outputs, and customers receiving the outputs (Urban & Rogowska, 2026). As an initial diagnostic tool, SIPOC helps visualize end-to-end workflows before conducting detailed process analysis. The tool is particularly useful in complex organizational environments where activities involve multiple departments and interdependent process stages. By clarifying process ownership and stakeholder relationships, SIPOC supports transparency and facilitates subsequent improvement efforts.

Performance measurement provides quantitative evidence for assessing process effectiveness and establishing operational baselines. Objective indicators allow organizations to evaluate current performance conditions and monitor the impact of improvement initiatives over time. This study utilizes four performance indicators: Mobilization Lead Time (MLT), Mobilization Fulfillment Ratio (MFR), Readiness Compliance (RC), and Delay Frequency (DF). Collectively, these indicators measure process efficiency, workforce readiness, compliance achievement, and schedule reliability. The use of measurable indicators ensures that process evaluation and improvement recommendations are supported by empirical evidence rather than subjective assessment.

The Individual–Moving Range (I-MR) control chart is a statistical process control tool used to evaluate process stability and identify abnormal variations over time. Montgomery (2019) explains that control charts distinguish between common-cause variation and special-cause variation, allowing organizations to identify process instability and prioritize corrective actions (Mhatre & Somatkar, 2026). The I-MR chart is particularly suitable when observations are collected individually and subgrouping is not feasible. By monitoring individual performance values and the variation between consecutive observations, the tool provides insights into process consistency and helps detect unusual patterns that may indicate inefficiencies, delays, or operational disruptions.

Waste identification analysis is derived from Lean principles and focuses on identifying non-value-added activities that consume resources without contributing to desired process outcomes (Prenesti, 2025; Womack & Jones, 2003). The objective is to eliminate activities that increase lead time, create unnecessary complexity, or reduce operational efficiency. Common forms of waste include waiting time, excessive processing, duplication, rework, unnecessary motion, and communication delays. Identifying these sources of waste enables organizations to focus improvement efforts on activities that directly influence process effectiveness and customer value. Waste analysis is particularly valuable in administrative and coordination-intensive workflows where inefficiencies are often embedded within approval processes and information exchanges.

Failure Mode and Effects Analysis (FMEA) is a structured risk assessment tool used to identify potential process failures and prioritize corrective actions before failures occur. According to Stamatis (2003), FMEA evaluates each failure mode using three dimensions: Severity (S), Occurrence (O), and Detection (D) (Wikoyati & Kurniyaningrum, 2026). These dimensions are combined to generate a Risk Priority Number (RPN), which assists in prioritizing improvement actions. FMEA is widely used to support proactive risk management by identifying critical process vulnerabilities and assessing their potential impact on performance. Through the systematic evaluation of failure modes, organizations can allocate resources more effectively and implement targeted improvement initiatives that reduce operational risk and improve process reliability.

Previous studies have examined project delays, workforce planning, contractor involvement, communication effectiveness, and project performance using various analytical approaches. These studies have contributed valuable insights into delay drivers, workforce challenges, scheduling optimization, and project risk management across industrial and construction environments. For instance, Memon et al. (2023) employed statistical analysis to identify information flow disruptions and contract management weaknesses as critical delay drivers in construction projects. Abdellatif and Alshibani (2019) ranked poor coordination and late procurement as the most influential causes of delays in industrial and manufacturing environments, while Álvarez-Pozo et al. (2024) classified delay factors across turnkey industrial projects, emphasizing that multi-stakeholder coordination failures represent a persistent and largely unresolved challenge (Alqahtani et al., 2026). Despite these valuable contributions, these studies predominantly address macro-level project factors rather than the specific operational mechanisms within contractor mobilization workflows.

Several researchers have applied structured methodologies such as DMAIC, CPM-PERT, Monte Carlo simulation, Partial Least Squares Structural Equation Modeling (PLS-SEM), Relative Importance Index (RII), and qualitative case-study approaches to investigate project performance issues. While these studies provide important contributions to the literature, most focus on project-level outcomes, workforce planning strategies, scheduling optimization, or macro-level delay factors. However, limited research has specifically examined contractor mobilization as an operational process that directly influences workforce readiness before project execution begins. Existing studies rarely investigate how documentation requirements, medical clearances, safety compliance, approval workflows, and cross-functional coordination collectively affect mobilization performance. Furthermore, prior research generally emphasizes identifying delay factors rather than diagnosing process inefficiencies embedded within contractor mobilization workflows.

Another limitation of existing studies is the lack of integration between process mapping, performance measurement, process stability assessment, waste identification, and risk prioritization within a single improvement framework. As a result, the operational mechanisms that create mobilization delays remain insufficiently understood despite their direct influence on project readiness and execution performance. This study addresses these gaps by examining contractor mobilization through a structured process-improvement perspective. The integration of DMAIC with a SIPOC diagram, performance measurement indicators, an I-MR control chart, waste identification analysis, and FMEA within a single study is not claimed as an entirely new methodological combination per se; rather, the novelty lies in its contextual application to contractor mobilization workflows in large-scale mining operations, a domain that has been largely overlooked in the process-improvement literature. The research contributes to the literature by identifying operational bottlenecks, sources of waste, and process risks specific to pre-deployment contractor mobilization, while proposing practical improvement initiatives to enhance workforce readiness, coordination effectiveness, and overall project performance.

This study offers contributions from theoretical, methodological, and practical perspectives. Theoretically, it extends coordination theory and Lean-DMAIC scholarship to the relatively underexplored domain of pre-deployment contractor mobilization in the mining industry. Methodologically, it demonstrates how integrating process stability analysis using the Individual and Moving Range (I-MR) chart, waste identification, and Failure Mode and Effects Analysis (FMEA) within the DMAIC framework provides a more comprehensive operational diagnosis than relying on a single analytical approach. Practically, the findings provide project owners with actionable guidance for redesigning contractor mobilization workflows, establishing service-level agreement (SLA)-based performance targets, and implementing digital solutions such as the Contractor Mobilization Application (CMA) to reduce mobilization lead time and improve workforce readiness.

The scope of this study is limited to pre-deployment contractor mobilization activities within the power generation and transmission function. The analysis focuses on interactions among project owners, supporting functions, and contractor organizations involved in the mobilization process, covering workforce administration, competency verification, medical clearance, safety compliance, logistics arrangements, and stakeholder coordination. Activities occurring after contractor deployment, including project execution, contractor performance evaluation, and technical maintenance operations, are beyond the scope of this research.

## METHOD

This study employed a mixed-methods case study approach, specifically an explanatory sequential design, to examine and improve the contractor mobilization process during a major overhaul project within the Power Generation and Transmission Division of a large-scale mining company. Quantitative data (mobilization records, KPI measurements, and control chart analyses) established the performance baseline and identified patterns of process instability, while qualitative data (semi-structured interviews and direct observations) provided contextual explanations for the quantitative findings and informed the development of improvement initiatives. The integration of both data types occurred at the interpretation stage, enabling a comprehensive and triangulated assessment of mobilization process performance. A case study approach was selected because the research focuses on understanding a real operational process within its organizational context and identifying opportunities for process improvement. The case organization is a large-scale mining company operating in Indonesia. The Power Generation and Transmission Division oversees planned maintenance activities, including major overhaul projects that require the mobilization of hundreds of specialized external contractor personnel across multiple occupational classifications. The identity of the company is withheld to preserve confidentiality; however, the operational scale, project complexity, and regulatory environment are representative of major mining operators in the Indonesian resource sector. The integration of qualitative and quantitative methods enabled a comprehensive assessment of both operational performance and process-related challenges throughout the contractor mobilization workflow. Specifically, this study adopted an explanatory sequential mixed-methods design (Creswell & Plano Clark, 2018; Njeri Mugwe & Runo, 2026), in which quantitative performance data (KPI measurements and I-MR control charts) were collected and analyzed first, and qualitative data (interviews and observations) were subsequently used to explain and contextualize the quantitative findings. Both data strands were integrated at the interpretation stage to develop improvement recommendations grounded in empirical evidence.

Data were collected from both primary and secondary sources to ensure a comprehensive understanding of the contractor mobilization process. Primary data were obtained through semi-structured interviews and direct observations involving key personnel responsible for contractor mobilization activities across project management, safety, training, and contractor functions. The interviews explored existing mobilization practices, coordination challenges, process bottlenecks, and potential improvement opportunities. Direct observations were conducted to understand actual workflow execution, stakeholder interactions, and information flow throughout the mobilization process. Secondary data consisted of mobilization records, readiness reports, approval logs, scheduling documents, Service Level Agreements (SLAs), standard operating procedures, and system-generated records from the Contractor Mobilization Application (CMA). Additional supporting documents included mobilization reports, coordination records, and internal process documentation used to reconstruct mobilization timelines and evaluate process performance. The use of multiple data sources enabled triangulation and enhanced the validity and reliability of the research findings.

Data analysis was conducted using the DMAIC (Define–Measure–Analyze–Improve–Control) framework as the primary process improvement methodology. The framework provided a structured approach for identifying operational problems, measuring current performance, analyzing bottlenecks and waste, developing improvement initiatives, and establishing mechanisms for sustainability. The analysis integrated qualitative interpretation with quantitative evaluation through SIPOC, descriptive statistics, I-MR control charts, waste identification analysis, and Failure Mode and Effects Analysis (FMEA).

The Define phase focused on establishing a clear understanding of the contractor mobilization process and identifying key operational issues. A SIPOC (Supplier–Input–Process–Output–Customer) diagram and process mapping were developed to define process boundaries, identify key stakeholders, and document the end-to-end mobilization workflow. This phase also clarified project objectives, stakeholder expectations, and critical issues affecting mobilization effectiveness.

**Measure Phase**

The Measure phase established baseline performance conditions through four key performance indicators (KPIs):

1) Mobilization Lead Time (MLT) – the average duration required to complete the contractor mobilization process from initiation to site readiness.
2) Mobilization Fulfillment Ratio (MFR) – the proportion of planned contractor personnel successfully mobilized before project execution.
3) Readiness Compliance (RC) – the percentage of contractor personnel meeting administrative, safety, training, and mobilization requirements before deployment.
4) Delay Frequency (DF) – the proportion of mobilization cases experiencing delays relative to the total number of mobilization requests.

Descriptive statistical analysis was applied to evaluate baseline process performance and establish measurable improvement targets. To ensure methodological transparency, each KPI employed a specific denominator: MLT was calculated per individual mobilization case across all 270 mobilized contractors; MFR used 329 planned contractors as the denominator (overall MFR = 270/329 = 82.1%; initial/start-date MFR = 160/329 = 48.6%); RC used 270 successfully mobilized contractors as the denominator (75/270 = 27.8%); and DF used 270 mobilized contractors as the denominator (110/270 = 40.7%).

**Analyze Phase**

The Analyze phase focused on identifying bottlenecks, performance variations, and non-value-added activities within the contractor mobilization process. Individual–Moving Range (I-MR) control charts were utilized to evaluate process stability and detect abnormal variations in mobilization performance. Waste identification analysis was subsequently conducted to classify non-value-added activities, coordination gaps, approval delays, rework, and other inefficiencies contributing to mobilization delays. Findings from the quantitative analysis were validated through interview results and operational observations to ensure consistency between numerical performance indicators and actual process conditions.

**Improve Phase**

The Improve phase focused on developing process improvement initiatives based on the bottlenecks and sources of waste identified during the analysis stage. Proposed solutions included workflow redesign, SLA alignment, enhanced interdivisional coordination, and system integration improvements aimed at reducing delays and improving process efficiency. Failure Mode and Effects Analysis (FMEA) was employed to evaluate potential risks associated with the proposed improvements and prioritize corrective actions based on severity, occurrence, and detection ratings. The results were used to identify high-priority initiatives with the greatest potential impact on mobilization performance.

**Control Phase**

The Control phase established mechanisms to sustain the proposed improvements and ensure long-term process consistency. Control measures included mobilization tracking dashboards, SLA monitoring, escalation procedures, and periodic performance evaluations. These mechanisms were designed to provide visibility into mobilization performance, support the timely identification of issues, and maintain accountability among stakeholders involved in the mobilization process.

Through the integration of SIPOC, descriptive statistics, I-MR control charts, waste identification analysis, and FMEA within the DMAIC framework, this study systematically identified process inefficiencies and developed practical improvement recommendations. The methodology supports enhanced workforce readiness, improved coordination effectiveness, reduced mobilization delays, and improved overall project execution performance.

## RESULTS AND DISCUSSION

**Problem Identification (Define)**

The Define phase aimed to establish a comprehensive understanding of the contractor mobilization process and identify the key issues affecting project readiness. Based on observations, document reviews, and stakeholder interviews, contractor mobilization was found to involve multiple interdependent activities across several organizational functions, including manpower administration, competency verification, safety clearance, medical examinations, travel arrangements, accommodation preparation, and site access activation. Despite the existence of a formal mobilization procedure, the process remained highly dependent on coordination among multiple stakeholders and a combination of system-based and manual activities. Several critical activities were performed outside the Contractor Mobilization Application (CMA), resulting in fragmented information flows, duplicated administrative work, and extended coordination cycles. These conditions increased process complexity and reduced overall responsiveness to project requirements. The existence of a performance gap was evident during the major overhaul project examined in this study. While the project was initially planned to be completed within 35 calendar days, actual execution extended to 84 calendar days, indicating substantial delays that affected project readiness and execution performance. Interview findings further revealed recurring issues related to approval waiting times, readiness verification, incomplete documentation, communication delays, and limited integration among supporting processes. To provide a structured overview of the mobilization process, a SIPOC (Suppliers–Inputs–Process–Outputs–Customers) analysis was conducted. The SIPOC mapping demonstrated that contractor mobilization involved numerous stakeholders, multiple process handoffs, and parallel activities that required extensive coordination. The analysis highlighted process fragmentation and dependencies among functions as preliminary indicators of inefficiency, providing the foundation for the subsequent measurement and analysis phases.

**Table 1**

*SIPOC Diagram of Contractor Mobilization Process*

| Suppliers | Inputs | Processes | Outputs | Customers |
|---|---|---|---|---|
| External Contractors | Candidate documents | Project approval and planning | Approved mobilization plan | Project Owner / Requesting Division |

| Suppliers | Inputs | Processes | Outputs | Customers |
|---|---|---|---|---|
| Project Owner / Requesting Division | Mobilization plan and manpower requirement | Position and manpower setup | Position and UID ready | External Contractors |
| Operation Excellence Team | Project details (contract number, work location, duration, cost centre) | Assessment and eligibility verification | Contractor data validated in CMA | |
| Human Resources Function | Management approvals | Data submission and system processing (Contractor Mobilization Application) | Medical and compliance clearance | |
| Training and Competency Function | Operation Excellence Team approval and masterlist | Medical and compliance validation | Flight and accommodation confirmed | |
| Medical Provider | Floating position request and position UID | Premobilization and activation | Safety and training completed | |
| Industrial Relations | Contractor detailed data for CMA submission | Accommodation and travel arrangements | Contractor ready and deployed on site | |
| Occupational Health and Safety | Pre-Screen Assessment form and supporting documents | Site onboarding and readiness | | |
| Travel Provider | MCU schedule and medical results | Contractor deployment | | |
| | Training and certification requirements | | | |
| | Accommodation request data | | | |
| | Flight request and booking details | | | |

**Current Performance Evaluation (Measure)**

The Measure phase was conducted to establish the baseline performance of the contractor mobilization process using four key performance indicators: Mobilization Fulfillment Ratio (MFR), Readiness Compliance (RC), Mobilization Lead Time (MLT), and Delay Frequency (DF). These indicators were selected to assess workforce availability, operational readiness, process efficiency, and schedule adherence. The analysis showed that, of the 329 planned contractors, only 270 were successfully mobilized, resulting in a Mobilization Fulfillment Ratio (MFR) of 82.1%. Furthermore, only 160 contractors were available at the beginning of the project, indicating an initial fulfillment rate of 48.6%. This finding suggests a substantial gap between workforce planning and actual mobilization readiness at project commencement. Readiness Compliance (RC) was measured based on the proportion of contractors who were fully prepared to perform their assigned work immediately upon arrival. The results indicate that only 75 of the 270 mobilized contractors met all readiness requirements, producing an RC value of 27.8%. This low level of readiness suggests that a significant portion of the contractors required additional preparation activities after arriving at the worksite, potentially delaying operational deployment. Mobilization Lead Time (MLT), defined as the duration from mobilization initiation to contractor readiness, averaged 57 days. This duration exceeded the organizational target of 30 working days, indicating substantial delays within the mobilization process. The prolonged lead time reflects inefficiencies associated with administrative processing, verification activities, and coordination among multiple stakeholders. Delay Frequency (DF) analysis further revealed that 110 of the 270 mobilized contractors arrived later than planned, resulting in a delay frequency of 40.7%. This finding indicates that a considerable proportion of workforce deployment did not occur according to the required project schedule. Overall, the measurement results demonstrate that the existing contractor mobilization process was unable to consistently achieve the expected performance targets. Low readiness levels, extended lead times, and frequent deployment delays indicate the presence of process inefficiencies and coordination challenges. These findings provide the basis for further analysis to identify key bottlenecks, sources of performance inefficiencies, and opportunities for improvement.

## Bottlenecks and Sources of Inefficiencies (Analyze)

### *Process Stability Analysis Using I-MR Control Chart*

To evaluate the stability of the contractor mobilization process, an Individuals–Moving Range (I-MR) control chart was employed using the overall mobilization lead time data. The analysis was conducted to assess whether the observed delays were caused by isolated exceptional events or reflected inherent variation within the mobilization process. Unlike descriptive performance metrics, the I-MR chart provides a statistical assessment of process consistency by identifying variation patterns and out-of-control conditions across individual mobilization cases. The initial control chart revealed substantial process variation, with multiple observations exceeding the upper control limits in both the Individuals (I) and Moving Range (MR) charts. These findings indicate that mobilization lead times varied considerably between cases and that the process did not operate under statistically controlled conditions. Several clusters of unusually high lead times were observed, suggesting the presence of recurring operational disturbances rather than random variation alone. To distinguish special-cause variation from common-cause variation, iterative recalculations were performed by excluding extreme observations identified as exceptional cases. Although the recalculation process reduced several abnormal signals and narrowed the control limits, instability patterns remained evident throughout the analysis. The persistence of out-of-control observations after multiple recalculations suggests that process variability is embedded within the mobilization workflow rather than being solely attributable to isolated incidents. As presented in Figure 1, the final stability assessment showed that approximately 21.0% of observations in the Individuals (I) chart and 3.4% of observations in the Moving Range (MR) chart remained outside the control limits. In addition, several instability indicators, including shifts in the process mean and unstable moving-range patterns, continued to be detected. These findings confirm that the contractor mobilization process had not yet achieved statistical control and continued to experience significant operational variability. The results indicate that process instability is associated with recurring operational factors, including manual coordination activities, fragmented system interactions, repetitive verification requirements, and dependencies among multiple stakeholders. Consequently, the observed variation cannot be treated merely as exceptional anomalies but should be regarded as evidence of systemic inefficiencies within the mobilization process. This finding provides the foundation for subsequent stage-level performance analysis and bottleneck identification.

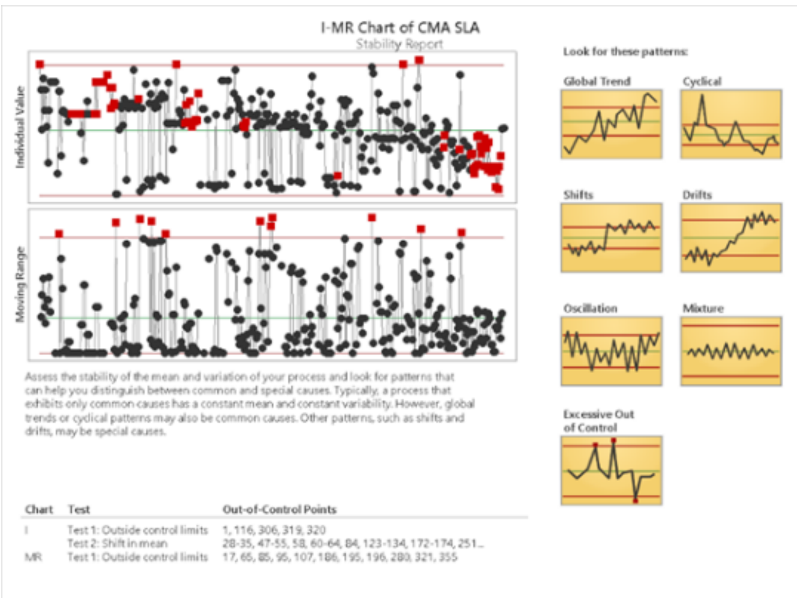


**Figure 1.** *Final Stability Report of I-MR Chart*

***Stage Performance Against SLA Targets***

Following the identification of process instability through the I-MR control chart analysis, a stage-level performance assessment was conducted to determine which activities contributed most significantly to mobilization delays. The analysis compares the average actual processing time for each stage within the Contractor Mobilization Application (CMA) workflow with its corresponding Service Level Agreement (SLA) target. Table 2 presents a comparison of the established SLA targets and actual processing performance. The results indicate that process delays are not uniformly distributed across the mobilization workflow. Several stages exhibit substantial positive gaps between actual performance and target completion times, suggesting the presence of localized bottlenecks within the process. Among all evaluated stages, Data Submission demonstrated the largest deviation from its target, with an average delay of 11 days. Significant gaps were also identified in several pre-mobilization activities, particularly UID Activation and Complete Pre-Mobilization, which collectively contributed an additional 10 days beyond the established SLA. These findings indicate that delays are concentrated primarily in administrative coordination and readiness-related activities rather than in technical verification processes. In contrast, stages such as Data Review, Document Competency Check, and Medical Checkup (MCU) generally operated within or close to their respective SLA targets. Meanwhile, Headcount Control and Background Check recorded negative gaps, indicating that their processing times were shorter than the allocated SLA. Although these stages did not directly contribute to the overall escalation of lead time, their performance highlights variability in resource allocation and process execution across different mobilization activities. Overall, the comparison reveals that contractor mobilization delays originate from a limited number of critical stages rather than from the workflow. The concentration of performance gaps within specific activities suggests that process improvement efforts should prioritize administrative coordination, pre-mobilization readiness management, and system integration issues. These findings provide a basis for the subsequent bottleneck and waste analyses to identify the underlying causes of delays and operational inefficiencies.

**Table 2**

*Comparison of SLA and Actual Performance*

| Stages | SLA | Stages | Average Actual | Gap |
|---|---|---|---|---|
| Data Submission | 0 | Data Submission | 11 | 11 |
| Data Review | 3 | Data Review | 3 | 0 |
| Headcount Control | 2 | Headcount Control | 1 | -1 |
| Background Check | 2 | Background Check | 1 | -1 |
| Doc. Competency Check | 2 | Doc. Competency Check | 2 | 0 |
| MCU (Medical Check Up) | 14 | Waiting for Schedule | 7 | 0 |
| | | Waiting for Results | 7 | |
| Pre-Mobilization | 7 | Submit Pre-Mobilization (CRP) | 4 | 10 |
| | | UID Activation (HR-VCS) | 6 | |
| | | Accommodation and Safety Status (HR-VCS) | 3 | |
| | | Complete Pre-Mobilization (HR-VCS) | 4 | |
| TOTAL | 30 | | 49 | 19 |

***Stage-Level Bottleneck Analysis Summary***

The stage-level I-MR analysis revealed that process stability varied across the contractor mobilization workflow. While several stages achieved their respective SLA targets, significant operational variation remained evident. Data Submission and pre-mobilization activities, including UID Activation, Accommodation and Safety Status, and Complete Pre-Mobilization, exhibited the highest levels of instability and SLA deviations, indicating that they were the primary bottlenecks in the process. In contrast, Document Competency Check and MCU demonstrated relatively stable performance with lower levels of variation. These findings suggest that process instability is concentrated within specific workflow stages rather than being distributed across the entire mobilization process. Furthermore, the results indicate that SLA achievement alone does not necessarily reflect process stability, as several stages remained statistically unstable despite meeting their targeted service levels.

**Table 3**

*Stage-Level Bottleneck Analysis*

| Stage | SLA Performance | Process Stability | Key I-MR Finding |
|---|---|---|---|
| Data Submission | Exceeded SLA | Unstable | Highest SLA gap and significant process variation |
| Data Review | Met SLA | Unstable | High out-of-control observations despite meeting SLA |
| Headcount Control | Better than SLA | Unstable | Significant variation across mobilization cases |
| Background Check | Better than SLA | Unstable | Processing time varies considerably between cases |
| Document Competency Check | Met SLA | Relatively Stable | Lowest variability and most consistent performance |
| MCU | Met SLA | Moderately Stable | Variation primarily caused by isolated exceptional cases |
| Submit Pre-Mobilization | Exceeded SLA | Unstable | Persistent variation associated with mobilization timing |
| UID Activation | Exceeded SLA | Unstable | Recurrent process variation despite recalculation efforts |
| Accommodation & Safety Status | Exceeded SLA | Highly Unstable | Highest instability among pre-mobilization activities |
| Complete Pre-Mobilization | Exceeded SLA | Unstable | Strong dependency on preceding mobilization activities |

**Waste Analysis**

The waste analysis indicates that contractor mobilization inefficiencies are primarily driven by waiting, overprocessing, rework, and excessive coordination activities. Waiting waste is the most dominant form of waste and is caused by approval dependencies, limited assessment capacity, scheduling delays, and manual coordination. Overprocessing occurs through duplicate document submissions, repeated validations, and fragmented systems. Rework arises from incomplete requirements and failed assessments that require repeated processing, while coordination-related waste results from heavy reliance on manual communication among multiple stakeholders. Overall, these inefficiencies reflect limited system integration, process fragmentation, and operational constraints that collectively extend mobilization lead time and reduce workforce readiness.

**Table 4**

*Waste Identification in the Contractor Mobilization Process*

| Waste Type | Description | Related Stage |
|---|---|---|
| Waiting | Waiting time caused by dependency on approvals, limited capacity, batching, and system-related delays. | PSA scheduling, MCU coordination, safety induction, RPL assessment. |
| Overprocessing | Redundant approvals, duplicate document submissions, and manual data handling across platforms. | PSA, MCU, RPL, Airfast Flight booking. |
| Rework | Repetition of the process or replacement of manpower when quality requirements are not met. | Failed PSA, incomplete MCU, drug testing after arrival on site. |
| Motion/ Coordination | Reliance on manual communication via email and external coordination with third parties. | Nearly all activities conducted outside the CMA. |

### RPL Readiness Constraint

The RPL stage emerged as a critical readiness constraint despite not being included in SLA measurements. Limited assessment capacity, scheduling uncertainty, and redundant administrative requirements delayed workforce readiness after arrival at the jobsite. Approximately 85% of assessment requests had been completed, indicating that a portion of the workforce remained unable to perform assigned tasks due to pending assessments. These conditions created idle manpower, extended readiness lead times, and contributed to increased operational costs, highlighting the importance of integrating readiness validation into overall mobilization performance management.

### Discussion

The findings presented above confirm that the contractor mobilization process does not consistently meet the expected performance levels and is not statistically controlled, indicating that delays originate from structural and systemic issues rather than isolated incidents. Crucially, the present study moves beyond identifying delay symptoms to tracing how specific operational mechanisms namely, documentation sequencing, competency assessment timing, medical clearance dependencies, fragmented system usage, and cross-functional approval chains interact to produce systemic process instability. This operationalization of delay causation within a pre-deployment workflow represents a distinctive contribution compared with prior studies that addressed delays at the project or industry level.

### *Prioritization of Improvements (Improve)*

Based on the Analyze phase, improvement initiatives were developed by integrating the findings from the I-MR control chart, waste identification analysis, and Failure Mode and Effects Analysis (FMEA). The FMEA results identified the Recognition of Prior Learning (RPL), Prescreening Assessment (PSA), and Medical Checkup (MCU) stages as the most critical contributors to mobilization delays. Among all evaluated stages, RPL obtained the highest Risk Priority Number (RPN = 432), followed by PSA and MCU (RPN = 384). These findings indicate that manpower readiness constraints are primarily driven by assessment-related activities, fragmented coordination, and inefficient process sequencing. The waste analysis further revealed several non-value-added activities throughout the mobilization process, including duplicate data submission, repeated verification, excessive manual coordination, waiting time between sequential approvals, and fragmented information management across multiple functions. These inefficiencies contribute to extended mobilization lead times and reduced readiness performance. To address these issues, the study proposes three major improvement initiatives. First, the RPL process is repositioned from a post-arrival activity to a planned pre-mobilization requirement supported by automated scheduling and monitoring mechanisms. This approach distributes the assessment workload earlier in the process and improves manpower readiness before deployment. Second, the PSA process is integrated into the Contractor Mobilization Application (CMA) through automatic eligibility validation, duplicate-submission prevention, and prescreening functionality to reduce reviewer workload and unnecessary processing activities. Third, a centralized system integration strategy is proposed by enhancing CMA as an end-to-end mobilization platform. Under the proposed workflow, UID activation serves as a trigger for downstream activities, including PSA requests, RPL scheduling, accommodation arrangements, safety induction, and other mobilization requirements. The proposed improvements are expected to reduce non-value-added activities, improve process visibility, strengthen cross-functional coordination, and establish a more standardized mobilization workflow. Consequently, the redesigned process is anticipated to reduce mobilization lead time, increase manpower readiness, and improve overall operational efficiency in contractor mobilization projects.

**Table 5**
*FMEA of Critical Contractor Mobilization Stages*

| Rank | Process Step | Potential Failure Mode | Potential Effect | S | O | D | RPN | Recommended Action |
|---|---|---|---|---|---|---|---|---|
| 1 | RPL | Delay in RPL completion due to post-arrival assessment and high workload | Manpower idle at jobsite and delayed operational readiness | 9 | 8 | 6 | 432 | Integrate RPL into CMA and scheduled before arrival |
| 2 | PSA | Delay in PSA scheduling and result confirmation due to manual coordination and outside system process | Delay in manpower readiness and data submission cycle | 8 | 8 | 6 | 384 | Integrate PSA into CMA and implement scheduling system |
| 3 | MCU | Inefficient MCU process due to redundant email coordination and incomplete initial testing | MCU and scheduling delays leading to extended mobilization lead time | 8 | 8 | 6 | 384 | Eliminate redundant email process and ensure required tests are completed during initial MCU |
| 4 | UID Activation | Delay due to manual UID activation and stage progression | Process cannot proceed to the next stage on time | 8 | 7 | 6 | 336 | Automate UID activation and workflow progression |
| 5 | Accommodation and Safety Induction | Redundant approval process despite automatic ticket generation | Delay in process progression and manpower readiness | 7 | 7 | 6 | 294 | Simplify approval process and reduce redundant approval layers |
| 6 | Drug Test | Positive drug test result after arrival | Manpower replacement and re-mobilization | 9 | 5 | 6 | 270 | Shift drug test earlier before mobilization (if possible) |
| 7 | Submit Pre-Mobilization | Duplicate data submission through Excel form | Increased processing time and administrative workload | 6 | 8 | 5 | 240 | Eliminate Excel form and use CMA as a single data source |
| 8 | Approval OPEX | Delay due to weekly approval review cycle and manual follow-up | Delayed mobilization initiation and approval confirmation | 7 | 6 | 5 | 210 | Implement integrated approval tracking and notification system |
| 9 | Position Number Creation | Delay in position number | Mobilization process cannot proceed to | 7 | 6 | 5 | 210 | Simplify approval hierarchy and |

| Rank | Process Step | Potential Failure Mode | Potential Effect | S | O | D | RPN | Recommended Action |
|---|---|---|---|---|---|---|---|---|
| | | creation due to multi-layer approval process | CMA submission | | | | | automate request routing |
| 10 | Data Submission | Repeated submission due to strict validation errors and incomplete documents | Increased administrative workload and submission delay | 7 | 7 | 4 | 196 | Improve validation guidance and document standardization |
| 11 | Data Review | Delay caused by repeated review and correction cycle | Extended review duration and manpower processing delay | 7 | 6 | 4 | 168 | Standardize review checklist and improve submission quality |
| 12 | Headcount Control | Redundant approval despite existing approved headcount | Delay in manpower processing and approval dependency | 6 | 6 | 4 | 144 | Integrate headcount validation automatically within CMA |
| 13 | Background Check | Delay due to dependency on external coordination and manual verification | Mobilization process waiting time increases | 6 | 5 | 4 | 120 | Centralize background check monitoring and tracking |
| 14 | Document Competency Check | Delay caused by repeated manual verification of competency documents | Slower manpower readiness confirmation | 6 | 5 | 4 | 120 | Digitize competency verification and document repository |
| 15 | Complete Pre-Mobilization | Delay in completion confirmation due to pending drug test readiness | Manpower status remains incomplete despite arrival preparation | 6 | 5 | 4 | 120 | Synchronize drug test and completion status automatically within CMA |

**Table 6**

*Top Three Priority Issues from the FMEA*

| Stage | Main Failure Mode | Impact |
|---|---|---|
| RPL | Assessment conducted after arrival on site; limited assessor capacity; no defined SLA. | Idle manpower; extended lead time; increased cost. |
| PSA | Conducted outside CMA; manual coordination; no initial filtering; limited reviewers. | Long queues; high reviewer workload; rework of submission cycle. |
| MCU | Coordination via email; dependency on external facilities across locations. | Variable waiting time for schedule and results; rescheduling. |

### *Implementation Plan and Control*

The proposed improvements are designed to be implemented through the enhancement of the Contractor Mobilization Application (CMA) as an integrated platform supporting end-to-end contractor mobilization processes. The future-state workflow incorporates the integration of Pre-Screening Assessment (PSA), Recognition of Prior Learning (RPL), and pre-mobilization activities into a centralized system supported by automated scheduling, validation mechanisms, and standardized workflows. Implementation is expected to be carried out gradually through system configuration, workflow integration, pilot testing, user training and familiarization, and full deployment involving relevant stakeholders across operational functions. To ensure sustainability, the proposed workflow incorporates several control mechanisms within the CMA environment. These include centralized monitoring dashboards, SLA-based performance monitoring, automated notifications and escalation procedures, system-based validation controls, and periodic operational reviews. The integration of these controls is intended to improve process visibility, strengthen accountability, reduce manual follow-up activities, and enable the early identification of potential delays throughout the mobilization process. Overall, the implementation and control framework supports the long-term sustainability of the proposed improvements by promoting standardized execution, data accuracy, and continuous performance monitoring. Through enhanced system integration and governance mechanisms, the redesigned mobilization process is expected to reduce recurring inefficiencies, improve visibility into manpower readiness, and support more reliable mobilization performance in large-scale project environments. To sustain the proposed improvements over time, the Control phase incorporates several interdependent mechanisms. First, performance governance is maintained through monthly SLA compliance reviews conducted by the Operation Excellence Team, with escalation protocols triggered when any stage exceeds its SLA threshold by more than two days. Second, the CMA system generates automated performance dashboards that are updated in real time, allowing project owners and mobilization coordinators to monitor mobilization status across all active cases. Third, quarterly process audits are planned to evaluate whether RPL pre-mobilization completion rates, PSA rejection rates, and UID activation timelines remain within established targets. Fourth, a continuous improvement loop is embedded through post-project debriefs following each major overhaul, with findings channeled back into SOP updates and CMA system configurations. Collectively, these control mechanisms ensure that the improvements are institutionalized rather than treated as one-time interventions, thereby supporting the DMAIC principle of long-term process sustainability (Evander et al., 2020; Wang et al., 2022).

**Table 7**
*Implementation Timeline of Proposed Improvements*

| Implementation Stage | Estimated Timeline |
|---|---|
| CMA system development and configuration | Month 1–2 |
| Integration of PSA and RPL workflows | Month 2–3 |
| Pilot testing in selected projects | Month 3–4 |
| Stakeholder training, socialization, and SOP updates | Month 4–5 |
| Full-scale deployment and continuous monitoring | Month 5–6 |

## CONCLUSION

This study evaluated the effectiveness of the contractor mobilization process in a large-scale mining project using the DMAIC framework. The findings demonstrate that the existing process was hindered by prolonged mobilization lead times, low workforce readiness, high process variability, and significant deviations between planned and actual project schedules. Process instability identified through the I-MR control chart, together with the presence of waiting, overprocessing, rework, and motion waste, indicates that fragmented workflows, repetitive administrative activities, manual coordination, and limited system integration substantially reduced mobilization efficiency. To address these issues, this study proposed a DMAIC-based improvement framework incorporating workflow redesign, SLA alignment, system integration, and standardized information-sharing mechanisms. The proposed future-state process is expected to improve workforce readiness, enhance cross-functional coordination, reduce non-value-added activities, and strengthen overall operational performance. These findings contribute to the literature on Lean process improvement and contractor mobilization management while providing practical guidance for improving mobilization processes in complex project environments.

This study is limited by its focus on a single organizational setting, which may restrict the generalizability of the findings to other industries or operational contexts. In addition, the proposed improvements have not yet been validated through post-implementation performance measurement; therefore, the expected outcomes should be interpreted as projected benefits derived from process analysis rather than empirically confirmed results. Future research should evaluate the effectiveness of the proposed framework through before-and-after implementation studies, investigate its applicability across different industrial sectors and project types, and explore the integration of digital technologies such as workflow automation, predictive analytics, and integrated workforce management systems to further improve contractor mobilization planning, workforce readiness, and operational performance.

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## AUTHOR CONTRIBUTION STATEMENT

Author 1: Conceptualization, Methodology, Investigation, Data Curation, Formal Analysis, Visualization, and Writing – Original Draft Preparation. Author 2: Conceptualization, Methodology, Validation, Supervision, and Project Administration. All authors have read and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

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