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Application of Critical Chain Project Management (CCPM) in Overcoming Resource Inefficiency in Multi-Project Management of Drinking Water Treatment System (SPAM) Development in The National Capital City (IKN)

Habib Amrulloh[1]*, Kamalul Asfiyak[2], Rian Ramadhan[3], and Ina Agustini Murwani[4]

[1,2,3,4] Binus Business School, Program Studi Magister Manajemen Bisnis, Binus University, Indonesia

Email: habib.amrulloh@binus.ac.id

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Abstract

The development of the Drinking Water Supply System (SPAM) in Indonesia's new capital city (Ibu Kota Nusantara/IKN) is executed through multiple concurrent projects under tight deadlines and high resource interdependence. This setting has generated recurring resource inefficiencies, including equipment and labor idle time, schedule overlap, and delayed material availability. This study investigates the dominant inefficiency patterns, explains their root causes, and formulates an improvement and control model by integrating Critical Chain Project Management (CCPM) with Six Sigma DMAIC and Theory of Constraints (TOC) thinking processes. A qualitative case study was conducted in the SPAM program environment at IKN, focusing on PT Virama Karya KSO as the construction management supervision consortium. Data were collected through semi-structured interviews with three key stakeholder groups (owner/OIKN, consultant, and contractor; ~60 minutes each), field observations, and document review (master schedule packages, S-curve, and work-resource allocation records). Evidence was coded into issue themes and summarized using descriptive frequencies to support the Define–Measure stages. The results identified six recurrent inefficiency themes (n = 23 coded references), dominated by planning–execution fragmentation across projects (39%) and the absence of a unified cross-project command for resource allocation (26%), jointly accounting for 65% of observed issues. Root-cause analysis using Fishbone and TOC Current Reality Tree indicates that silo-based scheduling, non-real-time information flows, and weak cross-project governance trigger resource competition, idle time, and delayed procurement responses. The proposed improvement package consists of (i) establishing a digital-based Resource Control Center (RCC) as a cross-project governance and resource orchestration unit, (ii) implementing CCPM buffer management with a shared multi-project master schedule, and (iii) adopting real-time project information dashboards to enable execution feedback and dynamic resource redistribution. Sustainability is ensured through buffer monitoring, periodic multi-project audits, shared cross-project KPIs, and an escalation protocol formalized in a Transition Tree. Overall, the CCPM–DMAIC integration offers a structured and actionable model for improving resource efficiency and coordination in multi-project national infrastructure delivery.

INTRODUCTION

The development of Ibu Kota Nusantara (IKN) represents one of Indonesia's most ambitious national strategic projects, envisioned to establish a modern, environmentally sustainable, and inclusive capital city that embodies Indonesia's long-term vision of becoming a developed nation by 2045. The project integrates technological innovation, sustainability, and equitable regional development across the archipelago. According to the Otorita Ibu Kota Nusantara (OIKN, 2023), the IKN master plan covers approximately 56,159 hectares of core area and 252,660 hectares of expansion zone in East Kalimantan, specifically in Penajam Paser Utara and parts of Kutai Kartanegara. The site was chosen for its strategic central location, relative safety from major natural disasters, and abundant natural resources that support large-scale infrastructure development.

The construction of IKN is organized into five stages from 2022 to 2045, emphasizing phased development of urban areas, core infrastructure, and sustainable industries (Ministry of Public Works and Housing [PUPR], 2023). The first phase (2022–2024) focuses on essential urban and infrastructure foundations, including the Sistem Penyediaan Air Minum (SPAM – Drinking Water Supply System), which plays a crucial role in ensuring the city's livability and sustainability. Managing multiple simultaneous infrastructure projects within this early stage presents complex challenges, particularly in time management, cost control, and resource allocation (OIKN, 2023).

From a managerial standpoint, IKN's multi-project environment requires integrated strategies to synchronize schedules, optimize limited resources, and mitigate time-based risks. The Ministry of Public Works and Housing (PUPR) has emphasized comprehensive project governance based on quality, cost, benefit, and administration principles, supported by digital supervision and internal compliance systems (PUPR, 2023). However, the simultaneous execution of over 50 projects within tight deadlines has led to resource inefficiencies, including material delivery delays, low labor productivity, and underutilized heavy equipment. These inefficiencies are frequently driven by fragmented planning, weak inter-project coordination, and the absence of centralized control mechanisms.

The literature on project management in complex environments underscores similar challenges. Ordoñez et al. (2019), Araszkiewicz (2017), and Apaolaza and Lizarralde (2020) highlight the importance of time, resource, and uncertainty management, identifying Critical Chain Project Management (CCPM) as an effective approach to enhance project efficiency through resource optimization and cycle-time reduction. CCPM, developed from the Theory of Constraints (TOC), emphasizes identifying and protecting the project's critical chain by introducing buffers and focusing managerial attention on the most constraint-sensitive activities. Complementarily, the Six Sigma DMAIC (Define–Measure–Analyze–Improve–Control) framework provides a systematic methodology to diagnose inefficiencies and design continuous-improvement strategies for large infrastructure systems.

This study focuses on evaluating the effectiveness of CCPM integrated with Six Sigma DMAIC in improving multi-project management performance during the early phase of the IKN SPAM construction. Specifically, it seeks to (1) identify the dominant factors contributing to resource inefficiencies (labor, materials, heavy equipment); (2) analyze their root causes using the Six Sigma DMAIC framework; and (3) design a sustainable improvement and control mechanism based on CCPM and TOC principles.

The research is expected to contribute both theoretically and practically. Theoretically, it advances the integration of continuous-improvement and constraint-based management concepts within multi-project infrastructure contexts. Practically, it provides concrete recommendations for the IKN Authority, contractors, and policymakers to develop an integrated Resource Control Center and digital monitoring system that strengthen coordination, transparency, and sustainability in Indonesia's new capital development.

METHODS

This study employed a qualitative case study design to examine the causes of resource inefficiency in a multi-project environment and to develop an improvement–control model by integrating Critical Chain Project Management (CCPM) with Six Sigma DMAIC and the Theory of Constraints (TOC) thinking processes. A case study approach was selected because the SPAM development program at Ibu Kota Nusantara (IKN) represents a bounded real-life setting with high interdependence among work packages, shared resource pools (labor, materials, and equipment), and complex coordination demands across multiple stakeholders.

The research was conducted in the SPAM development program within the IKN construction area, East Kalimantan, Indonesia, during the early implementation phase. The focal organizational context was PT Virama Karya KSO, the consortium responsible for construction management supervision, which provided access to cross-project planning practices, reporting routines, and resource coordination mechanisms. SPAM was selected as the focal case because it is a critical infrastructure component directly associated with urban livability and sustainability targets in IKN (OIKN, 2023), and its delivery involves intensive resource usage under strict time constraints.

This study used primary and secondary data (Sugiyono, 2019). Primary data were obtained through three techniques to support triangulation (Fiantika et al., 2022):

1. Semi-structured interviews with three key stakeholder (groups, such as owner/OIKN, consultant, and contractor) conducted for approximately 60 minutes each, focusing on schedule conflicts, cross-project coordination issues, and constraints in resource allocation.
2. Field observations to document work sequencing, site-level bottlenecks, and the actual utilization of labor, equipment, and materials.
3. Document analysis of project artifacts, including administrative and technical documents, Work Breakdown Structure (WBS), Gantt charts, project charter (scope, assumptions, risks), master schedule packages, S-curve progress reports, and resource allocation sheets detailing workload distribution and capability requirements.

Secondary data were compiled from institutional reports, government documents, and peer-reviewed literature to strengthen contextual interpretation and provide supporting evidence regarding SPAM governance and multi-project management challenges. Moreover, data analysis followed the DMAIC sequence and incorporated TOC thinking processes and CCPM principles (Table 1). In the Define–Measure phases, interview transcripts, observation notes, and documents were coded into recurring inefficiency themes. Coded references were tabulated and summarized using descriptive frequencies to identify dominant patterns using Pareto logic. In the Analyze phase, causal mechanisms were structured using an Ishikawa (Fishbone) diagram and formalized through TOC tools, Current Reality Tree (CRT) and Evaporating Cloud (EC) to explain cause–effect propagation and the systemic conflict between local project optimization and program-level efficiency. In the Improve phase, solution "injections" were developed using Future Reality Tree (FRT) and Prerequisite Tree (PRT) and strategically aligned using the SWOT–TOWS matrix, resulting in an intervention package emphasizing a Resource Control Center (RCC), integrated master scheduling, and CCPM buffer management supported by real-time reporting. In the Control phase, sustainability mechanisms were specified through a Transition Tree (TT), including buffer monitoring, KPI dashboards, periodic audits, and escalation protocols to reduce regression risks.

Table 1. DMAIC Stages, Objectives, and Analytical Tools

Research Stage (DMAIC)	Objective	Tools / Methods Used	Expected Output
Define	Identify dominant inefficiency issues in SPAM multi-project resource management	Field interviews and observations; Pareto Analysis (80/20)	Definition of dominant problems and research focus
Measure	Quantify problem frequency and dominance	Frequency tabulation and coding analysis	Quantitative distribution of issue categories
Analyze	Identify root causes of inefficiency	Fishbone Diagram (Ishikawa); TOC tools (Current Reality Tree, Evaporating Cloud); Undesirable Effects (UDE) Analysis	Cause–effect mapping and dominant root causes
Improve	Formulate corrective actions integrating CCPM and TOC	Future Reality Tree (FRT); Prerequisite Tree (PRT); SWOT–TOWS Matrix	Strategic improvement model (buffer management, centralized coordination)
Control	Establish sustainability and monitoring mechanisms	Transition Tree (TT); CCPM Buffer Monitoring	Continuous control and evaluation framework

RESULTS AND DISCUSSION

3.1 Overview of Evidence and Analytical Flow

Evidence consisted of semi-structured interviews with three stakeholder groups (owner/OIKN, consultant, contractor), direct field observations, and project documents (S-curve, master work packages, schedules, and resource allocation records). The analytical logic followed an integrated DMAIC–TOC–CCPM flow:

i. Theme identification and prioritization (Define–Measure)
ii. Causal modelling with Fishbone and TOC thinking processes (Analyze)
iii. Solution design combining governance and CCPM buffer mechanisms (Improve)
iv. Sustainability controls through buffer monitoring, audits, and KPI dashboards (Control).

This integration aligns with Six Sigma's improvement cycle logic and TOC's focus on system constraints and flow (Goldratt, 2001; Taghizadegan, 2006; Johari et al., 2024).

3.2 Define–Measure: Dominant Inefficiency Patterns

Coding produced six recurring themes representing resource inefficiency drivers. A total of 23 coded references were recorded across all evidence sources (interviews, observations, and documents). Theme frequencies are presented in Table 2. The use of frequency tabulation in the Measure stage supports Pareto-based prioritization by highlighting the most dominant recurring patterns that drive performance loss (Taghizadegan, 2006; Johari et al., 2024).

Table 2. Frequency of Issue Occurrences

Issue Theme	Brief Description	Theme Occurrence Frequency	Frequency Score	% of Occurrence	Cumulative %
		IPA	T1	T1	JDU
Theme 1: Planning & Execution Fragmentation	Projects managed in silos; unsynchronized schedules; misaligned resource allocation	3	2	2	2
Theme 2: Weak Information Systems	Manual, non–real-time data; difficult resource redistribution	1	1	1	1
Theme 3: Sectoral Ego & Limited Collaboration	Contractors/consultants reluctant to share resources	1	0	0	1
Theme 4: Non-Adaptive Procurement System	Rigid procedures; frequent delays in material delivery	1	0	0	0
Theme 5: Absence of Unified Command	No centralized resource control; competition over equipment/labor	2	1	1	2
Theme 6: Misconceptions about Efficiency	Efficiency equated solely with "on-time" completion, not resource optimization	0	0	0	1

Two themes dominate the pattern: planning–execution fragmentation (39%) and absence of unified command (26%), jointly representing 65% of observed issues. Operationally, these themes manifest as schedule overlap, idle time in some packages alongside shortages in others, and delayed or mismatched material availability. Similar governance fragmentation and interdependency challenges have been noted in megaproject delivery, where silo-based control and weak integration tend to degrade system performance (Love et al., 2022). These results justify prioritizing improvement actions that strengthen cross-project integration and enable timely resource governance, which is consistent with CCPM's emphasis on managing resource constraints and protecting system flow (Ordoñez et al., 2019; Araszkiewicz, 2017).

3.3 Analyze: Root Causes and System Logic

Fishbone analysis grouped the drivers of resource inefficiency into four categories: Methods, Organization/Governance, Information, and Contracts/Procurement. Under Methods, the dominant issue was the absence of an integrated multi-project master schedule and weak scheduling discipline across work packages. Under Organization/Governance, the system lacked a formally mandated cross-project authority to prioritize and redistribute shared resources. Under Information, reporting remained manual and non–real-time, delaying visibility of resource status and constraints. Under Contracts/Procurement, rigid administrative procedures reduced flexibility in responding to rapidly changing field needs. These categories reflect typical root domains in construction performance problems where methods, governance, and information delays reinforce execution variability (Kerzner, 2017; Fewings & Henjewele, 2019).

The TOC Current Reality Tree (CRT) was then used to formalize the cause–effect chain and identify the main constraint driving undesirable effects (UDEs). The CRT indicates that two interacting constraints, the absence of an integrated cross-project command mechanism and silo-based planning, propagate into operational disruptions such as idle time of labor and equipment, material unavailability at execution time, schedule overlap, and cost escalation. This causal logic is consistent with TOC's focus on identifying the primary constraint that governs system throughput and generates recurring undesirable effects (Goldratt, 2001). Multi-project CCPM literature similarly highlights that resource contention and unsynchronized schedules are key drivers of delay propagation and productivity loss (Ordoñez et al., 2019; Santolini et al., 2020).

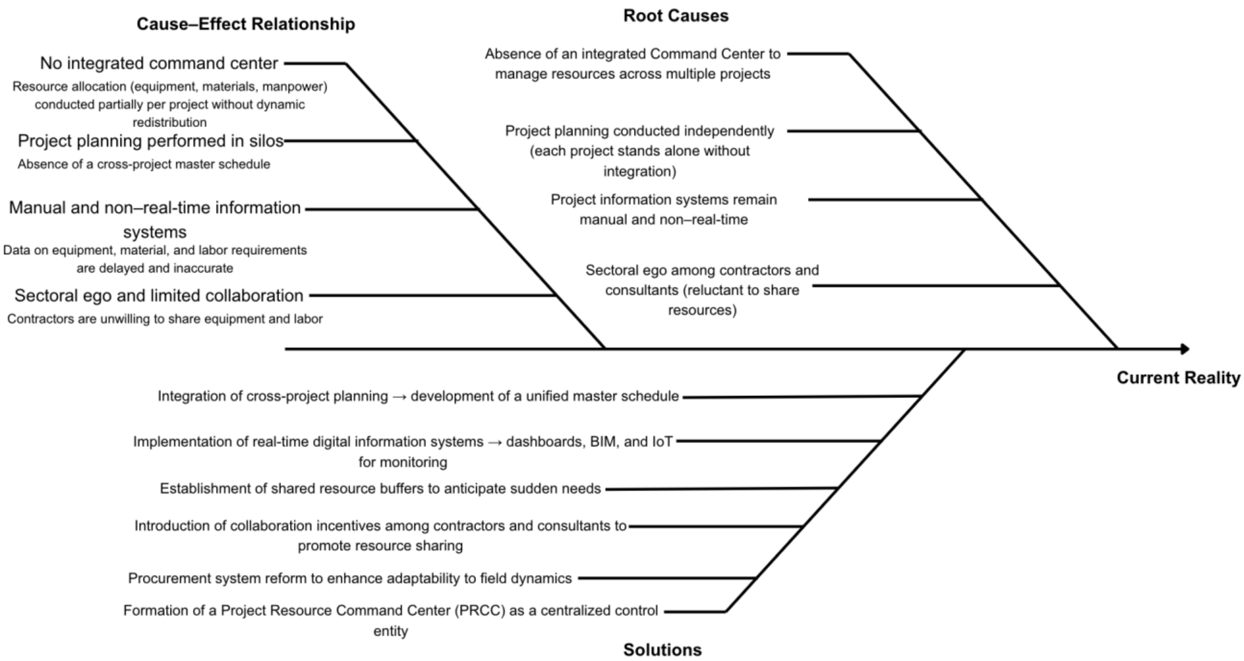

Figure 1. Current Reality Tree (CRT)

Table 3. Current Reality Tree Descriptions

Level	Element	Description / Cause–Effect Relationship	Final Impact
Root Cause	Absence of an integrated cross-project Command Center Silo-based interproject planning	Resource allocation conducted partially by each project → no dynamic redistribution Absence of a cross-project master schedule → unsynchronized timelines	Becomes the main constraint

Level	Element	Description / Cause–Effect Relationship	Final Impact
	Manual and non–real-time information systems	Data on equipment, materials, and labor requirements are delayed and inaccurate	
	Sectoral ego and lack of collaboration	Contractors are reluctant to share equipment and labor → focus only on individual project performance	
Intermediate Effects	Inefficient resource allocation	Idle time occurs in one project while others face shortages	
	Overlapping project schedules	Causes work bottlenecks in the field	
	Inaccurate field data	Material distribution is often delayed and mismatched with needs	
	Lack of coordination among contractors	Competition for resources and conflicts arise on site	
Undesirable Effects (UDE)	Increased idle time of equipment and labor	Leads to cost overruns and low productivity	
	Competition for labor and equipment among projects	Causes tension and delays	
	Untimely material distribution	Project completion is delayed	
	Overlapping work schedules	Field bottlenecks occur	
	Escalating project costs	Budget inefficiencies and waste	
Final Outcome	Delays in the completion of SPAM multi-projects in IKN	Project performance becomes inefficient; IKN development targets are postponed	
Solutions (Injections)	Establishment of a Project Resource Command Center (PRCC)	Integrates cross-project planning and resource allocation	

The Evaporating Cloud (EC) clarifies a structural conflict between local efficiency, defined as contractors' autonomy to maximize performance against unit-level KPIs, and global efficiency, defined as the owner's requirement for synchronized delivery across interdependent projects. This type of conflict is typical in multi-project environments where local optimization can reduce program-level throughput unless governance and incentives are aligned (Goldratt, 2001; Love et al., 2022). To break this conflict, the proposed injection is a digital-based Resource Control Center (RCC) supported by a unified multi-project master schedule, CCPM buffer management, and real-time reporting for feedback-driven resource redistribution. Digital dashboards and real-time monitoring have been shown to improve responsiveness and coordination quality in complex construction settings when paired with clear decision rules (Smith & Lee, 2024).

The Future Reality Tree (FRT) indicates that, once these injections are operational, UDEs can be converted into desirable effects such as reduced idle time, fewer schedule overlaps, improved material readiness, and lower cost variance through better flow and faster cross-project decision-making. These expected effects align with CCPM's goal of cycle-time reduction through buffer-based managerial focus and resource synchronization (Araszkiewicz, 2017; Ordoñez et al., 2019; Wang et al., 2024).

Table 4. Current Reality Tree (CRT) vs Future Reality Tree (FRT)

Level	Current Reality Tree (CRT) – Existing Condition	Future Reality Tree (FRT) – Condition After Solution Implementation
Core Problem / Injection	Absence of a cross-project command center → fragmented planning and resource allocation	Establishment of a Project Resource Command Center (PRCC) supported by real-time digital information systems
Intermediate Causes / Solutions	• Silo-based interproject planning (no master schedule) • Manual information systems, delayed data • Sectoral ego and limited collaboration	• Integration of cross-project planning through a unified master schedule • Real-time redistribution of equipment and workforce • Establishment of shared resource buffers • Provision of collaboration incentives among contractors
Undesirable Effects (UDE)	• Idle time of equipment and workforce • Competition for resources among projects • Untimely material distribution • Overlapping schedules and on-site bottlenecks • Increased costs due to inefficiencies • Extended project duration → delays in IKN targets	**Desirable Effects (DE):** • Significant reduction in idle time • Materials arrive on time and according to project needs • Elimination of resource competition conflicts • Synchronized project schedules and reduced bottlenecks • More efficient cost utilization • Project duration aligned with IKN development targets
Final Outcome	Multi-project performance is inefficient, costs escalate, and SPAM projects risk delay → impeding IKN development targets	Multi-project performance becomes efficient, costs remain controlled, resources are optimized, and SPAM projects are completed on schedule to support IKN development

Potential side effects of the intervention were evaluated through Negative Branch Reservation (NBR), including behavioral resistance, contractual rigidity, digital investment burden, and governance risks. Considering these side effects is consistent with TOC thinking processes to prevent new constraints and improve implementation realism (Goldratt, 2001).

Table 5. Negative Branch Reservation (NBR)

Negative Risk	Impact	Mitigation (Additional Injections)
Contractor resistance (loss of autonomy)	Rejection of PRCC implementation	Develop a Memorandum of Understanding (MoU), provide financial incentives, initiate voluntary pilot projects, and guarantee that technical decisions remain under local control
Legal or contractual restrictions on resource redistribution	Implementation delays	Revise contract clauses and adopt contractual addenda for newly initiated projects
High implementation cost of digital systems and PRCC	Budget overruns	Start with small-scale pilot projects, evaluate return on investment (ROI), and apply phased deployment
PRCC becomes a single point of failure	Creation of new bottlenecks	Design operational redundancy, prepare backup Standard Operating Procedures (SOPs), and establish an escalation matrix
Data privacy or ownership disputes	Lack of data sharing	Develop a data governance policy and implement role-based access control mechanisms

3.4 Improve: Feasible Intervention Package

The Improve phase translated the root causes identified in the Analyze stage into an implementable intervention package. Using the Prerequisite Tree (PRT), this study specifies the readiness conditions and key barriers for three integrated pillars: (1) establishing an RCC as a cross-project governance and resource orchestration unit, (2) CCPM-based multi-project scheduling and buffer management to protect the critical chain and reduce execution variability, and (3) a real-time digital information system to provide rapid execution feedback and enable dynamic resource redistribution. This sequencing is consistent with CCPM in multi-project environments, where governance structure and data visibility are prerequisites for disciplined buffer management and effective prioritization (Ordoñez et al., 2019; Santolini et al., 2020).

Table 6. Prerequisite Tree (PRT) Analysis

Improve (Enhancement)	Obstacle (Barrier)	Intermediate Objective (Prerequisite / Required Condition)
Establishment of a Resource Control Center (RCC) as a centralized unit for cross-project resource management	Resistance from contractors and consultants accustomed to working in silos	Formal regulation from the IKN Authority granting institutional legitimacy to the RCC; dissemination of RCC benefits through multi-project coordination forums
Integration of multi-project scheduling based on CCPM	Invalid baseline data and inconsistent formats across projects	Verification and standardization of baseline data; assignment of a Person in Charge (PIC) for each project to ensure data consistency
Implementation of real-time digital information systems	Limited human resource competence and potential system downtime	Intensive training and technical assistance for project staff; provision of manual backup systems for emergency situations

Optimization of shared resource utilization (equipment, materials, labor)	Lack of coordination mechanisms and insufficient incentives for resource sharing across projects	Development of Standard Operating Procedures (SOPs) for resource sharing; implementation of performance-based collective and regional efficiency incentives
Promotion of collaborative culture and shared accountability	Sectoral ego and weak collective responsibility among stakeholders	Establishment of cross-project communication forums; formulation of a shared vision and collective Key Performance Indicators (KPIs) mutually agreed upon

To align the intervention package with the broader environment and implementation feasibility, the study applied SWOT–TOWS. The SWOT results indicate that the program is supported by institutional momentum and professional capacity, but constrained by weak coordination and limited real-time practices. Digitalization opportunities and program-level policy alignment can be leveraged to overcome these internal weaknesses, while threats related to delay propagation and cost escalation require disciplined buffer monitoring and escalation rules. This strategic logic is consistent with prior multi-project governance findings emphasizing integration mechanisms and decision speed as determinants of performance (Love et al., 2022; Wang et al., 2023).

Based on the TOWS matrix, four strategic directions were formulated. SO strategies leverage institutional support and existing monitoring practices to integrate CCPM buffer management with digital dashboards, strengthening transparency across projects. WO strategies are prioritized as the most actionable pathway because they directly address internal weaknesses which are coordination gaps and resistance to change, by establishing a digital-based RCC, co-developing SOPs with contractors, and conducting regular training to build buffer-management discipline. ST strategies focus on using CCPM strengths to contain delay and cost threats via stricter buffer monitoring and rapid decision cycles. WT strategies reduce vulnerability by standardizing SOPs, strengthening escalation mechanisms, and improving digital readiness to minimize delays caused by manual information processing.

Table 7a. SWOT Analysis

Dimension	Key points in the SPAM IKN multi-project context
Strengths (S)	(S1) CCPM provides a proven logic for managing uncertainty and protecting critical chain flow. (S2) Strong institutional commitment and regulatory support to accelerate IKN delivery. (S3) Availability of professional resources in construction management and IT. (S4) Existing monitoring practices (e.g., S-curve and reporting routines) that can be upgraded for buffer/digital use.
Weaknesses (W)	(W1) Weak cross-project coordination; no formal RCC for integrated resource governance. (W2) Change resistance and sectoral ego among contractors/consultants. (W3) Limited on-site adoption of real-time digital monitoring and reporting. (W4) Lack of standardized SOPs for buffer management and cross-project resource allocation.

Dimension	Key points in the SPAM IKN multi-project context
Opportunities (O)	(O1) National strategic momentum enables multi-stakeholder collaboration and policy alignment. (O2) Digital tools (BIM, IoT, dashboards) can support real-time monitoring and execution feedback. (O3) Cross-project KPI integration can strengthen collaborative culture. (O4) Potential state funding support for SPAM infrastructure and digital transformation.
Threats (T)	(T1) Delay risk due to suboptimal resource distribution across projects. (T2) Stakeholder conflicts driven by competition over shared resources and sectoral ego. (T3) Cost overruns triggered by planning fragmentation and execution variability. (T4) Policy/bureaucratic changes may slow decision cycles and approvals.

Table 7b. TOWS Analysis

Strategy type	Strategic direction	Operational actions (aligned with the intervention package)
SO (S × O)	Leverage strengths to capture digitalization and institutional momentum	(SO1) Integrate CCPM buffer management with BIM/IoT-enabled dashboards for real-time visibility. (SO2) Upgrade existing monitoring (S-curve/reporting) into cross-project transparency tools and KPI dashboards. (SO3) Use institutional support to formalize RCC as the central unit for cross-project resource governance.
WO (W × O) ***(prioritized)***	Use opportunities to overcome coordination weaknesses and resistance	(WO1) Establish a **digital-based RCC** to address weak coordination and enable data-driven redistribution. (WO2) Co-develop SOPs for CCPM buffer rules and resource-sharing with contractors to reduce resistance and increase ownership. (WO3) Conduct routine training and technical assistance to close competency gaps in buffer discipline and digital reporting.
ST (S × T)	Use CCPM and governance strength to reduce delay/cost threats	(ST1) Apply CCPM scheduling discipline to reduce delay propagation in interdependent work packages. (ST2) Tighten buffer monitoring and escalation rules to contain cost variance and schedule slippage. (ST3) Mobilize expert CM/IT resources to improve responsiveness to policy and regulatory changes.
WT (W × T)	Minimize exposure by standardizing governance and readiness	(WT1) Standardize SOPs for cross-project allocation to prevent recurring resource conflicts. (WT2) Implement escalation mechanisms (SLA, decision rights, RCC cadence) to avoid unresolved issues disrupting execution.

	(WT3) Strengthen digital readiness (data standards, backup procedures) to reduce delays caused by manual processing.

The SWOT–TOWS assessment indicates that the SPAM multi-project program at IKN is supported by strong institutional momentum and a well-established CCPM logic for managing uncertainty. However, the program remains constrained by weak cross-project coordination, limited real-time visibility, and inconsistent governance practices. The TOWS matrix therefore prioritizes the WO strategy as the most actionable pathway because it converts external opportunities, especially digitalization and program-level policy support, into mechanisms that address internal weaknesses. In practical terms, WO translates into three immediate actions: establishing a digital-based Resource Control Center (RCC) to legitimize cross-project prioritization, co-developing standardized SOPs with contractors to reduce resistance and improve adoption, and strengthening competence through routine training and technical assistance to ensure disciplined buffer management and reliable reporting. SO strategies reinforce digital integration and transparency by leveraging existing strengths, whereas ST and WT strategies focus on risk containment through tighter buffer governance, standardized escalation rules, and stronger digital readiness to reduce delays caused by manual processing. Overall, the SWOT–TOWS results support RCC governance, CCPM buffer discipline, and real-time information as the core levers to improve efficiency and coordination in the SPAM multi-project environment.

3.5 Control: Sustaining the Gains

The Control phase translates the proposed improvements into a sustainability mechanism to prevent regression into silo-based practices. A Transition Tree (TT) was used to specify routine control actions, responsible governance mechanisms, and measurable indicators. Control is centered on three essentials: RCC decision cadence and authority, standardized CCPM buffer discipline, and reliable real-time reporting supported by data-quality assurance. These controls are reinforced by periodic multi-project audits, a shared KPI dashboard to align incentives, explicit escalation protocols, and annual evaluation reports to OIKN for institutional learning and accountability. The emphasis on disciplined monitoring and feedback is consistent with Six Sigma's Control logic and with CCPM buffer management practices that rely on execution feedback (Taghizadegan, 2006; Johari et al., 2024; Wang et al., 2024).

Table 8. Transition Tree (TT) Analysis

Control Step	Objective	Justification	Monitoring Indicator
1. Establish a Resource Control Center (RCC) monitoring unit	Ensure centralized coordination and resource allocation	Without a control mechanism, the RCC may lose legitimacy and effectiveness	Frequency of coordination meetings; percentage of resolved resource allocation conflicts
2. Define standard SOPs for CCPM buffer management	Maintain consistency in the application of the CCPM method	CCPM requires strict discipline in buffer management to ensure optimal results	Level of SOP compliance; deviation from buffer baseline

Control Step	Objective	Justification	Monitoring Indicator
3. Conduct regular monitoring of the digital information system	Ensure real-time data accuracy and functionality	The system may experience disruptions without periodic supervision	Percentage of system downtime; accuracy of field data reports
4. Provide regular refresher training for personnel	Maintain workforce competence with new technologies	Personnel may lose technical proficiency without continuous training	Total annual training hours; rate of input data errors
5. Conduct periodic multi-project audits (every 3–6 months)	Evaluate improvement effectiveness and implementation consistency	Audits serve as an objective tool to identify performance gaps	Number of audit findings; follow-up compliance rate
6. Develop a collective cross-project KPI dashboard	Enhance transparency and accountability of project outcomes	Shared KPIs promote collaboration and reduce sectoral ego	Cross-project KPI achievement; monthly performance reports
7. Establish a problem escalation mechanism	Accelerate issue resolution before significant impacts occur	Unresolved issues can disrupt overall project timelines	Number of cases resolved within SLA; average problem resolution time
8. Prepare an annual evaluation report for the IKN Authority	Provide an overview of improvement achievements and future recommendations	Strategic evaluation supports long-term planning and sustainability	Resource efficiency rate (% idle time); achievement of cost and schedule targets

The TT-based control framework ensures that improvements are sustained through routine governance, standardized execution discipline, and measurable performance monitoring. In a multi-stakeholder SPAM environment, this control design is essential to maintain coordination quality, preserve real-time visibility, and keep resource allocation decisions aligned with program-level objectives.

CONCLUSION

This study concludes that integrating Critical Chain Project Management (CCPM) with the Six Sigma DMAIC framework and TOC thinking processes provides a structured approach to diagnose and address resource inefficiency in the SPAM multi-project development at Ibu Kota Nusantara (IKN). The Define–Measure stages identified six recurring inefficiency themes based on coded evidence, dominated by planning and execution fragmentation (39%) and the absence of a unified cross-project command for resource allocation (26%). Together, these two issues accounted for 65% of observed inefficiency patterns and were associated with schedule overlap, resource competition, idle time, and delayed material readiness. The Analyze stage, using Fishbone and the Current Reality Tree (CRT), indicates that silo-based scheduling, non–real-time information flows, and weak cross-project governance amplify execution variability and hinder timely redistribution of shared resources. Based on the Improve stage outputs from EC, FRT, and PRT, this study proposes an intervention package consisting of establishing a digital-based

Resource Control Center (RCC), implementing CCPM multi-project master scheduling with buffer management, and deploying real-time digital dashboards to support feedback-driven decision-making. The Control stage, structured through a Transition Tree (TT), specifies sustainability mechanisms including standardized SOPs for buffer discipline, RCC coordination cadence, periodic multi-project audits, cross-project KPI dashboards, escalation protocols, and annual evaluation reports to the IKN Authority. The SWOT–TOWS assessment positions the WO strategy as the most actionable, using digitalization momentum and institutional support to overcome internal weaknesses in coordination, change resistance, and limited real-time visibility. Practical recommendations are as follows: (1) the IKN Authority should formally mandate the RCC, define decision rights, and standardize integrated digital reporting across SPAM work packages; (2) contractors and consultants should adopt shared cross-project KPIs and comply with buffer management SOPs to align local execution with program-level efficiency; (3) project managers should implement routine training and data-quality controls to ensure disciplined dashboard reporting and buffer monitoring; and (4) future studies should validate the proposed model through longitudinal implementation with before–after performance metrics (for example, idle time rate, buffer consumption trends, milestone adherence, and cost variance) and complementary simulation approaches to assess program-level impacts.

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