Data Integration of The Construction Work Package to Reduce Preparation Time

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Abstract. Technological advancements have driven the construction sector to adopt the latest methodologies to enhance work efficiency. Advanced Work Packaging (AWP) is a methodology for creating Work Packages that involves the construction phase during the early preparation stages. AWP is crucial in ensuring that planning and preparation proceed as expected by minimizing errors and delays. However, the creation of Work Packages often faces challenges, especially in terms of data integration involving multiple departments. This research aims to improve workflow efficiency and the utilization of automation technology in the data integration process using a Business Process Management (BPM) approach. The research methodology includes problem identification through interviews, modeling the current business processes (as-is), qualitative analysis using Process Activity Mapping (PAM) and Root Cause Analysis (RCA), and quantitative analysis using simulations. The business processes are then redesigned (to-be) using a heuristic approach, and simulations are conducted to monitor and measure their impact compared to the current business processes (as-is). The research results show that business process redesign can help reduce cycle time by approximately 496 days and reduce average costs by 13,242.76 USD over 30 process instances.

Keywords: Advanced Work Packaging, Work Package, construction, data integration, Business Process Management, redesign.

1 Introduction

Engineering, Procurement, Construction, and Installation (EPCI) companies provide comprehensive services in executing projects in the energy and infrastructure sectors. These projects are often complex and high-risk, such as the construction of offshore and onshore facilities. One crucial step to enhance operational efficiency and effectiveness is the adoption of the latest technologies, such as Advanced Work Packaging (AWP).

AWP is a methodology that organizes work into Work Packages involved in the construction phase during the early preparation stages. This allows teams to quickly identify and address obstacles, improve transparency and collaboration among teams, and minimize the risk of errors and delays.

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However, the implementation of AWP faces challenges, especially for companies with mature business processes. The traditional methods used by workers for data storage and processing become major obstacles in data integration. These practices can hinder communication and information flow, resulting in work duplication, errors in data transfer, and difficulties in obtaining real-time data.

The research methodology includes problem identification through interviews, modeling the current business processes (as-is), qualitative analysis using PAM, Waste Analysis, and RCA, and quantitative analysis using simulations. The business processes are then redesigned (to-be) with a heuristic approach, and simulations are conducted to monitor and measure their impact compared to the current business processes (as-is).

The novelty of this research lies in the application of the BPM approach to cross-departmental data integration in the construction industry. This research not only focuses on problem identification but also on providing solutions to address data integration challenges to reduce cycle time and costs.

2 Method

This research draws upon various literature related to Business Process Management (BPM), Business Process Model and Notation (BPMN), Interview-Based Discovery, Process Activity Mapping (PAM), Waste Analysis, Root Cause Analysis (RCA), business process simulations, and Heuristic Process Redesign. The following are the research stages explained using the flowchart shown in Figure 4.

2.1 Business Process Management (BPM)

According to Dumas et al. [1], Business Process Management (BPM) is the art and science of overseeing how work is performed in an organization to ensure consistent outcomes and to take advantage of improvement opportunities. According to Benedict et al. [2], Business process management (BPM) is both a management discipline and a set of technologies that support managing by process. According to Geiger & Lenhard [3], BPM is also a subject that is strongly tailored to the modeling of organizational processes and the subsequent implementation of process models in executable software. According to Pyon et al. [4], BPM has the following basic premises: process mapping and documentation activities, focus on the client, measurement activities for evaluating performance and continuous optimization of processes, use of best practices for improving competitive positioning and an approach for culture change in the organization. According to Dumas et al. [5], BPM is a continuous cycle comprising the following phases Figure 1.

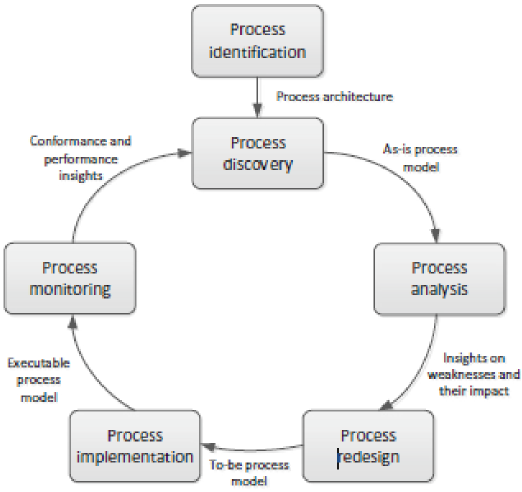


Fig. 1. BPM Lifecycle [5]

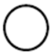
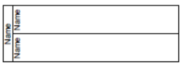
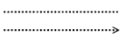
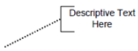
- Process identification. In this phase, a business problem is posed. Processes relevant to the problem being addressed are identified, delimited, and interrelated. The outcome of process identification is a new or updated process architecture, which provides an overall picture of the processes in an organization and their relationships. This architecture is then used to select which process or set thereof to manage through the remaining phases of the lifecycle. Typically, process identification is done in parallel with performance measure identification.
- Process discovery (also called as-is process modeling). Here, the current state of each of the relevant processes is documented, typically in the form of one or several as-is process models.
- Process analysis. In this phase, issues associated with the as-is process are identified, documented, and whenever possible quantified using performance measures. The output of this phase is a structured collection of issues. These issues are prioritized based on their potential impact and the estimated effort required to resolve them.
- Process redesign (also called process improvement). The goal of this phase is to identify changes to the process that would help to address the issues identified in the previous phase and allow the organization to meet its performance objectives. To this end, multiple change options are analyzed and compared in terms of the chosen performance measures.
- Process implementation. In this phase, the changes required to move from the as-is process to the to-be process are prepared and performed. Process implementation covers two aspects: organizational change management and automation. Organizational change management refers to the set of activities required to change the way of working of all participants involved in the process. Process automation refers to the development and deployment of IT systems (or enhanced versions of existing IT systems) that support the to-be process.

- Process monitoring. Once the redesigned process is running, relevant data are collected and analyzed to determine how well the process is performing concerning its performance measures and performance objectives. Bottlenecks, recurrent errors, or deviations concerning the intended behavior are identified and corrective actions are undertaken. New issues may then arise, in the same or other processes, which requires the cycle to be repeated continuously.

Business Process Model and Notation (BPMN)

According to Kahloun & Ghannouchi [6], BPMN is a graphical notation for defining BP through a Business Processes Diagram (BPD) and has become the standard de facto for representing BP. According to Aagesen & Krogstie [7], BPMN seeks to serve a broad audience in the business segment on the one hand, and on the other hand, it reaches out to the technical community. According to Object Management Group [8], The primary goal of BPMN is to provide a notation that is readily understandable by all business users, from the business analysts who create the initial drafts of the processes, to the technical developers responsible for implementing the technology that will perform those processes, and finally, to the businesspeople who will manage and monitor those processes. BPMN has the basic notation used in Table 1.

Table 1. Basic Modelling Elements

Element	Notation	Element	Notation
Event		Pool	
Activity		Lane	
Gateway		Data Object	
Sequence Flow		Message	
Message Flow		Group	
Association		Text Annotation	

- An event is a notation used for an occurrence within a process. Events can happen at the beginning, middle, or end.
- Activity is a notation used for an activity that occurs within a process.

- Gateway is a notation used to control the divergence and convergence of sequence flows within a process.
- Sequence Flow is a notation used to indicate the order in which activities will be performed in a process.
- Message Flow is a notation used to indicate the flow of messages between two participants, indicating who is ready to send and receive them.
- The association is a notation used to connect information and artifacts with BPMN graphical elements.
- A pool is a notation used to graphically represent a participant in a collaboration.
- Lane is a notation used as a sub-partition within a process, sometimes within a pool, and extends the entire length of the process.
- Data Object is a notation that provides information about what activities need to be performed and/or what is produced.
- Message is a notation used to describe the content of communication between two participants.
- Group is a notation used for grouping graphical elements that are in the same category.
- Text Annotation is a notation used to provide additional textual information.

2.2 Interview-Based Discovery

According to Dumas et al. [9], Interview-based discovery aims at interviewing domain experts to inquire about how a process is executed. Figure 2 illustrates the typical phases of the interview method.

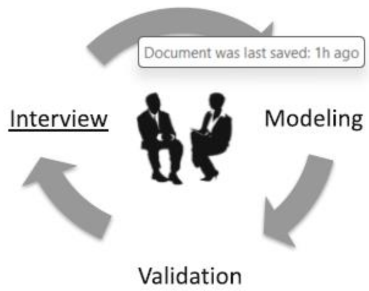


Fig. 2. Phases of the interview method [9]

- Use two strategies for conducting an interview starting from the process outcomes or starting from the triggers.
- Construct a process model offline based on our interview notes or recordings.
- Validate it with the domain experts to make sure that it correctly reflects their view.

2.3 Process Activity Mapping (PAM)

Process Activity Mapping (PAM) is a method used to describe business processes by detailing every activity that occurs throughout the process. The implementation of PAM is expected to identify the percentage of value-added and non-value-added activities. According to Eakin & Gladstone [10], The notion of "value-adding" is borrowed from economics where it refers to the increased worth or value of a product created during stages of the production process. PAM can also be used to simplify a business process by eliminating and combining activities, thereby increasing efficiency and reducing waste. According to Mulyana et al. [11], The prioritization of waste that must be reduced becomes the starting point for the improvement plan. According to Hines & Rich [12], There are five stages in this general approach:

- The study of the flow of processes.
- The identification of waste.
- A consideration of whether the process can be rearranged in a more efficient sequence.
- A consideration of a better flow pattern, involving different flow layouts or transport routing.
- A consideration of whether everything that is being done at each stage is really necessary and what would happen if superfluous tasks were removed.

The completed matrix Table 2 can then be used as the basis for further analysis and subsequent improvement.

Table 2. PAM matrix [12]

#	STEP	FLOW	MACHINE	DIST (M)	TIME (MIN)	PEOPLE	OPERATION	TRANSPORT	INSPECT	STORE	DELAY	COMMENTS
1	RAW MATERIAL	S	RESERVOIR				O	T	I	S	D	RESERVOIR/ ADDITIVES
2	KITTING	O	WAREHOUSE	10	5	1	O	T	I	S	D	
3	DELIVERY TO LIFT	T		120		1	O	T	I	S	D	
4	OFFLOAD FROM LIFT	T			0.5	1/2	O	T	I	S	D	
5	WAIT FOR MIX	D	MIX AREA		20		O	T	I	S	D	
6	PUT IN CRADLE	T		20	2	1/2	O	T	I	S	D	
7	PIERCE/POUR	O	MIX AREA 12		0.5	1	O	T	I	S	D	
8	MIX (BLOWERS)	O			20	1/2	O	T	I	S	D	BASE MATERIAL, BLOW & ADDITIVES
9	TEST #1	I			30	1+1	O	T	I	S	D	SAMPLE/TEST
10	PUMP TO STORAGE TANK	T	STORE TANK	100		1	O	T	I	S	D	DEDICATED RESERVOIR
11	MIX IN STORAGE TANK	O	STORE TANK		10	1	O	T	I	S	D	
12	I.R. REST	I			10	1+1	O	T	I	S	D	STAMP & APPROVE
13	AWAIT FILLING	D			15		O	T	I	S	D	LONGER IF SCREEN LATE
14	TO FILLER HEAD	T		20	0.1	1	O	T	I	S	D	
15	FILL/TOP/TIGHTEN	O	FILLER HEAD		1	1+1	O	T	I	S	D	1 UNIT
16	STACK	T	PALLET	3	0.1	1	O	T	I	S	D	1 UNIT
17	DELAY TO FILL 1 PALLET	D			30		O	T	I	S	D	
18	STRAP PALLET	O			2	1	O	T	I	S	D	
19	TRANSFER TO STORE	T		80	2	1	O	T	I	S	D	
20	AWAIT TRUCK	D	STORE		540		O	T	I	S	D	BATCH 360/ QUEUE 180
21	PICK/MOVE BY FORK LIFT	T		90	3	1	O	T	I	S	D	FORK LIFT
22	WAIT TO FILL FULL LOAD	D	LORRY		30	1+1	O	T	I	S	D	1 OPERATOR, 1 HAULIER
23	AWAIT SHIPMENT	D	LORRY		60	1	O	T	I	S	D	1 HAULIER
	TOTAL		23 STEPS	443	781.2	25	6	8	2	1	6	
	OPERATORS				38.5	8						
	% VALUE ADDING				4.93%	32%						

- Step: A brief description of the activity being performed.
- Flow: The type of activity being carried out. These include Operation (O), Transportation (T), Inspection (I), Storage (S), and Delay (D).
- Machine: The equipment required during the activity.
- Distance: The distance traveled during the activity.
- Time: The time required for the execution process. Units can be in minutes, hours, days, weeks, or months, depending on the issue being studied.
- People: The number of personnel involved in the activity.
- Comments: Notes that can be added to clarify the description of the activity.

2.4 Waste Analysis

According to Dumas et al. [13], Waste analysis can be seen as the reverse of value-added analysis. This method helps improve process efficiency by focusing on waste reduction. In business processes, there are 7 types of waste, which can be categorized into 3 types:

- Move: Waste related to movement or relocation. The types of waste categorized as moves are transportation and motion.
- Hold: Waste related to the retention or holding of an activity. The types of waste categorized as hold are inventory and waiting.
- Overdo: Waste related to excessive activities. The types of waste categorized as overdo are defect, overprocessing, and overproduction.

2.5 Root Cause Analysis (RCA)

According to Dumas et al. [14], Root cause analysis is a family of techniques that helps analysts identify and understand the root cause of issues or undesirable events. According to Rooney & Heuvel [15], Root Cause Analysis helps in developing effective recommendations. Root Cause Analysis is typically used in the context of accident or incident analysis and in manufacturing processes where this analysis is employed to understand the root causes of defects in a product. Figure 3 is the template of a cause-effect diagram.

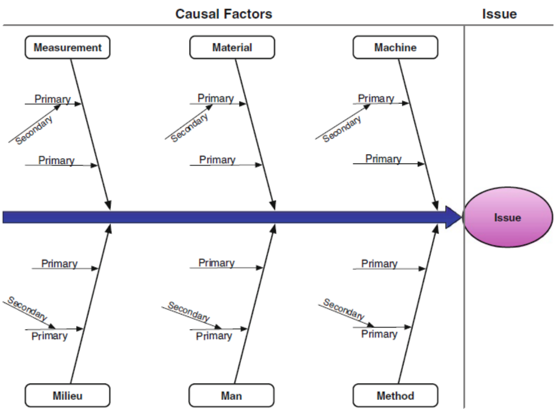


Fig. 3. Template of a cause-effect diagram based on the 6 M's [14]

- Machine (technology) - factors about the technology used, like for example software failures, hardware failures, network failures, or system crashes that may occur in the information systems that support a business process.
- Method (process) - factors stemming from the way the process is defined or understood or in the way it is performed.
- Material - factors stemming from the raw materials, consumables, or data required as input by the tasks in the process, like for example incorrect data leading to a wrong decision being made during the execution of the process.
- Man - factors related to a wrong assessment or an incorrectly performed step, like for example, a claims handler accepting a claim even though the data in the claim and the rules used for assessing the claim require that the claim be rejected.
- Measurement - factors related to measurements or calculations made during the process.
- Milieu - factors stemming from the environment in which the process is executed, like for example factors originating from the customer, suppliers, or other external actors.

2.6 Simulation

According to Dumas et al. [15], Process simulation is arguably the most popular and widely supported technique for quantitative analysis of process models. The essential idea underpinning process simulation is to use the process simulator for generating a large number of hypothetical instances of a process, executing these instances step-by-step, and recording each step in this execution. The following information needs to be specified for each task in the process model to simulate it:

- The probability distribution for the processing time of each task such as fixed, exponential distribution, normal distribution, etc.

- Other performance attributes for the task such as cost and added value produced by the task.
- The resource pool that is responsible for performing the task.
- The mean inter-arrival time and its associated probability distribution.
- The starting date and time of the simulation.
- The end date and time of the simulation.
- The real-time duration of the simulation.
- The required number of process instances to be simulated.

2.7 Heuristic Process Redesign

According to Dumas et al. [16], Redesign heuristics can be seen as rules of thumb for deriving a different process from an existing one. The redesign heuristics are important to the Design stage. The selection of redesign heuristics is in Table 3.

Table 3. A selection of redesign heuristics [16]

Time	Cost	Quality	Flexibility
Parallellism Case-based work	Activity elimination Empower	Empower Triage	Flexible assignment Centralization

- Parallelism: “Put activities in parallel”. Activities in a business process are often ordered in a strictly sequential way even though there is no good reason for doing so. Some activities may well be carried out in an arbitrary order or even simultaneously.
- Case-based work: “Remove batch-processing and periodic activities”. Getting rid of such constraints is in general a good way to significantly speed up a process.
- Activity elimination: “Eliminate unnecessary activities”. Over time, processes get clogged up with activities that were useful at some point but have lost their purpose or rationale. Getting rid of unnecessary activities is an effective way to reduce the cost of handling a case.
- Empower: “Give workers decision-making authority”. In traditional settings, If workers are empowered to make decisions autonomously, this may render much of the work of middle managers superfluous, in this way reducing cost significantly.
- Triage: “Split an activity into alternative versions”. By creating alternative versions of an activity, it is possible to better deal with the variety of cases that need to be processed.
- Case assignment: “Let participants perform as many steps as possible”. If someone carries out an activity, then that person becomes acquainted at some level with the case for which the work is done.
- Flexible assignment: “Keep generic participants free for as long as possible”. Suppose that an activity can be executed by either of two available participants, then it should be assigned to the most specialized person.

- 8. Centralization: "Let geographically dispersed resources act as if they are centralized". This heuristic is explicitly aimed at exploiting the benefits of a Business Process Management System (BPMS).

2.8 Research Flowchart

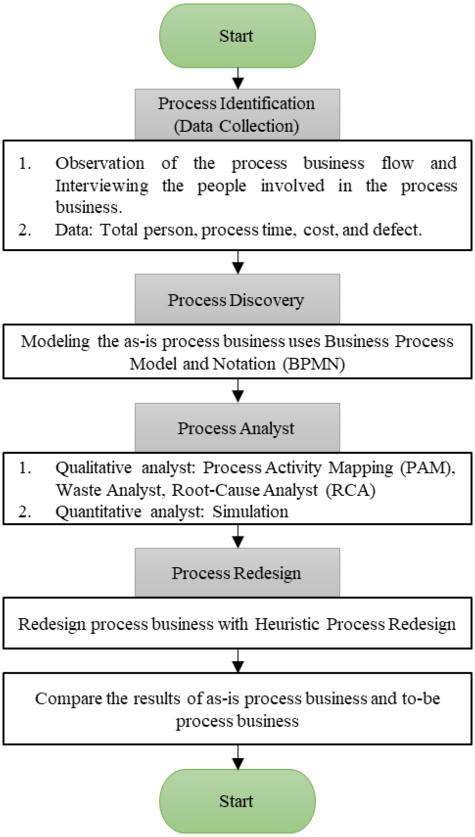


Fig. 4. Research Flowchart

3 Result and Discussion

3.1 Observations on existing conditions

The results of interviews with parties involved in the business process revealed that there are 6 departments directly involved in the data integration process, and each department has its specific duties and responsibilities. Figure 5 shows the flow used in data integration.

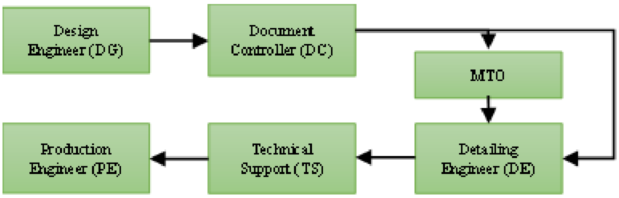


Fig. 5. The Flow of Data Integration

- The Design Engineer (DG) is responsible for developing drawings based on specifications from the client.
- The Document Controller (DC) is responsible for receiving, checking, and validating the drawing before inputting it into EDMS, and distributing the drawing in both softcopy and hardcopy format.
- Material Take Off (MTO) is responsible for details of the information from the drawing such as material identification, material location, etc.
- Detailing Engineer (DE) responsible for developing the 3D Model.
- Technical Support (TS) is responsible for publishing the 3D Model into Work Packaging Software.
- The Production Engineer (PE) is responsible for creating the Work Package.

The process that starts from receiving specifications from the client to the creation of the Work Package has varying durations. Table 4 provides information on the time required for the data integration process.

Table 4. The Times of Data Integration

#	Department	Description	Time (Min)	Source
1	Design Engineer (DG)	Receive the client's specifications	1	Interview
2		Design the drawing	180	Interview
3		Submit the drawing	1	Interview
4		Receiving a request to revise the drawing	1	Interview
5		Revising the drawing	30	Interview
6		Receive the drawing	1	Interview

7	Document Controller (DC)	Check and validate the drawing	2	Interview
8		Register the drawing in EDMS	2	Interview
9		Distribute the drawing (Softcopy)	1	Interview
10		Print the drawing	1	Interview
11		Distribute the drawing (Hardcopy)	10	Observation and Interview
12		Request to revise the drawing	1	Interview
13	MTO	Receive the drawing (Softcopy)	1	Interview
14		Receive the drawing (Hardcopy)	1	Interview
15		Identifying component attributes from the drawing	360	Interview
16		Waiting for the MTO Report distribution schedule	10080	Observation and Interview
17		Distribute the MTO Report	1	Interview
18	Detailing Engineer (DE)	Receive the drawing (Softcopy)	1	Interview
19		Receive the drawing (Hardcopy)	1	Interview
20		Receive the MTO Report	1	Interview
21		Create the 3D Model	5760	Interview
22		Add the additional information from the MTO Report to the 3D Model	2880	Interview
23		Export the 3D Model	120	Observation
24		Receiving a request to check and validate the IFC Analyzer result	1	Observation
25		Check and validate the 3D Model	60	Interview
26		Revising the 3D Model	240	Interview
27		Give a confirmation	1	Observation
28		Receiving a request to revise the 3D Model	1	Interview
29	Technical Support (TS)	Receive the 3D Model	1	Observation
30		Run the IFC Analyzer	120	Observation
31		Publish the 3D Model	720	Observation
32		Request to check and validate the IFC Analyzer result	1	Observation
33		Receive a confirmation	1	Observation
34	Production Engineer (PE)	Check the data availability	120	Interview
35		Create the Work Package	3	Interview
36		Request to revise the 3D Model	1	Interview

The business process involves resources that execute each of its stages. Each resource utilized has a value that becomes a cost incurred by the company. Table 5 provides information on the costs required in the data integration process.

Table 5. The Costs of Data Integration

#	Department	Task	Class	Cost (USD / Day)
1	Design Engineer (DG)	Create design drawings (Drafter)	Clerk	17.9
		Check drawing (Checker)	Eng.	91.6

		Approve drawing (Approver)	Mgr.	190.8
2	Document Controller (DC)	Receive drawings and register in EDMS (Officer)	Clerk	17.9
		Print and distribute drawing (Officer)	Clerk	17.9
3	MTO	Identifying component attributes (Drafter)	Clerk	17.9
		Check detailed drawings (Checker)	Assoc. Eng	64.5
		Approve detailed drawings (Approver)	Eng	91.6
4	Detailing Engineer (DE)	Create 3D Model (Drafter)	Clerk	17.9
		Check 3D Model (Checker)	Assoc. Eng	64.5
		Approve 3D Model (Approver)	Eng	91.6
		Export 3D Model (TEKLA Administrator)	Clerk	17.9
5	Technical Support (TS)	Check and publish 3D Model (Work Packaging Admin)	Clerk	17.9
6	Production Engineer (PE)	Create Work Package	Engineer	91.6

Based on the information collected in Figure 5, Table 4, and Table 5, modeling is then carried out using BPMN to visualize how the business process operates. Figure 6 shows the BPMN notation of data integration, representing the current business process (as-is).

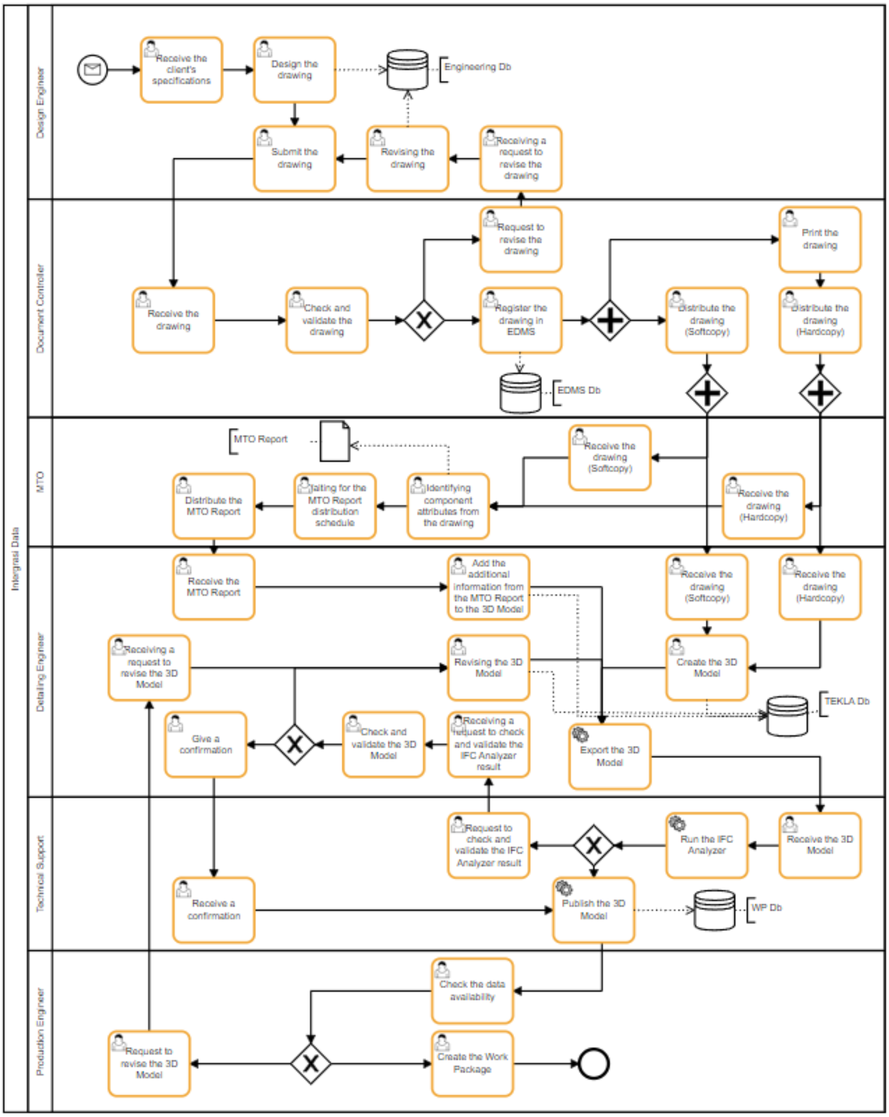


Fig. 6. BPMN of Data Integration (as-is)

Process Activity Mapping (PAM) helps in identifying data integration processes by categorizing activities and classifying them based on value-added (value-added). The data integration process is categorized into operation (O), transportation (T), inspection (I), storage (S), and delay (D). The activity categories are divided into three types: value-added activity (VA), non-value-added activity (NVA), and non-value-added but necessary activity (NNVA). Table 6 shows the Process Activity Mapping (PAM) of data integration.

Table 6. Process Activity Mapping (PAM) of Data Integration

#	Cate-gory	Machine	Dist. (M)	Time (Min)	Peo-ple	Activity O	Activity T	Activity I	Activity S	Activity D	Value
1	O	Computer	0	1	3	O					VA
2	O		0	180		O					VA
3	O		0	1		O					VA
4	D		0	1						D	NNVA
5	O		0	30		O					NNVA
6	O	Computer	0	1	2	O					VA
7	I		0	2				I			VA
8	O		0	2		O					VA
9	O		0	1		O					VA
10	O	Printer	0	1		O					NVA
11	T	Motorcycle	100 - 500	10			T				NVA
12	D	Computer	0	1						D	NNVA
13	O	Computer	0	1	3	O					VA
14	O		0	1		O					NVA
15	O		0	360		O					VA
16	D	-	0	10080						D	NVA
17	O	Computer	0	1		O					NVA
18	O	Computer	0	1	4	O					VA
19	O		0	1		O					NVA
20	O		0	1		O					NVA
21	O		0	5760		O					VA
22	O		0	2880		O					VA
23	O		0	120		O					VA
24	O		0	1		O					NNVA
25	I		0	60				I			NNVA
26	O		0	240		O					NNVA
27	O		0	1		O					NNVA
28	O		0	1		O					NNVA
29	O	Computer	0	1	1	O					VA
30	I		0	120				I			NNVA
31	O		0	720		O					VA
32	D		0	1						D	NNVA
33	O		0	1		O					NNVA
34	I	Computer	0	120	1			I			NNVA
35	O		0	3		O					VA
36	D		0	1						D	NNVA

Based on the information in Table 5, the Process Activity Mapping (PAM) for the data integration process identifies 36 activities within the business workflow. These activities are categorized as follows: 26 are operational (O), 1 is transportation (T), 4 are inspection (I), and 5 are delays (D). Regarding the value, 16 activities are value-added (VA), 7 are non-value-added (NVA), and 13 are non-value-added but necessary (NNVA). The total distance covered for distributing hardcopy drawings ranges from 100 to 500 meters. The overall time required to complete all these activities is 20,707 minutes. Table 7 provides a detailed identification of various types of waste occurring within the data integration process.

Table 7. Identification of Waste

#	Category / Type	Description	Source
W1	Move / Transportation	Distribution of drawings (Hardcopy)	Interview
W2	Hold / Waiting	Waiting for the revised drawings	Observation and interview
W3		Waiting for the distribution of the MTO Report	Observation and interview
W4		Waiting for 3D Model Extraction	Observation
W5		Waiting for the result of the IFC Analyzer	Observation
W6		Waiting for 3D Model publishing	Observation
W7		Waiting for confirmation	Observation
W8	Overdo / Defect	Revise the drawing	Interview
W9		Revise the 3D Model	Observation and interview
W10	Overdo / Overprocessing	Print the drawing	Interview

Based on the identification of waste in Table 6, there are 10 activities categorized as waste within the business process. These activities encompass various types such as Move (Transportation), Hold (Waiting), and Overdo (Defect and Overprocessing). In the Move category, there is one activity: distributing drawings in hardcopy form (from DC to MTO/DE). The Hold category includes six activities: waiting for drawing corrections (from DC to DG), waiting for MTO Report distribution (from MTO to DE), waiting for the 3D Model extraction process (from DE to TS), waiting for IFC Analyzer results (within TS), waiting for the 3D Model publication process (from TS to PE), and waiting for confirmation of IFC Analyzer results (from TS to DE). The Overdo category consists of two activities: correcting drawings (from DG to DC) and correcting the 3D Model (from TS/PE to DE). The Overprocessing category includes one activity: print the drawing (from DC to MTO/DE). These findings were obtained through interviews and observations. Table 8 provides the root cause of waste.

Table 8. Root Cause of Waste

#	Factor	Root Cause of Waste
W1	Machine	Insufficient vehicles for drawing distribution
	Method	Inadequate knowledge in scheduling distributions
	Man	Insufficient personnel for distribution processes, Poor coordination between teams during distribution
W2	Method	Design Engineers' inaccuracies in drawing designs, Absence of a review and feedback system for early issue identification and resolution
W3	Method	Precision-required manual tasks, MTO Report distributed only once a week
	Man	Lack of detailed information provided by assigned personnel
W4	Machine	Only one computer is available, and Unreliable computer specifications
	Method	Manual extraction process, Unable to perform extraction on multiple models simultaneously
	Material	Large capacity of 3D Models
	Man	Only one administrator is available.
W5	Machine	Unreliable computer specifications
	Method	Comprehensive examinations by IFC Analyzer on the 3D Model, a Very slow process
	Material	Large 3D Model capacity, the process is very slow.
W6	Machine	Unreliable computer specifications, the process is very slow
	Method	Limited access to the publication machine, Inability of the publication machine to multitask
	Material	Large capacity of 3D Models
W7	Method	Poor communication regarding changes to the 3D Model
	Man	Limited access to conducting examinations
W8	Method	Inaccurate design drawings, Hasty dispatch of drawings, and Change requests from the site office
	Man	Insufficient personnel for examination processes
W9	Material	Delayed information from the MTO section, Attribute mismatches in the 3D Model, Poor IFC Analyzer analysis
	Man	Inaccurate 3D Model creation, Poor communication between DE and PE
W10	Method	Activity is outdated in the digital era, with No updates to existing procedures.

The analysis reveals key inefficiencies in business processes. Transportation delays result from a lack of vehicles, poor scheduling, and insufficient, uncoordinated personnel. Waiting issues stem from design inaccuracies, no review system, manual tasks, infrequent reports, and incomplete information. Limited, unreliable computer resources and manual extraction processes slow progress, large 3D models require more computational power, and having only one administrator creates bottlenecks, better resource allocation, improved scheduling, enhanced communication, and updated procedures are needed to streamline processes and reduce waste.

The simulation was conducted by repeating the process 30 times (process instances). Table 9 provides a KPI obtained from the business process (as-is) simulation.

Table 9. KPI Business Process (as-is)

KPI	Min	Average	Max
Process Cycle Time (s)	30,939,187.59	55,617,674.28	63,433,239.39
Cost	12,795.57	16,816.63	24,956.07

Based on the data in Table 9, the minimum Process Cycle Time is 30,939,187.59 seconds (approximately 358 days). The average time is 55,617,674.28 seconds (approximately 643 days), while the maximum time is 63,433,239.39 seconds (approximately 734 days). The costs associated with the process vary significantly, with a minimum of 12,795.57 USD, an average of 16,816.63 USD, and a maximum of 24,956.07 USD.

Besides the KPI, there are 4 categories of BPMN heat map converted to score. These categories are waiting time, cost, count, and duration. Table 10 is the score Conversion of the BPMN Heat Map.

Table 10. Score Conversion of the BPMN Heat Map

Color	Hex Code	Score
	#FF0000	10
	#FF3333	9
	#FF6666	8
	#FF9966	7
	#FFCC66	6
	#FFCC99	5
	#FFFF66	4
	#FFFF99	3
	#66FF99	2
	#99FF66	1

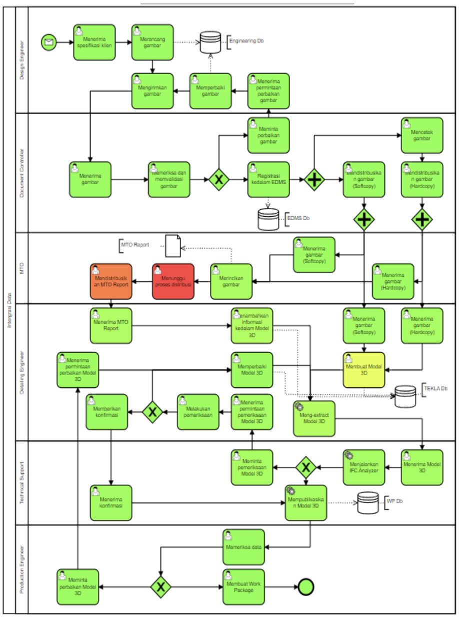


Fig. 7. Heat map waiting time (as-is)

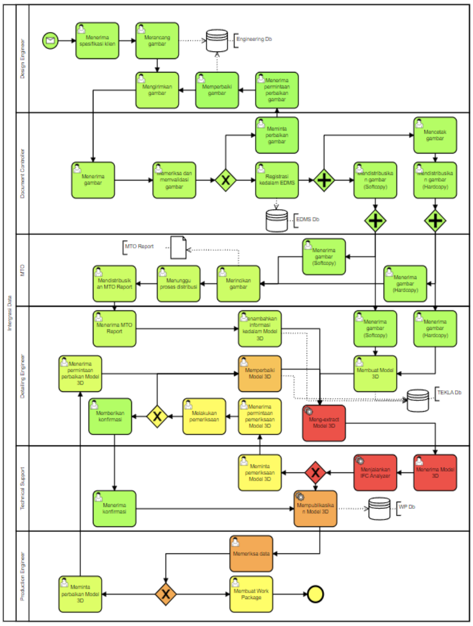


Fig. 8. BPMN Heat map Count (as-is)

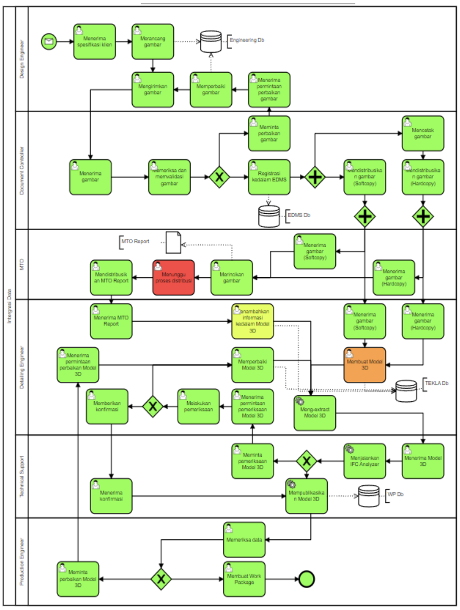


Fig. 9. BPMN Heat map Cost (as-is)

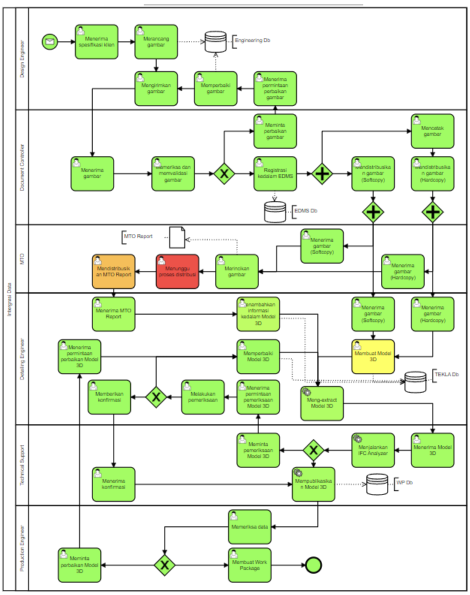


Fig. 10. BPMN Heat map Duration (as-is)

Figure. 7, Figure. 9, and Figure. 10 provides information on which activities have the longest waiting times, biggest costs, and longest durations in the data integration process. The first rank is waiting for the MTO Report distribution schedule. Figure. 8 provides information on which activities have many counts in the data integration process. The first rank is Export the 3D Model, Receive the 3D Model, and Run the IFC Analyzer. The results from the BPMN heat map were converted into scores to determine which activities are more dominant than others. Table 11 is the BPMN heat map conversion table.

Table 11. the BPMN heat map conversion table.

#	Description	BPMN Heat map (Score)				Total Score	%
		Waiting Times	Counts	Costs	Duration		
1	Receive the client's specifications	2	3	2	2	9	2.18%
2	Design the drawing	2	3	2	2	9	2.18%
3	Submit the drawing	2	3	2	2	9	2.18%
4	Receiving a request to revise the drawing	2	2	2	2	8	1.94%
5	Revising the drawing	2	2	2	2	8	1.94%
6	Receive the drawing	2	3	2	2	9	2.18%
7	Check and validate the drawing	2	3	2	2	9	2.18%
8	Register the drawing in EDMS	2	2	2	2	8	1.94%
9	Distribute the drawing (Softcopy)	2	2	2	2	8	1.94%
10	Print the drawing	2	2	2	2	8	1.94%
11	Distribute the drawing (Hardcopy)	2	2	2	2	8	1.94%
12	Request to revise the drawing	2	2	2	2	8	1.94%
13	Receive the drawing (Softcopy)	2	2	2	2	8	1.94%
14	Receive the drawing (Hardcopy)	2	2	2	2	8	1.94%
15	Identifying component attributes from the drawing	3	3	3	3	12	2.91%
16	Waiting for the MTO Report distribution schedule	10	3	10	10	33	7.99%
17	Distribute the MTO Report	8	3	2	7	20	4.84%
18	Receive the drawing (Softcopy)	2	2	2	2	8	1.94%
19	Receive the drawing (Hardcopy)	2	2	2	2	8	1.94%
20	Receive the MTO Report	2	3	2	3	10	2.42%
21	Create the 3D Model	4	3	7	5	19	4.60%
22	Add the additional information from the MTO Report to the 3D Model	3	3	4	3	13	3.15%
23	Export the 3D Model	3	10	2	3	18	4.36%

24	Receiving a request to check and validate the IFC Analyzer result	2	5	2	2	11	2.66%
25	Check and validate the 3D Model	2	5	2	2	11	2.66%
26	Revising the 3D Model	2	7	2	2	13	3.15%
27	Give a confirmation	2	2	2	2	8	1.94%
28	Receiving a request to revise the 3D Model	2	3	2	2	9	2.18%
29	Receive the 3D Model	3	10	2	3	18	4.36%
30	Run the IFC Analyzer	2	10	2	2	16	3.87%
31	Publish the 3D Model	3	8	2	3	16	3.87%
32	Request to check and validate the IFC Analyzer result	3	5	2	2	12	2.91%
33	Receive a confirmation	2	2	2	2	8	1.94%
34	Check the data availability	2	7	2	2	13	3.15%
35	Create the Work Package	2	5	2	2	11	2.66%
36	Request to revise the 3D Model	2	3	2	2	9	2.18%

Table 11 provides the converted scores. Based on these scores, the activity "Waiting for the MTO Report distribution schedule" has the highest score of 33 (7.99%). "Distribute the MTO Report" has a score of 20 (4.84%), and "Create the 3D Model" has a score of 19 (4.60%). Both "Export the 3D Model" and "Receive the 3D Model" have scores of 18 (4.36%). "Run the IFC Analyzer" and "Publish the 3D Model" each have a score of 16 (3.87%). The activities "Add the additional information from the MTO Report to the 3D Model," "Revising the 3D Model," and "Check the data availability" each have scores of 13 (3.15%). "Identifying component attributes from the drawing" and "Request to check and validate the IFC Analyzer result" each have scores of 12 (2.91%). Other activities have scores of 11 (2.66%), 10 (2.42%), 9 (2.18%), and 8 (1.94%).

3.2 Improvement Recommendations

Based on the qualitative and quantitative analysis conducted, the types of waste and root causes for each activity have been identified. The next step is improving the business process using a heuristic approach. Table 12 shows the results of the discussion on the heuristics to be used in redesigning the business process.

Table 12. Heuristic Process Redesign

#	Category / Type	Total Score	%	Notes	Heuristic	Action Item
W1	Move / Transportation	8	1.94%		Activity elimination	Revise DC procedures in the drawing distribution process.

W2		8	1.94%	Manual activity. Potential errors always occur.		
W3	Hold / Waiting	33	7.99%	This activity may result in errors in the modeling process and impact the published 3D Model.	Activity elimination	Utilize SharePoint for real-time data access.
W4	Hold / Waiting	18	4.36%	Extracting the 3D Model from TEKLA cannot be eliminated as it is a value-added activity.	Parallelism	Separate the 3D Model into several parts based on levels.
W5	Hold / Waiting	16	3.87%	Access can be given to DE to view IFC Analyzer results directly without TS having to request formally.	Flexible assignment	Delegate tasks to DE.
W6	Hold / Waiting	16	3.87%	Publishing the 3D Model cannot be eliminated as it is a value-added activity.	Parallelism	Receive the 3D Model in several parts to speed up the publication process.
W7	Hold / Waiting	12	2.91%	Since only DE can review data, tasks can be transferred from TS to DE.	Activity elimination	Delegate tasks to DE.
W8	Overdo / Defect	8	1.94%	Manual activity. Potential errors always occur. Especially for changes requested by the site office.		
W9	Overdo / Defect	13	3.15%	Manual activity. Potential errors always occur.		
W10	Overdo / Overprocessing	8	1.94%	In the digital era, printing and distributing drawings are no longer relevant. Process participants (DE and MTO) can use softcopies to continue their work.	Activity elimination	Revise DC procedures in the drawing distribution process.

Based on Table 12, there are 4 wastes addressed by Activity elimination. Distribution of drawings (Hardcopy) and print the drawing both have a score of 8, or 1.94%. Waiting for the distribution of the MTO Report has a score of 33, or 7.99%, and waiting for confirmation has a score of 12, or 2.91%. One waste, addressed by the Flexible assignment, is Waiting for the result of the IFC Analyzer with a score of 16, or 3.87%. Two wastes addressed by Parallelism are Waiting for 3D Model Extraction with a score of 18, or 4.36%, and waiting for 3D Model publishing with a score of 16, or 3.87%. The remaining three wastes Waiting for the revised drawings, Revise the drawing, and revise the 3D Model are considered normal business activities and do not require improvement. Figure 11 is the BPMN of Data Integration (to-be).

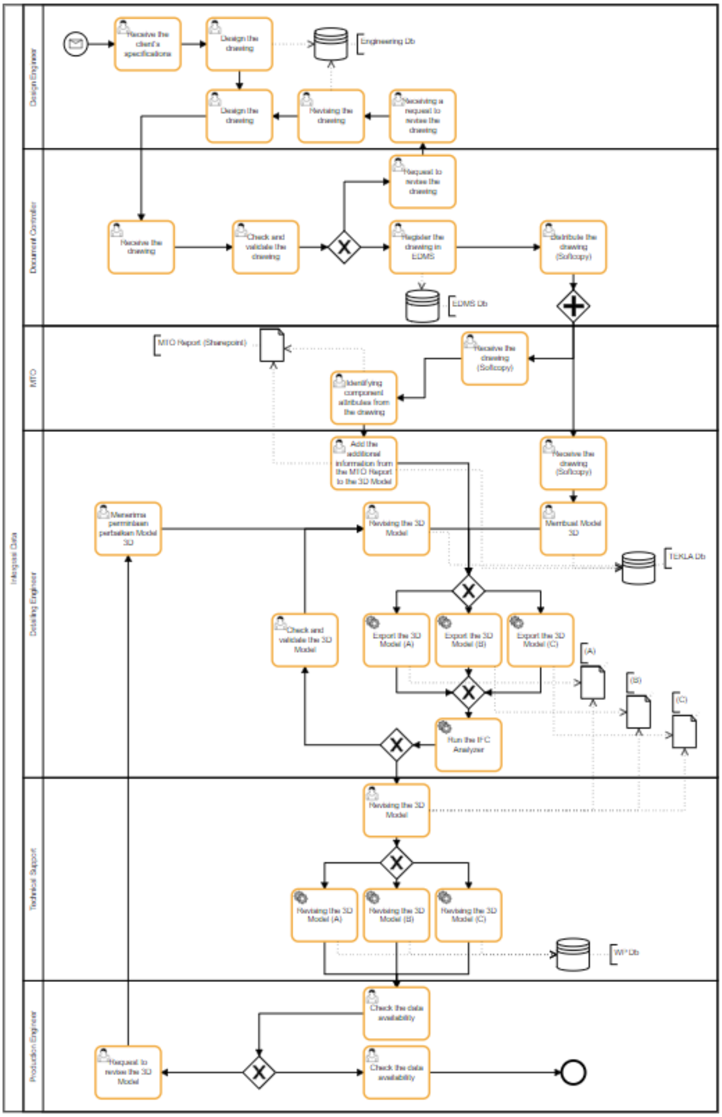


Fig. 11. BPMN of Data Integration (to-be)

The simulation was conducted by repeating the process 30 times (process instances). Table 13 provides a KPI obtained from the business process (to-be) simulation.

Table 13. KPI Business Process (to be)

KPI	Min	Average	Max
Process Cycle Time (s)	11,503,714.31	12,679,941.09	13,508,186.90
Cost	1,487.96	3,573.87	7,412.85

Based on the data in Table 13, the minimum Process Cycle Time is 11,503,714.31 seconds (approximately 133 days). The average time is 12,679,941.09 seconds (approximately 146 days), while the maximum time is 13,508,186.90 seconds (approximately 156 days). The costs associated with the process vary significantly, with a minimum of 1,487.96 USD, an average of 3,573.87 USD, and a maximum of 7,412.85 USD.

3.3 Comparison of Existing and Improved Conditions

Based on the analysis, Key Performance Indicators (KPIs) for the as-is and to-be business processes were compared to evaluate the improvements. Figure 12 shows the comparison of cycle times obtained from the simulation.

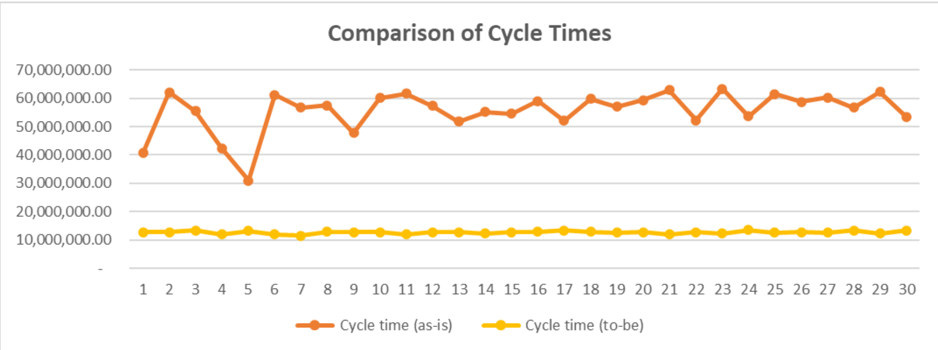


Fig. 12. Comparison of Cycle Times

Figure 12 shows the cycle time curve for 30 iterations. The as-is results are a minimum of 30,939,187.59 seconds (approximately 358 days), an average of 55,617,674.28 seconds (approximately 643 days), and a maximum of 63,433,239.39 seconds (approximately 734 days). In comparison, the to-be results are a minimum of 11,503,714.31 seconds (approximately 133 days), an average of 12,679,941.09 seconds (approximately 146 days), and a maximum of 13,508,186.90 seconds (approximately 156 days). The reduction in cycle times from the business process (as-is) to the business process (to-be) indicates that the proposed changes will lead to a more efficient process. The stability of the to-be cycle times highlights the potential for enhanced predictability, which can improve planning and resource allocation. Figure 13 shows the cost comparison obtained from the simulation process.

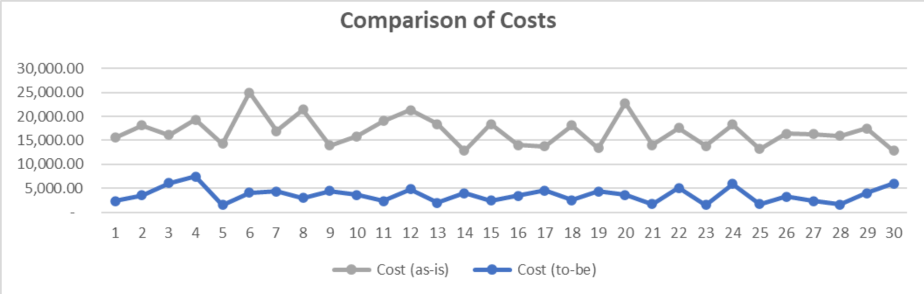


Fig. 13. Comparison of Costs

Figure 13 shows the cost curve for 30 iterations. The results for the business process (as-is) are a minimum of 12,795.57 USD, an average of 16,816.63 USD, and a maximum of 24,956.07 USD. For the business process (to-be), the results are a minimum of 1,487.96 USD, an average of 3,573.87 USD, and a maximum of 7,412.85 USD. This comparison shows a significant difference between the current costs and the expected costs after process improvements. The costs in the business process (to-be) are overall much lower compared to the as-is costs, with a drastic reduction in minimum, average, and maximum costs. This decrease indicates that the proposed process improvements significantly reduce operational costs.

Overall, the business process improvements not only shorten the cycle time but also significantly reduce costs. This demonstrates that the improvement measures taken have successfully created a better process.

4 Conclusion

Integrating data in the construction industry, especially through Advanced Work Packaging (AWP), offers a significant chance to boost efficiency and accuracy during project preparation. This research has examined the major challenges of cross-departmental data integration within the construction sector and proposed solutions using Business Process Management (BPM) techniques. The significance of this work is immense. Effective data integration is essential for reducing delays and errors in construction projects, leading to considerable cost savings and improved timelines. BPM approaches allow companies to redesign their business processes for greater efficiency and adaptability to the evolving demands of construction projects. Automation technologies further enhance these benefits by ensuring real-time data access and minimizing manual intervention. A key contribution of this research is showing how BPM can identify inefficiencies in current processes and develop streamlined workflows. This has profound implications for the construction industry, where complex projects require precise coordination and data handling. By adopting the strategies outlined in this study, construction companies can improve their project management capabilities, resulting in more successful outcomes. Future applications of this work could involve extending

BPM and automation strategies to other construction phases beyond preparation. Additionally, further research could explore integrating emerging technologies like artificial intelligence and machine learning into BPM frameworks to enhance predictive capabilities and decision-making.

5 Nomenclature

AWP	Advanced Work Packaging
BPM	Business Process Management
BPMN	Business Process Model and Notation
DC	Document Controller
DG	Design Engineer
EDMS	Electronic Document Management System
MTO	Material Take-Off
PAM	Process Activity Mapping
PE	Production Engineer
RCA	Root Cause Analysis
TS	Technical Support
WP	Work Package

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