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Performance Evaluation of Project Management Using System Dynamic Approach, Case Study: EPCC LNG Filling Station Cargo Dock Project

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Abstract— **Time delays are a common phenomenon in construction projects. The Engineering, Procurement, Construction, Commissioning (EPCC) LNG Filling Station Cargo Dock Project, the second company service in the technical service business segment in EPCC Project, was delayed by 8.98% at the end of the project. A system dynamic (SD) approach is proposed to simulate the interaction of delay factors to provide lesson learned and preventive actions so that the following project enables to completed on time. In this research, the combination of The project management knowledge area and project management process group on PMBOK®, KT-Problem Analysis (PA), Analytic Hierarchy Process (AHP), and sensitivity analysis is used to define the delay factors. The delay factors that significantly influence the project are inadequate procurement control, inadequate resource planning, incident, late payment, interruption from the client for design, and changing person. The system dynamic (SD) model is proven to find the significant root cause of project delay effectively, resulting in the proper lesson learned and preventive action in the following Company's project.**

Keywords— Analytic Hierarchy Process; Kepner-Tregoe; Project Management; Sensitivity Analysis, System Dynamic

I. INTRODUCTION

Completing the project on time is an indicator of efficiency. Still, many unpredictable factors will affect the construction process of the project results in time delays. Time delays are a common phenomenon in construction projects [1]. Project time delay is defined as the time beyond the deadline specified in the contract for delivering a project [2].

Following the natural gas supply continues to decline, the Company proposes to the shareholders to diversify its business to maintain and elevate its valuable assets for decades, namely, human resource capabilities in running the LNG plant. Since 2006, Company has provided commercial services to worldwide LNG companies. At that time, the service was intended to function as the Company's center of excellence for the LNG industry. Commercial business activities conducted by the Company are technical services, Commissioning and Start-Up Assistance (CSUA), Operation and Maintenance (O&M), training, and Research & Development (R&D).

The EPCC LNG Filling Station Cargo Dock Project is the second company service in the technical service business segment in EPCC Project. This project intends to fulfill increased liquefied natural gas (LNG) demand in the east part of Indonesia. On April 21st, 2021, which should be a completion date for the EPCC LNG Filling Station Cargo Dock Project, the project was delayed by 8.98%.

The project delay can impact project cost due to a penalty fee, extra spending on material expediting, and additional manpower to complete the project and damage the company image due to decreased trust levels. The delay also occurred in the Company's previous project.

Knowing the delay factors is important to get lessons learned from the project delays. Therefore, appropriate preventive actions can be generated to make the following project complete on time [1]. A system dynamic (SD) approach is proposed to simulate the interaction of delay factors to provide lesson learned and preventive actions. Due to the complex and dynamic behavior of the studied system, the overall dynamics of the effects of delay factors interactions on the project schedule are the main focus of this research. This analysis is used to determine the appropriate method in preventing the problem of project delays of the company. This study's contribution is to prove that the system dynamic model in the previous study can be used by improvising according to the delay factor of the project.

II. LITERATURE REVIEW

This paper proposed to simulate the interaction of delay factors using a system dynamic approach. In this research, the combination ofthe project management knowledge area and project management process group on PMBOK®,KT-Problem Analysis (PA), Analytic Hierarchy Process (AHP), and sensitivity analysis is used to define the delay factors that will be included in the system dynamic model.

The best external sources used for identifying best practices are PMBOK (Project Management Body of Knowledge) and PMI (Project Management Institution) publications[3]. PMBOK is a guide including principles and knowledge required for project management [4].PMBOK is used to find the delay causes and project risk. Reference [4] used PMBOK to make a novel model of delay analysis. Reference [5]presents a risk management tool based on two well-known sets of concepts: FMEA (Failure Mode and Effect Analysis) and PMBOK.

Kepner Tregoe Framework is used to generate criteria and sub-criteria of delay factors. Using Kepner Tregoe Framework allows researchers to acquire better to carry out root-cause analysis [6]. Based on [6], Kepner Tregoe is used for major concerns where all aspects need thorough analysis. Kepner Tregoe has a highly structured approach, focused on all aspects of the occurrence than other Root Cause Analysis (RCA) methods.

AHP has extensively become a predominant method in evaluating criteria weightings in various Multi-Criteria Decision-Making (MCDM) problems[7].Researchers widely use AHP to identify the delay factor of the project. Reference [8] used AHP to identify the delay-causing actors in the Indian real estate project. Reference [9] used AHP to evaluate the delay causes for BOT projects based on perceptions of different stakeholders in Turkey. Reference [10] used AHP for selecting the appropriate delay analysis method. Reference [11] using AHP for an analysis of causes of disputes in the construction industry. Reference [7] and [12] using AHP to assess construction schedule delay risk.The stability of the ranking under varying criteria weights is tested using sensitivity analysis.

Planning and managing project is challengingbecause project conditions and performance nature evolve feedback responses (involving non-linear relationships) and the accumulation of project schedule and resourcesover time. This condition has made the application of system dynamics to project management is suitable. Many different types of system dynamic models have been developed to improve project management. These models include some of the system features and characteristics addressed by system dynamics[13].Reference [14] used the SD method to show the logical link between cause and effect that is disruption /delay/acceleration and productivity loss. Reference [15] apply system dynamic in resolving the dispute of time delay in Viet Nam construction project. Reference [16] using system dynamic approach in a simulation of delay factors in sewage project. Reference [17] uses a system dynamic approach to investigate the risk effect on schedule delay in infrastructure projects. Reference [17]aims to take a holistic view to investigate the dynamics affecting risk effects on a schedule delay occurring in infrastructure projects.It also provides a practical tool through which projectrisk assessment can be improved by envisaging dynamic interactionsbetween various schedule risks. Therefore, this study usesthe system dynamic model in the reference[17] with modificationof the delay factor of the project.

The system dynamic approach is proven to simulate the complex interaction of delay factor to the project schedule. Combining the project management knowledge area and project management process group on PMBOK®, KT-Problem Analysis (PA), Analytic Hierarchy Process (AHP), and sensitivity analysis is used to define the appropriate delay factors that will be included in the system dynamic model. Therefore, the appropriate lesson learned and preventive actions are generated to prevent delay in the following project.

A. Project Management Evaluation using PMBOK ®

PMBOK is a guide including principles and knowledge required for project management[4].The PMBOK 6th Guide describes five process groups and ten knowledge areas that can be used to identify the relevant factors in projects management implementation. The ten knowledge areas are integration, scope, time, costs, quality, human resources, communications, risks, procurement, and stakeholders. The five process groups are initiating, planning, executing, monitoring and controlling, and closing[5].

B. Kepner-Tregoe Problem Analysis

The Kepner Tregoe Problem Analysis (PA) is used to find deviation in the system, which causes failure on the system. The technique examines in detail the specification of the problem[18].Kepner Tregoe Framework is used to generate criteria and sub-criteria of delay factors.

C. Analytic Hierarchy Process (AHP)

AHP is used to derive ratios from discrete and continuous pairwise comparisons. These comparisons can be derived from actual measurements or basic scales, reflecting the relative strength of preferences and feelings. The analytic hierarchy process pays special attention to the consistency, measurement, and dependence between and among the various element groups of its structure. It has been most widely used in multi-criteria decision-making, planning and resource allocation, and conflict resolution[19].Over the years, many researchers have modified it from a theoretical and practical point of view[20].

In this research, AHP is used for ranking the criteria and sub-criteria. The decision-makers methodically evaluate all the elements of the difference in each hierarchy by comparing the element with each other by seeing how much one factor impacts the other factor. The decision-makers used appropriate facts and their understanding and discussion to decide which factor causes more impact on others[21].

D. Sensitivity Analysis

The final priorities of the root causes are highly dependent on the weight attached to the main criteria [19]. The weight is based on highly subjective judgment. The stability of the ranking under varying criteria weights has to be tested. Small changes in the relative weights can result in significant changes in the final ranking [22]. For this purpose, sensitivity analysis is performed in the result of AHP.[21].

E. System Dynamic (SD) Modelling in Project Management

System Dynamic (SD) is the approach to four recent developments: advances in computing technology, growing experience with computer simulation, improved understanding of strategic decision-making, and developments in understanding the role of feedback in a complex system. The four foundations of SD are the theory of information feedback system, a knowledge of decision-making processes, the experimental model approach to a complex system, and the digital computer to simulate realistic mathematical models [23].Project Management is considered a complex system. All projects have intercommunication, hierarchy, communication, control, and emergency, which are generally valuable attributes for describing all types of systems. In addition, most projects have the characteristics of complex adaptive systems. They exhibit such characteristics as phase transition, adaptability, and sensibility to initial conditions[13]. A complex project is a complex system of different elements connected to achieve a goal. The most important characteristics exhibited by complex projects, seen as the complex adaptive system, are:

- Auto-organizations: a project can suffer two types of perturbations.
- Hierarchy: project as the system might contain other systems- the member of the project's temporary executive organization belongs to other sub-systems.
- Non-linearity: small perturbation cause effects in the project[13]—steps of establishing.

A system dynamics model is developed based on the Causal Loop Diagram(CLD). The CLD helps the user to communicate the feedback structure and underlying assumptions quickly. CLDs are used for representing the

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feedback structure of systems [24]. CLD consists of variables connected by arrows denoting the causal influences among the variables. Causal links, shown by arrows, relate to variables. The causal relationship depicts that one element was affecting another element. Link polarities of variables describe the structure of the system [24]. The causal diagram does not describe what will happen. Instead, it describes what would happen if the variable were to change [25].

The main concepts in a system dynamic system are stocks, flow, and feedback. The state of the system is characterized by stock. Stock generates information on which decisions and actions are based. Stocks give the system inertia and provide it with memory. Stock is delayed by accumulating the difference between inflow and outflow. By decoupling flow rates, the stock is the source of disequilibrium dynamics in the system[25].

III. METHODOLOGY

This study uses the system dynamic model in the reference [17] with modification according to the delay factor of the project. Reference [17]provides a practical tool through which projectrisk assessment can be improved by envisaging dynamic interactionsbetween various schedule risks. The research methodology is shown in Figure 1.

The project management knowledge area and project management process group on Project Management Body of Knowledge (PMBOK) evaluate project management implementation and identify the possible causes of the delay factors. Then, the Kepner-Tregoe Problem Analysis method is used to find delay factors. The Kepner Tregoe Problem Analysis generates criteria and sub-criteria of delay factors by carrying out root-cause analysis[6]. The Kepner Tregoe Problem Analysis (PA) will look for past eventsand find deviation in the system, which causes failure on the system deviation previously working[18].AHP is used to classify delay factors based on their impact to project delay. The final priorities of the root causes are highly dependent on the weight attached to the main criteria[19]. The weight is based on a highly subjective judgment of experts. The stability of the ranking under varying criteria weights has to be tested. Small changes in the relative weights can result in significant changes in the final ranking[22]. For this purpose, sensitivity analysis is performed in the result of AHP.Finally, the stock and flowgenerate the interaction between the main root causes related to delay and give a holistic view to investigate the dynamic affecting delay factors on the schedule delay in the project. A system dynamics model was developed based on the causal cycle diagram. The SD model can provide information about the delay factor that significantly affects the project schedule. Thus, the appropriate preventive mitigation and alternative implementation can be determined for the company's following project.

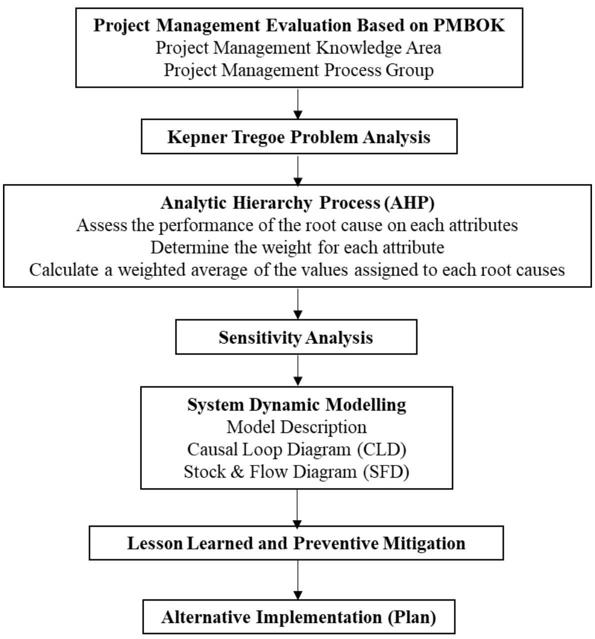

Fig. 1. Research Methodology

A. Project Management Evaluation Based on PMBOK

In PMBOK ® Guide, Project management processes are grouped into the five Project Management Process Groups. In addition to the process group, processes are also categorized by knowledge. A Knowledge Area is an identified area of project management defined by its knowledge requirements and described in its component processes, practices, inputs, outputs, tools, and techniques. The ten Knowledge Areas are used in most projects most of the time [26]. The combination of the five Project Management Processes and the ten-knowledge area is resulting a comprehensive forty-nine project management process evaluation shown in Table 1.

B. Kepner Tregoe (KT) Problem Analysis

There are several steps in Kepner-Tregoe Problem Analysis [27].

1) Problem Statement: an appropriate definition of the problem enabled examining the problem in a new perspective to reveal a previously unconsidered cause[27].
2) Problem Specification: describing the problem in four dimensions: identity, location, timing, and magnitude. Within each, ask questions that round out the description of the problem and provide useful analytical information. It is to help prevent focusing too early on individual theories that may be unrelated to the problem or obscure its actual cause. It is important to be comprehensive without preconceptions[28].
3) Developing possible causes from knowledge and experience or distinction or changes: Extract essential information to list possible causes. The information gathered in the problem specification is expanded into a table that compares the information (the known observations) with information (comparative information) and summarizes the distinctions between them. This step provides clues to the cause of the problem [28].

4) Testing the possible causes against the specification: In the testing step from Problem Analysis, the specification's facts are used to judge the relative likelihood of possible causes. The true cause must explain each aspect of the deviation since the true cause created the exact effect specified. Testing for the cause is a process of matching the details of a postulated cause with the details of an observed effect to see whether that cause could have produced that effect.
5) Determine the most probable cause.

C. *Analytic Hierarchy Process (AHP)*

The following are AHP steps [19]:

1) Identify the problem and determine the type of knowledge sought.
2) Structure the decision from the top (goal of the decision and objective from a broad perspective), the middle level (criteria on which subsequent elements depend), to the lowest level.
3) Construct a set of pairwise comparison matrices. Each element in an upper level is used to compare the elements immediately below for it.
4) Use the priorities obtained from the comparisons to weight values and obtain their overall or global priority. Continues this process of weighing and adding until the final priorities of the alternatives in the bottom-most level are obtained.

TABLE I. PROJECT MANAGEMENT PROCESS GROUPAND KNOWLEDGE AREA

Knowledge Area	Project Management Process Group				
	Initiating Process Group	**Planning Process Group**	**Executing Process Group**	**Monitoring and Controlling Process Group**	**Closing Process Group**
Project Integration Management	Develop Project Charter	Develop Project Management Plan	Direct and Manage Project Work	Monitor and Control Project Work	Close Project or Phase
			Manage Project Knowledge	Perform Integrated Change Control	
Project Scope Management	-	Plan Scope Management	-	Validate Scope	-
		Collect Requirement			
		Define Scope		Control Scope	
		Create WBS			
Project Schedule Management	-	Plan Schedule Management	-	Control Schedule	-
		Define Activities			
		Sequence Activities			
		Estimate Activity Durations			
		Develop Schedule			
Project Cost Management	-	Plan Cost Management	-	Control Cost	-
		Estimate Costs			
		Determine Budget			
Project Quality Management	-	Plan Quality Management	Manage Quality	Control Quality	-
Project Resource Management	-	Plan Resource Management	Acquire Resources	Control Resources	-
		Estimate Activity Resources	Develop Team		
			Manage Team		
Project Communication Management	-	Plan Communication Management	Manage Communication	Monitor Communication	-
Project Risk Management	-	Plan Risk Management	Implement Risk Response	Monitor Risks	-
		Identify Risks			
		Perform Qualitative Risk Analysis			
		Perform Quantitative Risk			
		Plan Risk Response			
Project Procurement Management	-	Plan Procurement Management	Conduct Procurements	Control Procurements	-
Project Stakeholder Management	Identify Stakeholder	Plan Stakeholder Engagement	Manage Stakeholder Engagement	Monitor Stakeholder Engagement	-

D. *Sensitivity Analysis*

Sensitivity analysis is a powerful tool to check the robustness of the model and eliminate biases during data collection and analysis. In order to execute sensitivity analysis, the weight highest evaluation value in the main category varied from 0.1 to 0.9, and subsequently, the weight of all the main category criteria also varied [21].

E. *System Dynamic Modelling*

The following are steps of establishing SD model:

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1) Creating a closed-system boundary within the system interactions takes place that gives the system its characteristic behaviour.The sub-system of a complex project system is divided into six sub-systems: completed project task, project reworks, accumulated project task completion, remaining project task, labour employment, and schedule plan.
2) Identification of Parameter. The major variables and units in the SD model should be listed based on sub-systems.
3) Causal Loop Diagram (CLD). The causal loop diagram represents how a system works. The CLD helps the user to communicate the feedback structure and underlying assumptions quickly. CLDs are used for representing the feedback structure of systems [24]. CLD consists of variables connected by arrows denoting the causal influences among the variables. Causal links, shown by arrows, relate to variables.The causal relationship depicts that one element was affecting another element. Link polarities of variables describe the structure of the system [24]. The causal diagram does not describe what will happen. Instead, it describes what would happen if the variable were to change [25].
4) Stock and Flow Diagram. The main concepts in a system dynamic system are stocks,flow, and feedback. The state of the system is characterized by stock. Stock generates information on which decisions and actions are based. Stocks give the system inertia and provide it with memory. Stock is delayed by accumulating the difference between inflow and outflow. By decoupling flow rates, the stock is the source of disequilibrium dynamics in the system [25].

IV. RESULT

A. PMBOK Project Evaluation Result

The combination of the five project management process groups and the ten knowledge areas,as shown in Table 1, is used to evaluate the project management implementation in the EPCC LNG Filling Station Cargo Dock. Project ManagementEvaluation is conducted using company documentation in the project, historical information during project charter, and highlight items from the weekly progress report to the client. The following is the description of the problem found in EPCC LNG Filling Station Cargo Dock:

1) Develop Project Charter
   In making a project charter or *Surat PerintahKerja (SPK),* there are negotiations to reduce the project period due to the owner's need so that the plant can be used in April 2021. This negotiation has reduced the project implementation time from 45 weeks in the initial study to 40 weeks.
2) Direct and Manage the Project Work
   Delays in this project indicate problems in directing and managing project work.
3) Manage Project Knowledge
   There is no lesson learned register in the EPCC LNG Filling Station Cargo Dock Project.
4) Collect Requirement
   There are deficiencies in collecting requirement phases in input engineering design: late assessment result data and late detailed cargo ship data.
5) Develop Schedule
   The project schedule was developed in the FEED phase but not considering bad weather conditions (since the project is carried out in the rainy season), Covid-19, and the deficiency in design data.
6) Control Schedule
   In this process, no lesson learned register could be applied to later phases to improve schedule control. Adjusting lags should be applied to find the best way to align project activities with the project plan. Adjusting lags should carry out by fast-tracking or crashing the schedule for the remaining work.
7) Control Cost
   There are difficulties in invoicing to the client due to many requirements in invoicing submissions. This had disrupted the cash flow of the S&BD division.
8) Control Quality
   There were several obstacles in working on engineering documents due to differences in perceptions between the agreement on the FEED and the EPCC work process. This misperception causes delays in the engineering design completion process.
9) Plan Resource Management
   The project manager ignores the personnel's involvement with other projects and involvement in the working department. There have also been errors in estimating the number of personnel from civilsubcontractors, resulting in relatively slow construction progress.
10) Control Resource
    Human resources cannot be controlled for working on that project. Besides, some personnel had to be replaced, which led to a learning curve.
11) There is no Project Risk Management.
12) Control Procurement
    There is no control in the procurement process, such as processing time, processing measurement, and expediting due to lack of personnel. This condition was resulting in long-time procurement processing and delayed equipment arrival. Even until the end of the project, there was still equipment that had not arrived at the EPCC LNG Loading Station Cargo Dock project.
13) Manage Stakeholder Engagement
    Stakeholder engagement was failed to engage one of the stakeholders, custodian area management, due to an Incident of Cable Cut at the LNG Filling Station Cargo Dock Project. The incident caused a decrease in the engagement level of custodian area management from neutral to resistant.

B. Root Causes

The root cause analysis is shown in Table II and Table III. The result of project management evaluation and Kepner-Tregoe problem analysis has been identified by several key factors related to different stakeholders and dimensions encompassing project (1) client, (2) designer or engineer, (3) contractor (S&BD) project team), (4) subcontractor, and (5) external environment.

C. Criteria and Sub-Criteria Weighting Using AHP

AHP is used for ranking the criteria and sub-criteria. Qualitative research methods, which are questionnaires, are conducted on root causes consisting of criteria and sub-

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criteria, resulting in a score of the influence of each root cause by comparing each other. Fig. 2 shows the delay factors criteria and sub-criteria.

The root-cause criteria are Client Related (d01), designer/engineer related (d02), contractor / project team related (d03), subcontractor related (d04), external environmental related (d05). The sub-criteria are late project payment (d11), interruption from client in design process (d12), deficiency in design (d21), changing personnel (d22), shorten schedule plan (d31), inadequate project management (d32), inadequate lesson learned (d33), inadequate resource planning (d34), inadequate procurement controlling (d35), inadequate risk identification (d36), lack of personnel (d41), incident (d42), bad weather (d51), epidemic (d52). The criteria calculation result, sub-criteria calculation result, and synthesis value are shown in Table IV and Fig. 3. The result is accepted due to it has a consistency ratio < 0.01.

TABLE II. KEPNER-TREGOE PROBLEM ANALYSIS RESULT (STEP 1 – 4)

	Specifying Question	IS – Performance Deviation	IS NOT – closest logical comparison	Distinction	Cause
WHAT	WHAT specific object has the deviation? WHAT is the specific deviation?	The project schedule is completed in more than 40 weeks.	The project schedule is completed in 281 days or less	The constraint was found during the project duration.	Shorten schedule plan; Inadequate project management; Deficiency in Design Data; Inadequate resource planning; Late project payment; Lack of personnel; Changing personnel; Inadequate risk identification; Inadequate procurement controlling.
WHERE	WHERE is the object when the deviation is observed? WHERE is the deviation on the object?	The EPCC LNG Filling Station Project in the company	Project outside the company	This project is the first EPCC project from the company, which acts as a contractor.	Inadequate lesson learned; Rework;
WHEN	WHEN was the deviation observed first? WHEN since that time has the deviation been observed?	During the project implementation time, from July 15th, 2020 to April 21st, 2021 (281 calendar days).	Any day other than the project implementation time.	The constraint found during project construction.	Bad weather and pandemic;
EXTENT	HOW MANY objects have a deviation? WHAT is the size of a single deviation? HOW MANY deviations are on each object? WHAT is the trend?	As of April 21st 2021, Delay in project execution Management is 0.25%, engineering is 0.48%; procurement is 0.21, construction is 6.22%, commissioning is 1.15%, and permit processing is 0.66%. The trend of delay is increasing since August 21st 2020.	The Project progress before August 21st 2020	A delay in the start of the project makes all the stages behind it become increasingly late.	Incident; rework; Deficiency in Design Data; Interruption from the client in the Design process; Changing personnel; lack of procurement controlling.

TABLE III. KEPNER-TREGOE PROBLEM ANALYSIS RESULT (STEP 5)

External & Controllable Possible Root Cause	**Root cause explanation**
Client Related	
Late Project Payment	There are difficulties in invoicing to the client due to many requirements in invoicing submissions. This condition had disrupted the flow of the project and the cash flow of the S&BD division.
Interruption from the client in the design process	There were several obstacles in working on engineering documents due to differences in perceptions between the agreement on the FEED and the EPCC work process. The change of personnel from the client has exacerbated the misperception causes delays in the engineering design completion process.
Sub-contractor Related	
Lack of Personnel	The personnel have involvement with other projects. There have also been errors in estimating the number of personnel from civil subcontractors, resulting in relatively slow construction progress.
Incident	The Incident of Cable Cut at the LNG Filling Station Cargo Dock Project resulted in a decrease in custodian area management from neutral to resistant.
Internal & Controllable Possible Root Cause	**Root cause explanation**
Contractor / (S&BD) Project Team	
Shorten Schedule Plan	In making a project charter or *Surat PerintahKerja (SPK),* there are negotiations to reduce the project period due to the owner's need so that the plant can be used in April 2021. This negotiation has reduced the project implementation time from 45 weeks in the initial study to 40 weeks.
Inadequate Project Management	Delays in this project indicate problems in directing and managing project work.
Inadequate Lesson Learned	There is no lesson learned register from the previous project.
Inadequate Resource Planning	Adjusting lags should be applied to find the best way to bring project activities behind into alignment with the project plan. Adjusting lags should carry out by fast-tracking or crashing the schedule for the remaining work.
Inadequate procurement controlling	There is no control in the procurement process, such as processing time processing measurement and expediting due to lack of personnel. This condition was resulting in long-time procurement processing and delayed equipment arrival. Even until the end of the project, there was still equipment that had not arrived at the EPCC LNG Loading Station Cargo Dock project.
Inadequate risk identification	The plan risk management, identify risk, qualitative risk analysis, and quantitative risk analysis, plan risk response, implement risk response, and monitor risks is not conducted in this project.
Designer / Engineer	
Deficiency in Design Data	There are deficiencies in collecting requirement phases in input engineering design, which are: 1. The assessment result data needed for DED input data and construction data was late in being obtained (August30th 2020) because it was waiting for an evaluation from client. 2. Detailed cargo ship data (Cargo Vessel) to evaluate ship to shore transfer optimization was late obtained (September29th 2020) from client. 3. The client delayed the Isotank 40FT Trailer Truck maneuver trial at the project site. This delay causes delays inhibits the completion of the engineering design.
Changing Personnel	Human resources cannot be controlled for working on that project. Besides, some personnel had to be replaced, which led to a learning curve.
Possible Root Cause	**Root cause explanation**
External Environment	
Bad Weather and Pandemic	The project schedule was developed in the FEED phase but not considering bad weather conditions (since the project is carried out in the rainy season) and Covid-19.

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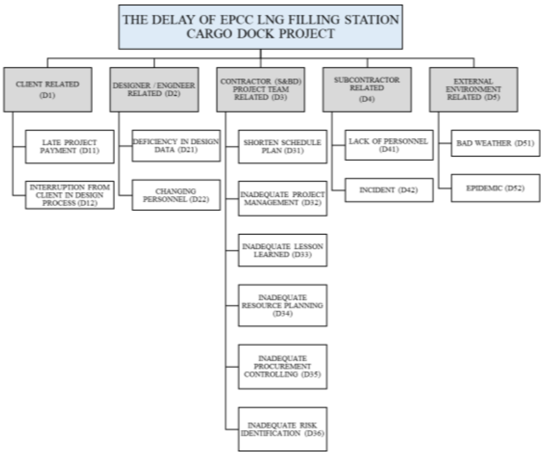

Fig. 2. Root causes hierarchy

TABLE IV. WEIGHT OF CRITERIA, SUB-CRITERIA, AND SYNTHESIS VALUE

Criteria	Weight of criteria	Sub-Criteria	Weight of criteria	Synthesis Value
d_1	0.187	d_{11}	0.620	11.56%
		d_{12}	0.380	7.07%
d_2	0.321	d_{21}	0.717	16.57%
		d_{22}	0.283	6.53%
d_3	0.075	d_{31}	0.092	1.73%
		d_{32}	0.089	1.67%
		d_{33}	0.153	2.87%
		d_{34}	0.170	3.19%
		d_{35}	0.311	5.82%
		d_{36}	0.183	3.42%
d_4	0.186	d_{41}	0.760	24.37%
		d_{42}	0.240	7.71%
d_5	0.231	d_{51}	0.682	3.74%
		d_{52}	0.318	3.74%

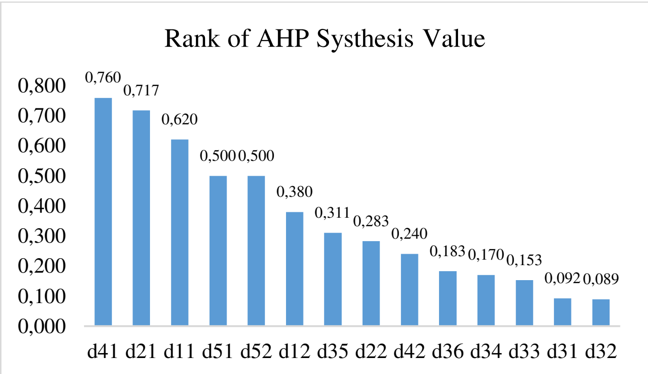

Fig. 3. The rank of AHP Synthesis Value

D. Sensitivity Analysis

The weight of criteria in sensitivity analysis is shown in Table VI. Subsequently, the weight of all the main category criteria also varied, as shown in Table VII and Fig. 4. The varied ranking of criteria is shown in Table VII and Fig. 5.

TABLE V. WEIGHT OF CRITERIA IN SENSITIVITY ANALYSIS

	w	Modified Weights of Criteria in Sensitivity Analysis								
		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
d_1	0.186	0.247	0.2	0.192	0.165	0.137	0.110	0.082	0.055	0.027
d_2	0.231	0.306	0.220	0.238	0.204	0.170	0.136	0.102	0.068	0.034
d_3	0.187	0.248	0.272	0.193	0.165	0.138	0.110	0.083	0.055	0.028
d_4	0.321	0.100	0.200	0.300	0.400	0.500	0.600	0.700	0.800	0.900
d_5	0.186	0.099	0.200	0.077	0.066	0.055	0.044	0.033	0.022	0.011
	1.000	1.000	0.088	1.000	1.000	1.000	1.000	1.000	1.000	1.000

TABLE V. WEIGHT OF SUB-CRITERIA IN SENSITIVITY ANALYSIS

	Syn. w	Modified Weights of Criteria in Sensitivity Analysis								
		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
d_{11}	0.116	0.153	0.136	0.119	0.102	0.085	0.068	0.051	0.034	0.017
d_{12}	0.071	0.094	0.083	0.073	0.062	0.052	0.042	0.031	0.021	0.010
d_{21}	0.166	0.220	0.195	0.171	0.146	0.122	0.098	0.073	0.049	0.024
d_{22}	0.653	0.087	0.077	0.067	0.058	0.048	0.038	0.029	0.019	0.010
d_{31}	0.017	0.023	0.020	0.018	0.015	0.013	0.010	0.008	0.005	0.003
d_{32}	0.016	0.022	0.020	0.017	0.015	0.012	0.010	0.007	0.005	0.002
d_{33}	0.029	0.038	0.034	0.030	0.025	0.021	0.017	0.013	0.008	0.004
d_{34}	0.032	0.042	0.038	0.033	0.028	0.023	0.019	0.014	0.009	0.005
d_{35}	0.058	0.077	0.069	0.060	0.051	0.043	0.034	0.026	0.017	0.009
d_{36}	0.034	0.045	0.040	0.035	0.030	0.025	0.020	0.015	0.010	0.005
d_{41}	0.244	0.076	0.152	0.228	0.304	0.380	0.456	0.532	0.608	0.684
d_{42}	0.077	0.024	0.048	0.072	0.096	0.120	0.144	0.168	0.192	0.216
d_{51}	0.037	0.050	0.044	0.039	0.033	0.028	0.022	0.017	0.011	0.006
d_{52}	0.037	0.050	0.044	0.039	0.033	0.028	0.022	0.017	0.011	0.006
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

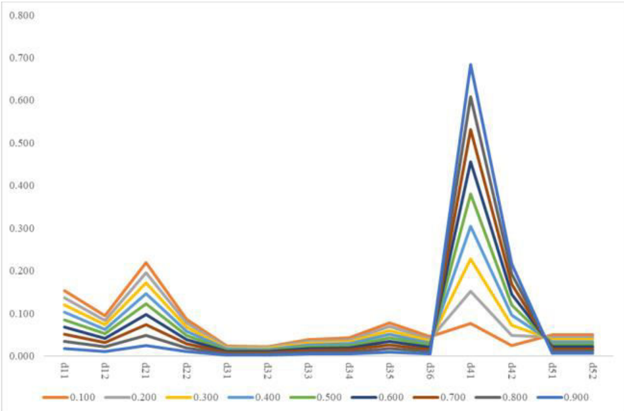

Fig. 4. Variation in Weights in Sensitivity Analysis

TABLE VI. THE RANK OF CRITERIA IN SENSITIVITY ANALYSIS

	Syn. rank	Modified Rank of Criteria in Sensitivity Analysis								
		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
d_{11}	3	2	3	3	3	4	4	4	4	4
d_{12}	5	3	4	4	5	5	5	5	5	5
d_{21}	3	1	1	2	2	2	3	3	3	3
d_{22}	4	4	5	6	6	6	6	6	6	6
d_{31}	10	13	13	13	13	13	13	13	13	13
d_{32}	10	14	14	14	14	14	14	14	14	14
d_{33}	9	11	12	12	12	12	12	12	12	12
d_{34}	8	10	11	11	11	11	11	11	11	11
d_{35}	4	5	6	7	7	7	7	7	7	7
d_{36}	6	9	10	10	10	10	10	10	10	10
d_{41}	2	6	2	1	1	1	1	1	1	1
d_{42}	2	12	7	5	4	3	2	2	2	2
d_{51}	2	7	8	8	8	8	8	8	8	8
d_{52}	2	7	8	8	8	8	8	8	8	8

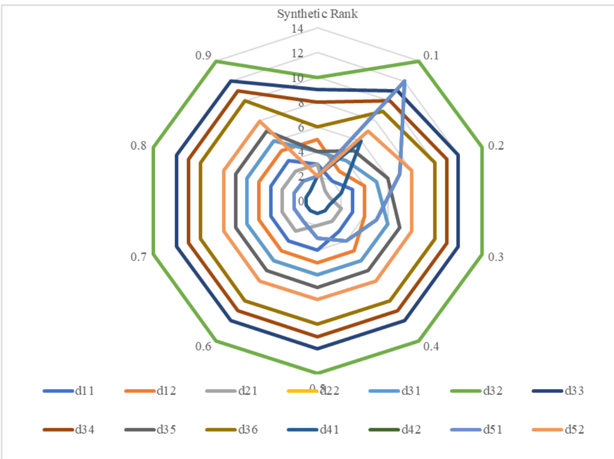

Fig. 5. Variation in Ranking in Sensitivity Analysis

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Based on the sensitivity analysis result, sub-criteria or delay factors d_{31}, d_{32}, d_{33}, d_{34}, d_{36}, d_{51}, and d_{52} will be excluded from the root cause of the problem.

E. *System Dynamic Modelling*

Based on the characteristic auto organization, hierarchy, and non-linearity, the EPCC LNG Filling Station Cargo Dock is considered a complex project.This study uses the system dynamic model in the reference [17] with modificationof the delay factors of the project.The following are the steps for creating SD Modelling for LNG Filling Station Cargo Dock Project.

1) Create Closed System Boundary.

The closed system boundary used for system dynamics regarding project tasks [17] is shown in Fig. 6.

- The sub-system of completed project tasks
  The completed project task depends on the rate of task completion. The rate of task completion depends on whether the completed task is accepted or not. The delay factor client's late payment (d_{11}) will affect the progress of the construction activities, thereby affecting the completion rate of the project tasks[17]. The incident (d_{42}) of Cable Cut at the LNG Filling Station Cargo Dock Project results in the custodian area management is reluctant to give the project construction team permission in several weeks. This condition will also decrease the initial rate of task completion. The changing personnel willbe led to a learning curve due to the labor adjustment time needed.
- The sub-system of project reworks
  Undetected rework is the frequency of rework, and the detected rework respectively serves as the input and output of the level variable. There is a non-linear relationship between the rework detection time and the proportion of tasks completed[17].The delay factor deficiency in design data (d_{21}) will affect the design drawings that guide the actual construction activities. Accordingly, all project tasks completed before the verified design data must be modified or even reconstructed, thereby increasing rework.
- The sub-system of accumulated project tasks completion
  The accumulated project task completion depends on the planned work quota, acceptance rate of completed tasks, and initially planned project tasks [17].

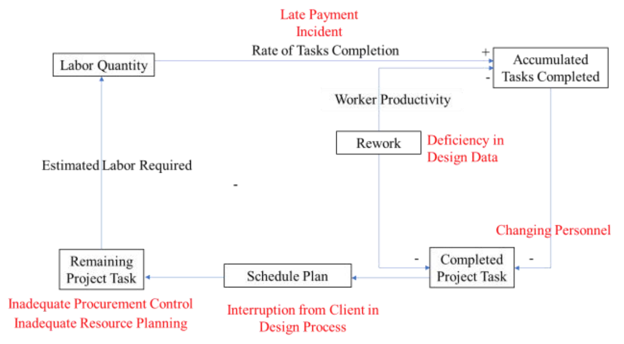

Fig. 6. Boundary and Structure of System Dynamic Model regarding Project Task

- The sub-system remaining project tasks
  In the early construction phase, the project manager cannot accurately estimate the productivity of the workers. On the contrary, the project manager must mainly rely on the planned timetable and workload to determine the planned work quota. In this case, the planned work quota should be more important in determining the estimated work quota. In the later stage of construction, the project manager gradually learned about the construction skills of the workers and the frequency of errors [6]. The inadequate procurement control (d_{35}) was resulting in long-time procurement processing and delayed equipment arrival. Even until the end of the project, there was still equipment that had not arrived at the EPCC LNG Loading Station Cargo Dock project. The delay factor inadequate procurement control (d_{35}) will directly affect the regular progress of construction activities and consequently prolonged the estimated time required and increase the remaining project task. A primary schedule delay culprit associated with contractors' management capacity is that contractors underestimate or overestimate the remaining project tasks in the construction process. There have also been errors in estimating the number of personnel (d_{41}) from civil subcontractors, resulting in relatively slow construction progress.
- The sub-system labor quantity. The labor employment of the sub-system depends on the remaining project tasks. If the remaining project tasks increase, labor employment will increase.
- The sub-systems schedule plan. The schedule plan sub-system will compare the actual completion task and the planned schedule. In practice, the delay factor direct interruption from the client in the design process (d_{12}) increases the project tasks[17].

2) Create Parameter Identification

The major variables in this study are shown in Table VIII.

3) Causal and Loop Diagram

The relationship between variables is described in Closed System Boundary. The CLD is shown in Fig. 7.

4) The Stock and Flow Diagram (SFD)

TABLE VII. MAJOR VARIABLES IN SYSTEM DYNAMIC MODEL

Type of Variables	Variables	Value (Initial Value)
Constants	Planned work quota (unit/person.week)	1
	The acceptance rate of completed tasks	0.95
	Initially planned project task (unit)	10134
	Labor Adjustment time (week)	2
	Planned schedule (week)	40
The cause of the delay	D01 (Late Payment)	1
	D02 (Lack of Procurement Controlling)	1
	D03 (Interruption from Client in Design Process) (unit/person)	0
	D04 (Incident)	1
	D05 (Deficiency in Design Data)	1
	D06 (Changing Personnel) (person)	0
Level Variables	Labor quantity (person)	97
	Completed project task (unit)	0
	Undetected Reworks (unit)	0
	Estimated project completion time (week)	40

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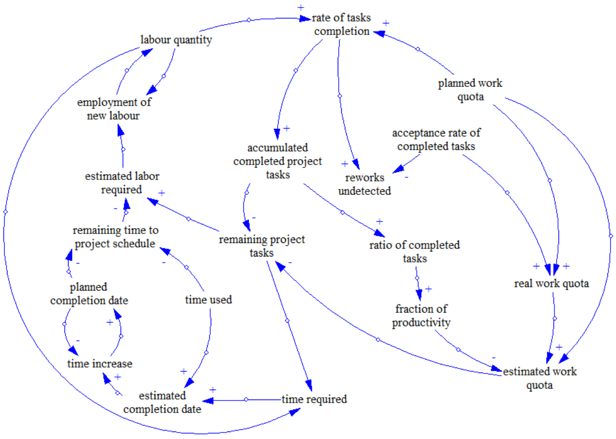

Fig. 7. Boundary and Structure of System Dynamic Model regarding Project Task

The delay identified in the study were integrated into the model as interruption factors. The relationship between variables and the interruption factors is described in Closed System Boundary. The CLD is shown in Fig. 8.

5) Model Verification

- All unit and equation check results are OK.
- The causes strip for actual project completion time describes the causal interaction between elements in the model developed. The causal strip output is shown in Fig. 8.

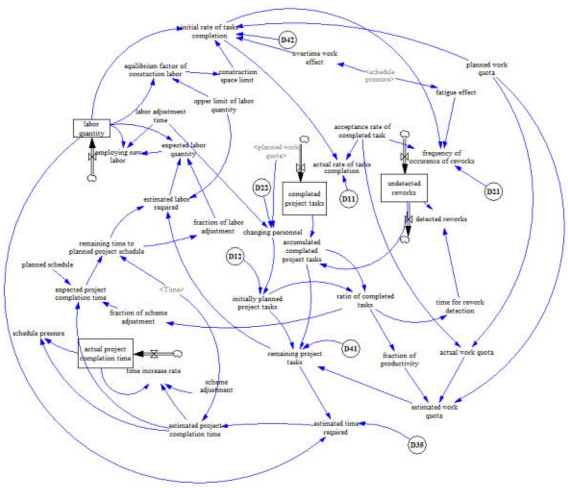

Fig. 8. Stock and Flow Diagram

The result concludes that the SFD is ready for validation based on the reference [17] and the actual data to know if the program represents the real condition.

6) Validation

Validation of the SFD is based on the reference [17] and the actual data in the EPCC LNG Filling Station Project.

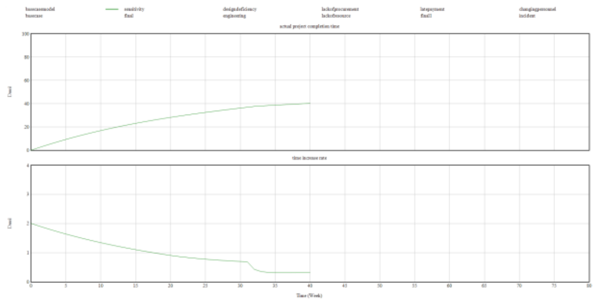

Fig. 9. Model Verification

The result of validation is shown in Fig. 9 and Fig. 10. The error for the project schedule is less than 1%. Therefore, the SFD is valid

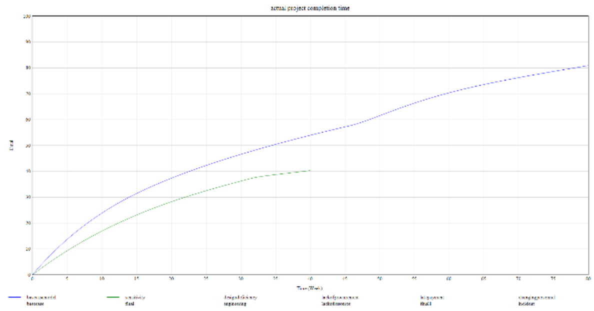

Fig. 10. Model Validation based on the Reference

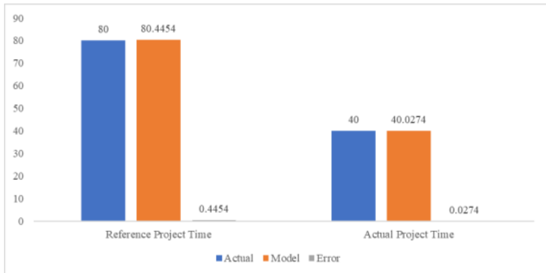

Fig. 11. Planned Time and Actual Time Validation

7) Simulation Scenario

Simulations are simulated seven times for each delay factors consists of late payment (d_{11}), inadequate resource planning (d_{41}), inadequate procurement control (d_{35}), interruption from the client for design (d_{12}), incident (d_{42}), deficiency in design data (d_{21}), and changing person (d_{22}). The simulation is conducted to find the impact of schedule delay in each delay factors for project completion time.The list scenario is shown in Table VIII.

The ratio of variables late payment (d_{11}), inadequate resource planning (d_{41}), inadequate procurement control (d_{35}), incident (d_{42}), deficiency in design data (d_{21}) is varied from 0.5 to 1 based on the characteristic of the project.

The interruption from the client for design (d_{12}) variable is based on the number of man-week affected if there is an interruption in design in the 2nd week of the project (actual). The changing person (d_{22}) variable is based on the number of personnel changes at the 30th week (actual) of the project.

The result of the actual project completion time is shown in Table IX. The delay of the project is significantly affected by late payment (d_{11}), inadequate resource planning (d_{41}), inadequate procurement control (d_{35}), and incident (d_{42}).The

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deviation from the schedule plan and the actual project time is shown in Figure 12.

The simulation for the combination of delay root cause based on the actual condition of the project is conducted. Refer to Table X, and the variable value is selected.
d_{11}: 0.90 (based on the delay prediction due to late payment)
d_{41}: 0.95 (based on the delay calculation due to lack of subcontractor personnel)

TABLE VIII. SCENARIO OF SD MODEL

D	Scenario						
	1	2	3	4	5	6	7
d_{11}	0.5	0.6	0.7	0.8	0.9	0.95	1
d_{41}	0.5	0.6	0.7	0.8	0.9	0.95	1
d_{35}	0.5	0.6	0.7	0.8	0.9	0.95	1
d_{12}	0.012	0.01	0.008	0.006	0.004	0.002	0
d_{42}	0.5	0.6	0.7	0.8	0.9	0.95	1
d_{21}	0.5	0.6	0.7	0.8	0.9	0.95	1
d_{22}	7	6	5	4	3	2	0

TABLE IX. THE ACTUAL PROJECT COMPLETION TIME OF SCENARIO

D	Scenario						
	1	2	3	4	5	6	7
d_{11}	44.63	43.9717	43.33	42.1788	41.081	40.55	40.027
d_{41}	66.7	56.6996	49.8192	45.8035	42.5949	41.4724	40.027
d_{35}	69.64	59.5026	51.8136	46.5438	42.9226	41.662	40.027
d_{12}	40.37	40.317	40.25	40.2	40.14	40.08	40.027
d_{42}	44.793	44.0921	43.416	42.2327	41.1053	40.565	40.027
d_{21}	40.14	40.11	40.09	40.07	40.04	40.03	40.027
d_{22}	40.036	40.0339	40.0323	40.0306	40.029	40.0274	40.027

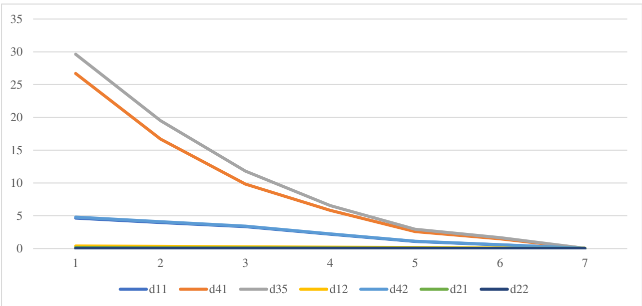

Fig. 12. Planned Time and Actual Time Validation

d_{35}: 0.85 (based on the delay of material arrival)
d_{12}: 0.008 (based on the number of man-week affected by an interruption in design in the 2nd week of the project)
d_{42}: 0.80 (based on the project halt due to incident)
d_{21}: 0.80 (based on the project halt due to data deficiency)
d_{22}: 0.95 (based on the number of personnel changes at the 30th week)

Figure 13 shows the result for the project completion time if the variable value from delay root causes is inserted at 52.2316 weeks. This condition is similar to the expected project completion time on July 7th, 2021 (51.71 weeks).

8) Result and Recommendation

A system dynamic model has been developed for the EPCC LNG Filling Station Cargo Dock project. The model describes the interaction of the delay factors with the project schedule.The system dynamic approach from the previous study is proven to simulate the complex interaction of delay factors to the project schedule. The model describes the interaction of the delay factors. This model can be used as a modelling platform for the company for preventive mitigation.

The order of root causes that has the significant influence on the EPCC LNG Filling Station Cargo Dock project delay is inadequate procurement control (d_{35}), inadequate resource planning (d_{41}), incident (d_{42}), late payment (d_{11}), interruption from the client for design (d_{12}), and changing person (d_{22}). The immediate action plan should be defined to prevent the risks in the following company's project.

V. DISCUSSION AND CONCLUSION

This paper proposed to simulate the interaction of delay factors using a system dynamic approach. In this research, the combination of the project management knowledge area and project management process group on PMBOK®, KT-Problem Analysis (PA), Analytic Hierarchy Process (AHP), and sensitivity analysis is used to define the delay factors that will be included in the system dynamic model.

Combining the five project management process groups and the ten knowledge areas is used to evaluate the project management implementation in the EPCC LNG Filling Station Cargo Dock.

The result of project management evaluation and Kepner-Tregoe problem analysis has been identified by several key factors related to different stakeholders and dimensions encompassing project (1) client, (2) designer or engineer, (3) contractor (S&BD) project team), (4) subcontractor, and (5) external environment.

AHP is used to classify delay factors based on their impact to project delay. The root-cause criteria are Client Related (d_{01}), designer/engineer related (d_{02}), contractor / project team related (d_{03}), subcontractor related (d_{04}), external environmental related (d_{05}). The sub-criteria are late

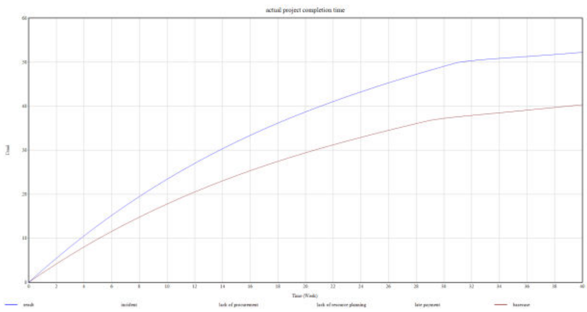

Fig. 13. Planned Time and Actual Time Validation

project payment (d_{11}), interruption from client in design process (d_{12}), deficiency in design (d_{21}), changing personnel (d_{22}), shorten schedule plan (d_{31}), inadequate project management (d_{32}), inadequate lesson learned (d_{33}), inadequate resource planning (d_{34}), inadequate procurement controlling (d_{35}), inadequate risk identification (d_{36}), lack of personnel (d_{41}), incident (d_{42}), bad weather (d_{51}), epidemic (d_{52}).Sensitivity analysis is performed in the result of AHP. Based on the sensitivity analysis result, sub-criteria d_{31}, d_{32}, d_{33}, d_{34}, d_{36}, d_{51}, and d_{52} will be excluded from the root cause of the problem.

This study uses the system dynamic model in the reference [17] with modificationof the delay factor of the project. The system dynamic approach from the previous study is proven to simulate the complex interaction of delay factors to the project schedule. The model describes the interaction of the delay factors. This model can be used as a modeling platform for the company for preventive mitigation. The order of delay factors that has asignificantimpact on the EPCC LNG Filling Station Cargo Dock project delay is inadequate procurement control (d_{35}), inadequate resource planning (d41), incident (d_{42}), late payment (d_{11}), interruption from the client for design (d_{12}), and changing person (d_{22}). The immediate action plan should be defined to prevent the risks in the following company's project. From the simulation result, it can be concluded that the order of preventive mitigation that needed to be conducted are as follows:

1) The improvement in the procurement process should be conducted.
2) Resource planning of sub-contractors should be monitored.
3) The incident should be minimized with construction monitoring and procedure.
4) There should be a clause about late payment to the project owner.
5) Prevent changing personnel to prevent learning curve

There is a limitation to this study. First, this research is relevant to the project in the author's company. Other companies may have different policies, approaches, and procedures. Second, the project cost analysis is not conducted in this research.

. This study's contribution is to prove that the system dynamic model in the previous study can be used by improvising according to the delay factor of the project.This research proposes other comprehensive methods for evaluating delay factors. In this sense, there are many opportunities to extend this research and further verify the results obtained in this article. Further research is needed through the application of other projects.

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