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Integrated Decision-making Approach to Solve Owner Estimate Overdue Problem in Services Procurement Activity

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***Abstract*—Owner Estimate (OE) is used in procurement activity to serve as a benchmark for evaluating the bidder's offer. OE failure to meet the target completion time becomes a common occurrence. The potential impact for an LNG plant is a loss of approximately USD 402 thousand from the gas losses due to the train trip. The research objectives are to identify possible causes of OE overdue problems, analyze and choose the best solution to improve internal effectiveness, and conduct the procurement process. This research also aims to demonstrate an integrated decision-making approach using a combination of methods. The criteria and alternatives solution is generated using Value-Focused Thinking (VFT), the combination of Best-Worst Method (BWM) and Analytic Hierarchy Process (AHP) is used in conjunction to select the most appropriate solution, and Discrete-Event Simulation (DES) is performed to devise evidence-based implementation scenarios. The root causes of the OE problem are the expired software license and insufficient manning quantity. Implementation scenarios are obtained depending on the number of purchase requisitions. From this research, the integrated decision-making approach is proven to effectively solve the problem in developing a solution that is easy to implement by the decision-makers and improves procurement activity as a whole.**

Keywords*— *Analytic hierarchy process, best-worst method, discrete-event simulation, kepner-tregoe, multi-criteria decision-making, sensitivity analysis

INTRODUCTION

Procurement delays are a common occurrence nowadays. The survey revealed that more than 50 percent of the bidding process had experienced delays, and most delays are found early in the lifecycle of procurement. The part of the business that suffers the most from the delays is operations [1].

The common causes of delay in the procurement process are a delay in preparing scope of work, failure to start the procurement process on time, the extension of bid, delay in opening bids, delay in starting or finishing the evaluation process, delays during the approval process, delay in contract negotiation, and supplier challenges the procurement process [2]. Five of eight of these common causes of procurement delay comes from within the internal organization. So, to improve procurement activity as a whole, Organizations need to improve their internal effectiveness first.

The main objective of procurement activity in the LNG plant is to support operation and maintenance activities. Procurement activity is concerned with managing a significant proportion of the non-employee-related spending and ensure that the best possible value for money is achieved when committing this expenditure. Avoiding delays in the procurement process can save time and money.

Owner Estimate (OE) is used in procurement activity to serve as a benchmark for evaluating the bidder's offer, created by Estimator. OE is calculated using various references to convert the scope of work to project value. OE is used as a benchmark in the commercial evaluation process, where the OE is compared to the bidder's offer. The Estimator will negotiate if the bidder's offer is higher than the OE value and clarify if the bidder's offer is lower than OE.

Delayed OE will contribute to several common causes of procurement delays, such as failure to start the procurement process on time, delay in opening bids, and delay in starting or finishing the evaluation process. If any of the OE is overdue and causes delays in the entire procurement activity, the potential impact for an LNG plant is a loss of approximately USD 402 thousand from the gas losses due to flaring and gas needed to start up the train. However, the failure to provide the OE within the completion time target is still found at many organizations in the past few years.

This research aims to identify possible causes regarding delayed OE, develop alternative solutions, analyze, and choose the best solution to improve internal effectiveness to conduct procurement activity. The scope of research is limited to services procurement activity in the author's company. This research also demonstrates an integrated decision-making approach using a combination of methods to obtain an easy-to-implement solution to the problem.

This paper contributes to prove that an integrated decision-making approach is effective in solving complex problems in developing a solution that easy to be implemented. The integrated approach used in this paper tries to leverage the benefit and overcome the weaknesses of each method to provide a reliable, evidence-based solution to a complex problem in procurement activity. Decision-makers can easily implement the appropriate scenario solution which fits the actual situation.

LITERATURE REVIEW

This paper proposed an integrated decision-making approach, which combines Value-Focused Thinking (VFT), Best-Worst Method (BWM), Analytic Hierarchy Process (AHP), and Discrete-Event Simulation (DES) to provide an evidence-based solution for decision-makers.

A set of criteria and alternatives are generated using the Value-Focused Thinking (VFT) approach. The fundamental objectives will build a value hierarchy as a prelude to the next step of quantitative decision analysis [3]. The purpose of VFT is to help define the decision problem clearly and explicitly to stimulate creative thinking in decision-making modeling and the entire decision-making process [4]. The determined value is then used to evaluate alternative solutions to the problem [5].

Integrated decision-making approaches are beginning to be used in many fields. Moslem used integrated BWM and fuzzy triangular sets for evaluating driver behavior factors related to road safety [6]. He also specifically used the BWM-AHP model for the complex problems of dealing with several criteria [7][8]. This research performs an integrated Multi-Criteria Decision-Making (MCDM) method, combining BWM and AHP to choose the best solution to solve the Owner Estimate overdue problem. This combination aims to reduce the number of pairwise comparisons and improve consistency. BWM-AHP provides more reliable results than a simple scoring method because it can prevent respondents from responding arbitrarily, incorrectly, or non-professionally by employing the consistency test [9].

The purpose of BWM is to minimize the lack of consistency when an individual is performing pairwise comparisons, which become a recurring phenomenon [10]. If the consistency is improved, it will reduce the effort required to obtain the result and avoid the risk of reworking to revise the comparison from the beginning. These are especially true for a large number of criteria. BWM will be carried out for a 5x5 matrix or larger pairwise comparison, assuming a limited mind's capacity to compare more than 7±2 elements simultaneously [7].

The purpose of AHP is to maintain the level of detail of individual preferences when choosing alternatives. In AHP, the comparison is made for every possible pair of sub-criteria and alternatives. Thus, AHP provides more information on the relation of the attribute's pairs than BWM. This purpose cannot be achieved using BWM alone, which is very straightforward in determining the criteria or alternatives.

The results obtained need to provide enough information for the analysis. Still, at the same time, the survey should be easy to conduct without burdening respondents with complex and time-consuming questionnaires. There is a tradeoff between the respondents' information, time, and energy saving during the survey process. BWM-AHP can balance these two conflicting aspects and does the survey close to optimal [8].

Zeeshan Aziz used an integrated approach using value stream mapping and DES to improve the productivity of road surfacing operations [11]. DES is performed to obtain the evidence-based implementation scenario, which is easy to implement and helps support decisions. From the simulation, the research of and experimentation how Estimator interacts within Services Procurement activity can be made possible. The simulation also provides value in suggesting an improvement to the system under study, which is services procurement activity. The simulation can also further validate the solution selected from BWM and AHP.

A. Kepner-Tregoe Problem Analysis

The second rational process in this study is Problem Analysis. This process is based on a causal thinking model. It enables individuals to identify, describe, analyze accurately, and solve situations with problems and need to be explained. In addition, it provides an organized way to extract necessary information from situational assessments and retain irrelevant information [12].

The problem is that the work environment may deviate from the expected performance without a known cause. The problem is the visible impact of a cause in the past. Problem analysis provides a means to explain any situation where the expected performance level is not reached, and the reason is unknown [12].

B. Value-Focused Thinking (VFT)

VFT emphasizes the identification and construction of objectives as a value hierarchy [3]. VFT is designed to enable decision-makers to always pay attention to achieving goals throughout the decision-making process [4].

Value is the principle of evaluating whether any possible alternatives or consequences are appropriate. These values are indispensable in any decision-making situation, more fundamental than alternatives [4].

Fundamental objectives describe the primary reasons for a decision problem. The set of fundamental objectives should collectively represent all potential consequences for evaluating a set of alternatives. Means objective refers to the degree to which the realization of the objective will affect the realization of the fundamental objective. Attributes or criteria are used to indicate the extent to which an associated objective is met [4].

Several alternatives will be created based on the attributes and criteria of fundamental objectives and means objective. An alternative is any mutually exclusive and collectively exhaustive set of options selected to a decision problem. An essential feature of the alternative is that its choice must be entirely under the control of the decision-making entity [4].

VFT is widely compatible with logical decision analysis tools like MCDM [13].

C. Best-Worst Method (BWM)

BWM derives the weights based on pairwise comparisons differently compared to the existing MCDM methods. BWM uses fewer comparison data, correcting the inconsistency of pairwise comparisons in the existing methods [10]. If the pairwise comparison matrix in the decision structure is 5x5 or larger, it will take a lot of effort

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for the decision-makers to fill the matrix consistently [6]. The main reason for the inconsistencies is in the unstructured comparisons in the pairwise comparison-based method [10].

BWM has established a new structure for pairwise comparisons. The best (most important or the most desirable) and the worst (the least important or the least desirable) are the pre-defined benchmarks or references for all the remaining criteria; only reference comparison is required [14]. Because BWM requires decision-makers to determine the best and the worst criterion before conducting a pairwise comparison, it enables the decision-makers to have a clearer understanding of the scope of the evaluation. This further supports the reliable comparisons and better consistency of the comparisons [15]. In a single optimization model that uses two opposing references, the best and the worst, BWM can reduce anchoring bias during pairwise comparison by decision-makers [16]. BWM has a high degree of consistency due to this consider-the-opposite-strategy has been proven effective [15].

BWM has several features [10]:

1) BWM requires fewer comparisons compared to matrix-based MCDM methods such as AHP. BWM only needs *2n-3* comparisons, whereas AHP needs *n(n-1)/2* comparisons.
2) The weights derived from BWM are highly reliable as it provides more consistent comparisons than AHP.
3) BWM can be combined with other MCDM methods.
4) While using a comparison matrix, BWM only used integers, making it much easier to use.

D. Analytic Hierarchy Process (AHP)

Analytical Hierarchy Process (AHP) is a decision analysis tool that uses measurement theory to obtain priority through pairwise comparison and relying on expert judgment. The comparisons are made using a scale of judgment, how much more one element dominates another concerning a given attribute [17].

AHP consists of three fundamental principles: decomposition of the problem, pairwise comparison of the various alternatives, and synthesizing the preferences [18].

AHP allows decision-makers to transform subjective judgments into objective measures [19]. AHP can elicit biased opinions of decision-makers in weighting and prioritization. The more a person knows the issue or the problem, the more consistent the results can be expected [9]. Through the use of actual data and subjective decisions of experts, both tangible and intangible elements can be included in the assessment [18]. AHP exploits the organization of human thoughts, which enables one to develop a flexible and straightforward model for solving complex problems [20].

Some people find it challenging to understand the AHP task (using the nine-point scale) initially but considered it easy to choose between two attributes or criteria and levels once understood. AHP creates high inconsistencies between a high number of attributes [21]. This is because humans cannot maintain consistent pairwise judgments when the number of elements increases. The problems become more serious when the decision-maker starts to manipulate the value of pairwise comparisons to eliminate inconsistency instead of performing a fair comparison between the elements [22].

E. Discrete-Event Simulation (DES)

Discrete-Event Simulation (DES) is a modeling system in which the state variable changes only at a discrete set of points in time [23]. DES aims to provide decision-makers with an evidence-based solution and help support decisions. DES is used because it provides flexibility to reconfigure the model to quickly analyze various possible future scenarios and rely on a minimal set of assumptions [24].

DES model can be used to explore performance in many ways. An overview process to examine different scenarios within the model can be seen in Fig.1. Any elements in the model can be changed to determine the

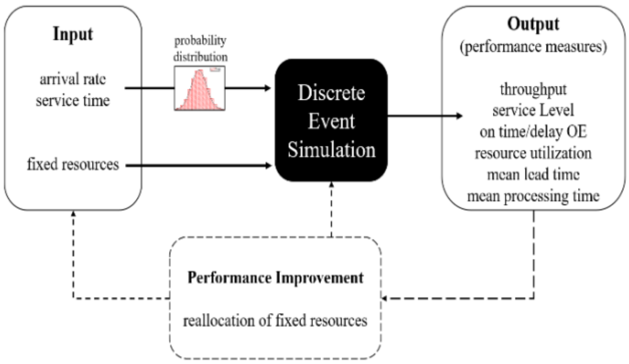

Fig.1. Simulation conceptual diagram

impact on the output (performance measures). This option allows users to test various changes and supports the development of implementation schemes [25].

DES model includes entities, resources, location, arrival rate, service time, and processing logic. Entities represent things that flow through the systems. When an entity moves in the system, resources handle it. Location is physical areas where resources process entities. Arrival rates define the rate at which the entity arrives at specific locations. Service time is defined as the time required for resources to process entities at a set location [25]. Processing logic identifies the rules for the flow of entities through the system and the interaction between entities and resources [26].

For this study, the simulation can be used for the following goals:

1) Simulation enables the research of and experimentation with the internal interactions of a complex system, how Estimator interacts within services procurement activity. The knowledge gained from the simulation

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model may be of great value in suggesting improvements to the system under study.

2) Simulation can verify analytic solutions and improve the decision-making process.

RESEARCH METHODOLOGY

The research methodology is shown in Fig. 2.

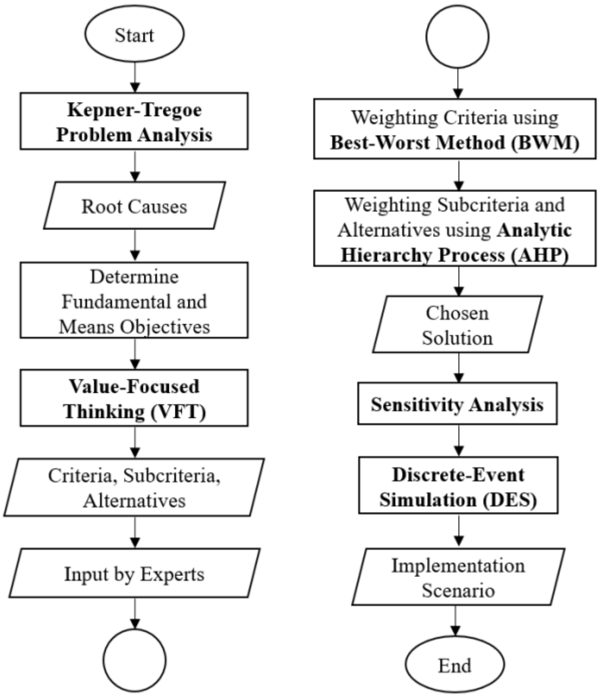

Fig. 2. Research methodology

The root cause of the OE overdue problem is obtained using Kepner-Tregoe problem analysis. Then, the fundamental objective is determined first before conducting a decision analysis.

A set of criteria and alternatives are generated using the Value-Focused Thinking (VFT) approach. The combination of BWM-AHP is performed to choose the best solution to solve the problem. BWM is performed to obtain the weight of the criteria. AHP is conducted to obtain the score of sub-criteria and alternatives. The two methods must be used in conjunction to choose the best solution with optimum effort.

Sensitivity Analysis is conducted next to test the robustness of the obtained solution from BWM-AHP. Since the weights from BWM-AHP are based on subjective judgments, it is necessary to test the ranking stability under different conditions [27]. These scenarios can be visualized, which helps observe the impact of changing the weights to the final alternative rank [28].

After the best solution is chosen and proven robust, the Discrete-Event Simulation (DES) is performed to obtain the evidence-based implementation scenario, which is easy to implement and helps support decisions.

A. Kepner-Tregoe Problem Analysis

This study using the Kepner-Tregoe Problem Analysis to find the root cause of the Owner Estimate overdue problem. Several steps need to be conducted [12]:

1) State the problem

   The problem statement is “Owner Estimate fail to achieve the completion target.”

2) Specify the problem

   The problem described in the problem statement must be elaborated in detail and specified in its four dimensions:

   WHAT – the identity of the deviation
   WHERE – the location of the deviation
   WHEN – the timing of the deviation
   EXTENT – the magnitude of the deviation

3) Develop possible causes from distinctions and changes

   The distinction and changes may provide clues to the cause of the problem. Most individuals who notice a decline in a formerly acceptable performance suggest that something has changed. Instead of searching randomly from a large number of changes, it is easier to start searching from a clearly defined area where it can be guaranteed to be found.

4) Test possible causes against the specification

   The true cause must explain all aspects of the deviation because the true cause will produce the exact effect specified. Testing for the cause is the process of matching the detailed information of the assumed reason with the detailed information of the observed result to see whether the reason is likely to produce the result. Each possible cause must be tested according to specifications.

5) Determine the most probable cause

   Judgment needs to be made to select the most probable cause. To be upgraded to the “most likely cause” status, it must explain or accept all the facts in the specification.

B. Criteria and Alternatives Generation using VFT

In this study, the implementation of VFT relied on in-person discussion with Experts in this field who know well about the issue discussed.

Several steps are needed to conduct VFT:

1) Determine the decision statement
2) Determine the fundamental objective
3) Determine the means objective

The criteria and alternatives can be generated by following the fundamental objective and means objective.

C. Calculating Criteria Weight using BWM

There are five steps to conduct BWM [29]:

1) Determine a set of decision criteria, which obtained from the VFT approach
2) Determine the best and the worst criteria
3) Determine the best criterion’s preference over all other criteria using a number between 1 and 9

4) Determine the preference of all criteria over the worst criterion using a number between 1 and 9
5) Find the optimal weights.
This step aims to determine the optimal weights of the criteria, such that the maximum absolute differences $\left|w_B - a_{Bj}w_j\right|$ and $\left|w_j - a_{jW}w_W\right|$ for all j is minimized, which is translated to the following min-max model:

$$\left|w_B - a_{Bj}w_j\right| \leq \xi, for\ all\ j \quad (1)$$

$$\left|w_j - a_{jW}w_W\right| \leq \xi, for\ all\ j \quad (2)$$

$$\sum_j w_j = 1 \quad (3)$$

$$w_j \geq 0, for\ all\ j \quad (4)$$

By solving all constraints above, the optimal weights and ξ can be obtained. For this model, ξ can be considered as an indicator of the consistency of the comparisons. The lower the ξ value means, the more consistent the comparisons and the more reliable result [29]. The threshold for the ξ value can be seen in Table I.

TABLE I. THRESHOLD FOR INPUT-BASED CONSISTENCY MEASUREMENT

	Criteria						
Scale	3	4	5	6	7	8	9
3	0.1667	0.1667	0.1667	0.1667	0.1667	0.1667	0.1667
4	0.1121	0.1529	0.1898	0.2206	0.2527	0.2577	0.2683
5	0.1354	0.1994	0.2306	0.2546	0.2716	0.2844	0.2960
6	0.1330	0.1990	0.2643	0.3044	0.3144	0.3221	0.3262
7	0.1294	0.2457	0.2819	0.3029	0.3144	0.3251	0.3403
8	0.1309	0.2521	0.2958	0.3154	0.3408	0.3620	0.3657
9	0.1359	0.2681	0.3062	0.3337	0.3517	0.3620	0.3662

The scale is the value of the highest evaluation grades in pairwise comparison, while the criteria are the pairwise comparison criteria. The threshold for consistency ratio in BWM depends on the combination of scales and the number of criteria [30].

D. Calculating Alternatives Score using AHP

According to Saaty, several steps need to be done to make a decision in an organized way [17]:

1) Define the problem.
2) Structure of the decision hierarchy, which is obtained from the VFT approach.
3) Construct a set of pairwise comparison matrices.
4) Use priorities obtained from the comparisons to weigh the priorities.

The consistency ratio (CR) is used to measure the consistency of pairwise comparison judgments. To further improve the consistency, the CR value for different matrix sizes is determined. If the consistency level falls into the acceptable range, the weight results are valid.

The acceptable CR value for different matrices' sizes is [9]:

- For 3-by-3 matrix; CR value is 0.05
- For 4-by-4 matrix; CR value is 0.08
- For larger matrices; CR value is 0.1

The final score of alternatives can be calculated using the weight of criteria obtained from BWM and the weight of sub-criteria & scores of alternatives obtained from AHP.

TABLE II. KEPNER-TREGOE PROBLEM ANALYSIS FRAMEWORK

	Specifying Question	**IS**	**IS NOT**	**Distinction**	**Change**	**Possible Cause**	**Test against Specification**
WHAT	WHAT specific object has the deviation? WHAT is the specific deviation?	Owner Estimate, which completed in more than 6 days	Owner Estimate, which completed in less than 6 days	The constraint found while preparing OE	Software license is expired; manning condition is reduced	Expired software license; insufficient manning condition	This possible cause is true for specification dimension **WHAT, WHERE, WHEN, and EXTENT**
WHERE	WHERE is the deviation observed? WHERE is the deviation on the object?	OE, which has done outside Estimating Group	OE, which has done in Estimating Group	The location where Estimator works	Estimator has other task or agenda besides main job description	Estimator special agenda	This possible cause is true for specification dimension **WHAT and WHERE**
WHEN	WHEN was the deviation observed first? WHEN since the time that the deviation has been observed?	Since 2017, in a condition with high arrival rate of Services Purchase Requisition in a month	In a condition with low – medium arrival rate of Services Purchase Requisition in a month	The quantity of Purchase Requisition being handled at the same time	The arrival rate of Purchase Requisition each month is always different	High arrival rate of Services Purchase Requisition	This possible cause is true for specification dimension **WHEN**
EXTENT	HOW MANY objects have a deviation? WHAT is the trend?	33 of 122 OE in 2017; 28 of 149 OE in 2018; 4 of 105 OE in 2020	89 of 122 OE in 2017; 121 of 149 OE in 2018; 101 of 105 OE in 2020	Number of Estimators	Software license is expired; manning condition is reduced	Expired software license; insufficient manning condition	This possible cause is true for specification dimension **WHAT, WHERE, WHEN, and EXTENT**

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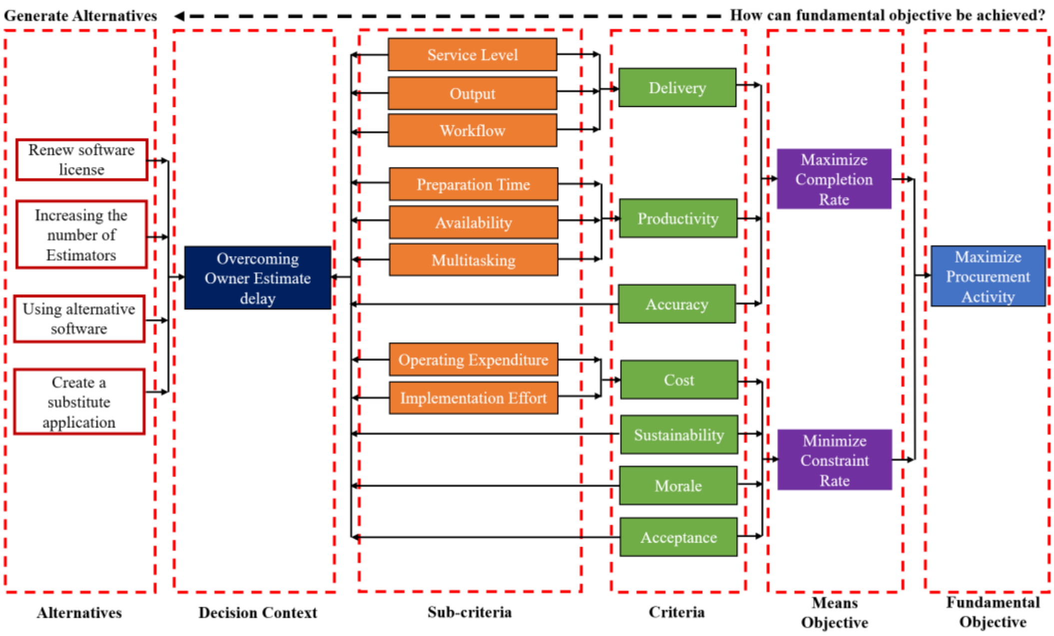

Fig. 3. Value hierarchy

E. *Sensitivity Analysis*

To explore the impact of change in the weights of criteria on the global ranking of other criteria, sub-criteria, and alternatives, sensitivity analysis is performed by changing the weight of all criteria according to the highest rank criteria [27]. Through increasing or decreasing the weight of individual criteria, the resulting changes of priorities and the ranking of the alternatives can be observed [31]. The weight of the highest rank criterion varied from 0.1 to 0.9, and subsequently, the weights of all remaining criteria also varied [32].

F. *Discrete-Event Simulation (DES)*

There are eight steps needed to perform DES [25]:

1) Determine simulation objective
2) Determine model specification
3) Data collection and processing
4) Construct simulation model
5) Verification and validation
6) Run simulation scenarios
7) Gather simulation results
8) Make recommendations based on the results

RESULTS

G. *Root Causes*

The analysis result from the Kepner-Tregoe framework can be seen in Table II. From testing against specification, the most probable causes of all dimension specifications and controllable are expired software license and insufficient manning condition.

H. *Criteria and Alternatives*

The decision statement for this study is "Select the action that will help to overcome the Owner Estimate overdue problem." The fundamental objective of this decision is to maximize procurement activity by overcoming Owner Estimate overdue problem. The mean objectives of the decision problem are minimizing constraint rate while creating Owner Estimate and maximizing the Owner Estimate completion rate.

The alternatives and criteria can be generated by following the fundamental objective and mean objective, as shown in Fig. 3.

I. *Criteria Weight*

The decision criteria to achieve the fundamental objective for this study, as shown in Fig. 3, are Cost (c_1), Delivery (c_2), Productivity (c_3), Accuracy (c_4), Sustainability (c_5), Morale (c_6), and Acceptance (c_7). The data collection result from the Experts can be seen in Tables III, IV, and V.

TABLE III. BEST & WORST CRITERION

	Expert 1	Expert 2	Expert 3	Expert 4
Best	Acceptance	Delivery	Productivity	Delivery
Worst	Cost	Acceptance	Cost	Sustainability

TABLE IV. BEST TO OTHERS PAIRWISE COMPARISON

	c_1	c_2	c_3	c_4	c_5	c_6	c_7
Expert 1	8	3	4	6	7	5	1
Expert 2	2	1	3	4	6	5	7
Expert 3	9	3	1	2	7	6	4
Expert 4	2	1	3	5	9	6	4

TABLE V. OTHERS TO WORST PAIRWISE COMPARISON

	Expert 1	Expert 2	Expert 3	Expert 4
c_1	1	6	1	8
c_2	5	7	7	9
c_3	7	5	9	6
c_4	3	4	8	2
c_5	2	2	2	1
c_6	4	3	3	4
c_7	8	1	5	5

The optimal criteria weights and ξ can be determined by solving (1), (2), (3), and (4) using the data obtained from the experts. The result for all criteria weights by each Expert can be seen in Table VI, and the consistency ratio can be seen in Table VII.

TABLE VI. CRITERIA WEIGHT RESULT

	Expert 1	Expert 2	Expert 3	Expert 4	Final Weight	Rank
c_1	0.035	0.209	0.032	0.214	0.122	5
c_2	0.172	0.353	0.145	0.344	0.253	1
c_3	0.129	0.139	0.361	0.142	0.193	2
c_4	0.086	0.105	0.218	0.085	0.124	4
c_5	0.074	0.070	0.062	0.037	0.061	7
c_6	0.103	0.084	0.073	0.071	0.083	6
c_7	0.400	0.041	0.109	0.107	0.164	3

TABLE VII. EXPERT CONSISTENCY RATIO

	Scales	Criteria	Threshold	CR
Expert 1	8	7	0.3408	0.118
Expert 2	7	7	0.3144	0.066
Expert 3	9	7	0.3517	0.076
Expert 4	9	7	0.3517	0.084

As shown in Table VII, all CR is below the allowable threshold for the respective combination of scale and criteria. So, the result is valid.

J. Subcriteria and Alternatives Weight

As shown in Fig. 3, the sub-criteria to achieve the objectives in this study are Operating Expenditure (c_{11}), Implementation Effort (c_{12}), Service Level (c_{21}), Output (c_{22}), Workflow (c_{23}), Preparation Time (c_{31}), Availability (c_{32}), Multitasking (c_{33}). The available alternatives for the solution are to renew software license (a_1), increase the number of Estimators (a_2), use alternative software (a_3), and create a substitute application (a_4).

TABLE VIII. SUBCRITERIA WEIGHT RESULT

Criteria	Sub-Criteria	Weight	Local Rank
c_1	c_{11}	0.726	1
	c_{12}	0.274	2
c_2	c_{21}	0.714	1
	c_{22}	0.151	2
	c_{23}	0.135	3
c_3	c_{31}	0.546	1
	c_{32}	0.239	2
	c_{33}	0.215	3

TABLE IX. ALTERNATIVES WEIGHT RESULT

	a_1	a_2	a_3	a_4	CR
c_4	0.060	0.462	0.101	0.378	0.021
c_5	0.068	0.559	0.110	0.262	0.029
c_6	0.077	0.433	0.118	0.372	0.020
c_7	0.468	0.370	0.110	0.052	0.048
c_{11}	0.092	0.057	0.311	0.540	0.007
c_{12}	0.490	0.313	0.124	0.073	0.030
c_{21}	0.063	0.514	0.125	0.299	0.013
c_{22}	0.060	0.610	0.110	0.221	0.038
c_{23}	0.079	0.136	0.205	0.581	0.015
c_{31}	0.083	0.131	0.216	0.571	0.015
c_{32}	0.075	0.535	0.112	0.278	0.025
c_{33}	0.080	0.086	0.245	0.589	0.023

The Sub-Criteria weight calculation result can be seen in Table VIII, and the alternative priority calculation result can be seen in Table IX.

K. Final Scores of Alternatives

After obtaining the result from BWM and AHP, the criteria weight from BWM are multiplied by sub-criteria and alternatives score from AHP. Then, the results are summed for respective alternatives to get the final score.

The final score calculation result can be seen in Table X and Fig. 4. All CR are below the acceptable value for the 4x4 matrix, 0.08, so the result is valid. Based on BWM-AHP, Alternatives 2, increasing the number of Estimators, is chosen as the best solution.

TABLE X. FINAL SCORE RESULT

	Final Weight	Rank	Synthesis Value			
			a_1	a_2	a_3	a_4
c_{11}	0.089	5	0.008	0.005	0.028	0.048
c_{12}	0.034	12	0.016	0.010	0.004	0.002
c_{21}	0.181	1	0.011	0.093	0.023	0.054
c_{21}	0.038	10	0.002	0.023	0.004	0.008
c_{23}	0.034	11	0.003	0.005	0.007	0.020
c_{31}	0.105	4	0.009	0.014	0.023	0.060
c_{32}	0.046	8	0.003	0.025	0.005	0.013
c_{33}	0.041	9	0.003	0.004	0.010	0.024
c_4	0.124	3	0.007	0.057	0.012	0.047
c_5	0.061	7	0.004	0.034	0.007	0.016
c_6	0.083	6	0.006	0.036	0.010	0.031
c_7	0.164	2	0.077	0.061	0.018	0.009
Total Score			0.1510	0.3662	0.1505	0.3323

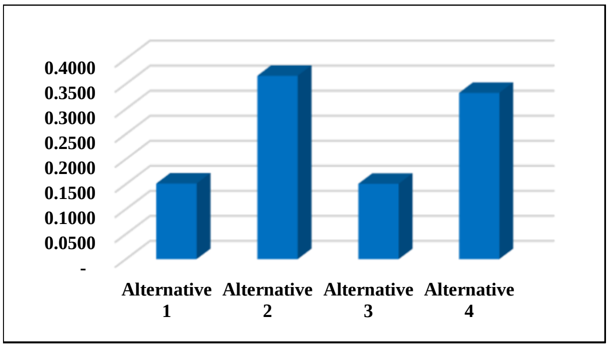

Fig. 4. Final score of alternatives

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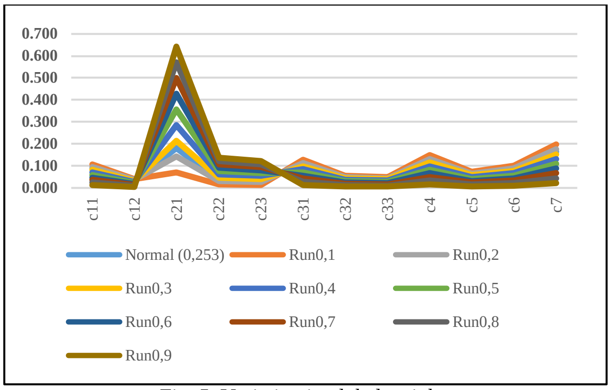

Fig. 5. Variation in global weights

L. *Sensitivity Analysis*

From previous results, the highest-ranking criterion is c_2 (0.253). The weight of c_2 is varied from 0.1 to 0.9 in an increment of 0.1. The modified weight of all criteria can be seen in Table XI.

TABLE XI. WEIGHTS OF CRITERIA DURING SENSITIVITY ANALYSIS

	Normal (0.253)	Modified Weights of All Criteria								
c_2	0.253	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
c_3	0.193	0.233	0.207	0.181	0.155	0.129	0.103	0.078	0.052	0.026
c_7	0.164	0.198	0.176	0.154	0.132	0.110	0.088	0.066	0.044	0.022
c_4	0.124	0.149	0.132	0.116	0.099	0.083	0.066	0.050	0.033	0.017
c_1	0.122	0.148	0.131	0.115	0.098	0.082	0.066	0.049	0.033	0.016
c_6	0.083	0.100	0.089	0.078	0.067	0.055	0.044	0.033	0.022	0.011
c_5	0.061	0.073	0.065	0.057	0.049	0.041	0.033	0.024	0.016	0.008
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

The results show that when c_2 is incrementally increased from 0.1 to 0.2, Acceptance criteria, c_7 gets rank 1, and Workflow sub-criteria c_{23} gets rank 12. Still, after 0.3 till 0.9, Service Level sub-criteria c_{21} gets rank 1 and Implementation Effort sub-criteria c_{12} gets rank 12.

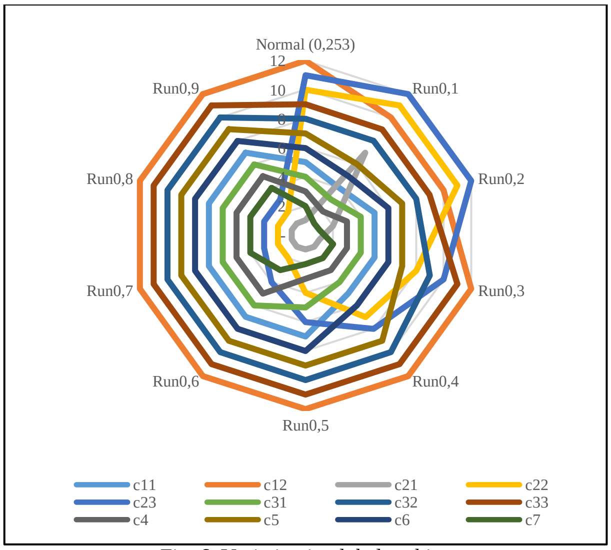

Fig. 6. Variation in global ranking

Sensitivity analysis shows that Delivery c_2 and Sustainability c_5 are the highest and lowest rank criteria, and Service Level c_{21} and Implementation Effort c_{12} are the highest and lowest importance, respectively.

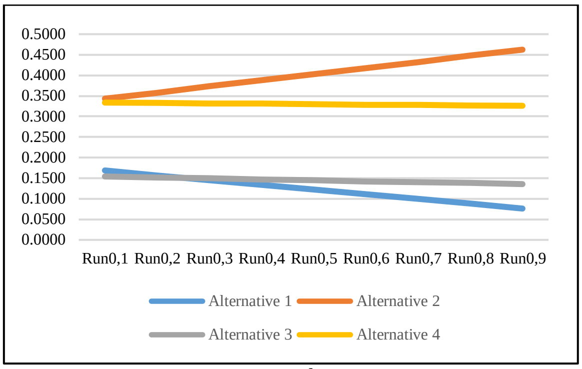

Fig.7. Variation in alternatives score

Fig. 7 shows no change in the highest-ranking alternative, even if the weight of the highest-rank criteria increases or decreases from its initial value. There is only a minor impact from the weight change, a rank reversal between Alternative 1 and 3 when the weight of c2 is changed from 0.2 to 0.3.

M. *Discrete-Event Simulation*

DES is conducted to determine the precise number of Estimators needed to overcome the OE overdue problem.

<u>Specifying Objective</u>

The question that needs to be answered is, "How many Estimators are needed to overcome the Owner Estimate overdue problem?" The chosen solution from BWM-AHP is to increase the number of Estimators, but how exactly the number of Estimators is needed is undefined.

<u>Model Specification</u>

The output performance measures to assess whether the simulation objective is achieved are service level, mean lead time, and delayed Owner Estimate quantity. The entity is services purchase requisition (services PR). The resources are Buyer, Estimator, and Officer. The model parameters consist of the number of resources and arrival rate of the services purchase requisition.

<u>Data Collection</u>

There is a common practice in DES whereby the model integrates actual data with a set of assumptions [25]. In designing the model, the historical data of services procurement activity in 2020 is used. Data is extracted from the e-contract system, which recorded the exact date of every step in the bidding process. Therefore, the actual duration for each step can be obtained that can be used as service time in the model. It should be noted that, in the real system, the resources are processing multiple entities at the same time, so the actual data extracted from the e-contract system should be adjusted with several assumptions of how many entities are processed at the same time.

The collected data was cleaned and processed to fit as input within the DES model. Outliers have the potential to skew simulation input. A simple way to account for the outliers is to use only data summarizing 95 percent of the population, omitting the lowest and highest 2.5 percent [25].

Due to the sample data is extracted from the historical data, no theoretical distribution seems appropriate and fits

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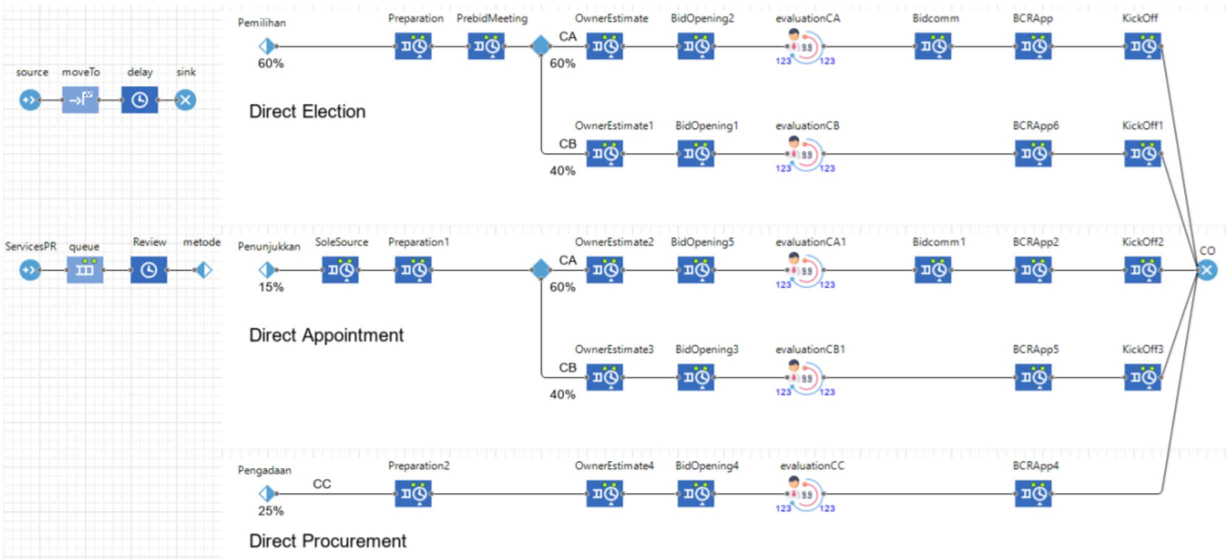

Fig. 8. Model process logic

the data. So, the distributions selected in this study are only uniform and triangular.

Constructing the model

In this step, the actual process of services procurement activity from the real world is transformed into a computer-recognizable format that can be run in simulation software. This research uses Anylogic 8 PLE to run a simulation model. The process logic is shown in Fig. 8.

Verification

The verification method which used in this study are:

1) Test and check the model output's reasonableness under various input parameter values (the number of entities and resources).
   The models show the logical output from a variety of input parameters. If the number of Estimators is reduced, then the number of delayed Owner Estimate increases, vice versa.
2) Make the built model display various output statistics and check all these statistics. The output statistic from the model shows a logical output of the system's performance.
3) From the model animation, verify that what is seen in the animation imitates the actual system. The 2D and 3D animation from the model imitates the actual system. The entity is processed as intended based on the process logic.

Validation

Validation is the process of comparing the model and its behavior with the actual system [23]. In this study, instead of predicting the future to validate the model, the modeler uses historical data different from the data used to calibrate the model. The prediction of the past can replace the prediction of the future.

The data used for calibrating the model is historical data from 2020, but for further validation purposes, the modeler also uses historical data from 2019.

As shown in Table XII, the validation result has a variance below 10%. This result proved that the simulation model that has been built is a correct model to represent the real system.

TABLE XII. VALIDATION RESULT

	2020			2019		
	Act	Sim	Var	Act	Sim	Var
Service PR	98	97	1.02%	155	158	1.94%
Lead Time	27.52	28.92	5.11%	42.3	45.45	7.46%
Delayed OE	4.08%	4.12%	0.04%	0%	0%	0%

Simulation Scenarios

A validated DES model may then be used to test different operational scenarios. The purpose of the simulation can be achieved by performing optimization via simulation. The parameter that needs to be maximized in this study is the Owner Estimate service level, which is the percentage of on-time Owner Estimate from total Owner Estimate finished.

There are three optimization scenarios depends on the number of services purchase requisition, pessimistic (100 services PR), most likely (150 services PR), and optimistic (175 services PR).

Results and Recommendations

The optimization via simulation result for three scenarios shows that the number of estimators required to overcome the Owner Estimate overdue problem is three persons for the pessimistic scenario, four persons for the most likely scenario, and five persons for the optimistic scenario.

Comparison of system performance between the actual number of Estimators, two persons, and optimum number

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based on optimization via simulation results can be seen in Table XIII.

TABLE XIII. SIMULATION RESULTS

Scenario 1	**Actual Number**	**Optimum Number**
Delayed OE	4	0
Service Level	0.928	0.971
Estimator Utilization	0.655	0.474
Mean Lead Time	28.926	24.501
Scenario 2	**Actual Number**	**Optimum Number**
Delayed OE	5	0
Service Level	0.406	0.873
Estimator Utilization	0.797	0.516
Mean Lead Time	94.107	45.456
Scenario 3	**Actual Number**	**Optimum Number**
Delayed OE	5	0

DISCUSSION AND CONCLUSION

This research aims to demonstrate the integrated decision-making approach to solve the strategic problem at hand by using a combination of Kepner-Tregoe problem analysis, value-focused thinking, BWM-AHP, sensitivity analysis, and discrete-event simulation to create an easy-to-implement and evidence-based solution for decision-makers. The proposed method is applied to solve the Owner Estimate overdue problem in services procurement activity.

The concern in procurement activity is to obtain the goods and services from appropriate suppliers to achieve its strategic goals in an economical, efficient, and effective manner. One of the procurement processes is the Owner Estimate calculation. The bidding process starts from Request for Proposal (RFP), prebid meeting, bid opening, administration evaluation, technical evaluation, commercial evaluation, award, and kickoff meeting. OE is used as a benchmark to evaluate the bidder's offer in the commercial evaluation process. OE created is compared to the bidder's offer, to determine the Estimator's following action, whether to negotiate or clarify.

The delay in the Owner Estimate can create a domino effect for other bidding processes. The higher the number of delayed OE will cause a longer delay in other OE and future procurement activity. Delayed OE will contribute to several common causes of procurement delays, such as delays in the opening bid and the evaluation process [2]. To improve procurement activity as a whole, the organization must improve its internal effectiveness to conduct the procurement process by ensuring all completion targets are achieved.

After conducting a problem analysis, the root causes for the delayed OE are expired software licenses and insufficient Estimators. These two factors mainly contribute to the constraint rate and completion rate of the Owner Estimate. That is why to solve the Owner Estimate problem, the dominant factor perceived by Experts must be defined.

The alternatives are generated using the VFT approach with means objectives are these two previous factors, minimize constraint rate and maximize completion rate.

Available alternatives are renewing software license, using alternative software, creating a substitute software that seeks to minimize constraint rate; and increasing the number of Estimators that seeks to maximize completion rate. Alternatives are judged based on their ability to meet these requirements [12].

The application of VFT helps the decision-maker define the decision-making problem clearly and explicitly, which stimulates creative thinking in the decision-making process [4]. A clear objective requires three characteristics: decision context, object, and direction of preference. The objective of this study matched these characteristics. The objective is to maximize procurement activity, with decision context is to overcome OE delay. The object is OE itself, and the means objective becomes the direction of preferences.

The combination BWM-AHP aims to reduce the number of pairwise comparisons and improve consistency, reducing the time and effort needed while maintaining the level of detail from individual preferences. BWM-AHP can provide a solution to decision-makers with optimum effort. If the consistency is improved, it will reduce the effort required to obtain the result and avoid the risk of reworking to revise the pairwise comparison.

When individuals perform numerical estimates that integrate information from previous comparisons, anchoring bias occurs. Individuals formulate estimates based on initial values and then make adjustments to obtain acceptable final answers, which leads to information processing biased toward previous judgment [16]. BWM can reduce anchoring bias by implementing a consider-the-opposite strategy using the best and worst references [15].

Due to the implementation of BWM instead of AHP, the pairwise comparison to determine criteria weight in this study only needs 11 pairwise comparisons, compared to 21 pairwise comparisons. Additionally, reworking is possible in the AHP method when the CR value does not satisfy the requirements. The possibility of the respondents' need to revise their judgment is increased for a high number of criteria conditions, like in this study. The possibility cannot be quantified due to the uncertain nature of the number of reworks required, which is unpredictable, but BWM diminished this possibility.

AHP can elicit biased opinions of decision-makers in weighting and prioritization [9]. Through the use of actual data and subjective decisions of experts, both tangible and intangible elements can be included in the assessments [18]. Therefore, AHP is needed to provide enough information for the analysis.

This research suggests that the integrated approach decision-making methods can create a more reliable and robust result from individual or more conventional approaches. Because of the consistency it provides, there is no ambiguity from the results obtained. It is proven by the sensitivity analysis conducted that there is no change in the ranking of final alternatives, even if the weight of criteria changes. The change in sensitivity analysis reflects the subjectivity of decision-makers, change in the value of decision-makers, and unavailability of information at the time.

Discrete Event Simulation results can provide decision-makers with an evidence-based solution that is easy to implement without complex considerations. DES provides a flexible and cost-effective way to evaluate operational changes before implementing these changes [26]. Several implementation scenarios can be created quickly to predict future conditions. Models can give information when relevant actual data is not yet available.

Bottleneck analysis can be performed to determine where the entities are delayed or which resources are being over or underutilized [33]. From the simulation results, it can be concluded that the bottleneck is on Estimators as resources. The number of Estimators affects the overall system performance, which is reflected in service level and mean lead time. Suppose the number of services PR is increasing, but the number of Estimators is not increased. In that case, the system will suffer a bad performance such as low service level, high Estimator utilization, and long lead time.

Additional resources by increasing the number of Estimators will significantly improve the system performance, as shown in Table XIII. As shown in Table XII, in Scenario 1, which reflected the past condition in 2020, if the number of Estimators is as it is, the simulation results are similar to the actual condition. The mean lead time is 28.926 days, and there are four delayed OE. However, if the number of Estimators uses the recommended quantity or optimum number, the system performance is greatly improved. The mean lead time was reduced to 24.501 days, the service level increase to 0.971 from 0.928, and there is no delayed OE. It is proven that the proposed solution will improve the existing condition.

The simulation results have also proven that the solution chosen by BWM-AHP to increase the number of Estimators is valid and reliable.

This study is not without limitations. First, the study was conducted exclusively in the author's organization using a limited expert as participants, limiting the generalizability of the results. Second, the attributes, criteria, and alternatives are obtained from an in-person discussion with each Expert. It may obtain better results if the brainstorming is performed by conducting Focus Group Discussion with all experts. Finally, the interview process may have a bias due to the explanation of criteria, sub-criteria, and alternatives in the questionnaire and interview process are coming from the author's perspective.

This study introduces a novel integrated decision-making approach by combining several methods. This approach exploits each method's benefits and advantages and overcomes each method's weakness if used individually by combining and executing these methods in conjunction. In this sense, there are many opportunities to expand the present study and further validate the results obtained herein. Further research is required through the application of other cases.

The integrated decision-making approach using the combination of Kepner-Tregoe problem analysis, value-focused thinking, best-worst method, analytic hierarchy process, sensitivity analysis, and discrete-event simulation has been demonstrated in this study. It has been proven to solve the MCDM problem effectively.

Kepner-Tregoe problem analysis concludes that the root causes of OE overdue problems are expired software licenses and insufficient manning conditions. Using the VFT approach, available alternatives to solve the problem are renewing software licenses, increasing the number of Estimators, using alternative software, and creating a substitute application. By combining BWM and AHP, the chosen solution is to increase the number of Estimators. The sensitivity analysis result shows that the chosen solution is robust and reliable. Several implementation scenarios are obtained from Discrete-Event Simulation. Decision-makers can implement the solution by executing one of the scenarios which fit the actual situation. By implementing the proposed solution, the delay in procurement activity can be avoided, internal effectiveness is improved, and great system performance for conducting procurement activity can be achieved.

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