Procurement Costs Optimization in the Construction Industry with CRITIC-EDAS Approach and Transhipment Model

Naufal D. Aditia, Dendi P. Ishak
Industrial Engineering Department
Universitas Indonesia
Jakarta, Indonesia
naufal.diaz@ui.ac.id
dendi@ui.ac.id

Abstract

In the past decade, construction supply chain management (CSCM) has become a considerable concern, because the cost of materials and material-related activities in most construction projects accounts for 50% to 60% of the total project costs. Where material costs are mostly paid to suppliers, supplier selection is one of the most important issues in running a supply chain system. Construction materials procurement and management activities play a role in responding to the challenges of reducing inventories, speeding up deliveries, and lowering overall project costs. This study proposes supplier selection with a multi-criteria decision-making method (MCDM) approach, as well as transportation planning with a transhipment model that is suitable for the construction industry. The hybrid MCDM strategy is applied sequentially by combining Criteria Importance Through Inter-Criteria Correlation (CRITIC) and Evaluation Based on Distance from Average Solution (EDAS) to get more effective results and get some of the best suppliers from the available options, which will then be simulated routes cost-optimized transportation using the transhipment model. This research will produce optimal procurement costs and show the relationship between supplier selection and material transportation to overall procurement costs in the construction industry.

Keywords
Procurement, Construction Industry, CRITIC, EDAS, Transhipment

1. Introduction
The construction industry accounts for about 13% of the global economy and serves as a key driver for other industries as a result of the construction of its infrastructure and facilities (Waddell 2008). However, the construction sector continues to face challenges related to productivity, safety, quality and environmental impact (Choudhry 2017). The construction industry has a lower level of productivity compared to other industries (Barbosa et al. 2017). This is forcing the construction industry to innovate and rethink the concept of project planning and execution (Moussaoui et al. 2021). Construction activities are highly dependent on logistics activities, around 60-80% of the total work involves materials and services (Sezer & Fredriksson 2021). Barbosa et al. (2017) highlights performance issues in construction and proposes seven performance-enhancing factors. Construction site logistics and supply chain management (SCM) are among the seven factors to improve construction project site performance (Sundquist et al. 2018; Vrijhoef & Koskela 2000). These factors develop over time to become more specific. The term construction supply chain management (CSCM) has developed in the last decade and has become a matter of considerable attention (Safa et al. 2014). The condition that underlies this is the total cost of purchasing materials and the costs of activities directly related to materials in the majority of construction projects reaching 50-60% of the total project costs (Cengiz et al. 2017; Safa et al. 2014). Activities that are directly related to materials such as handling in warehouses, loading and unloading at ports and shipping from point of origin to point of destination. Most of the material costs are paid to suppliers, with the result that supplier selection is one of the important issues in running the supply chain system (Pal et al. 2013). Most construction service companies prefer to make a contract with the supplier for the purchase of materials including delivery, so that the costs incurred by the construction service company for the purchase and delivery of materials are fully paid to the supplier (Thunberg 2016). Purchasing activities up to material delivery can be called procurement activities. Construction materials procurement and management activities play a role in

responding to challenges in reducing inventory, speeding up deliveries, and lowering overall project costs (Safa et al. 2014). A good supply chain network (SCN) design is needed to answer these challenges, broadly speaking, the SCN design aims to obtain a network that can achieve company objectives, such as minimizing costs and maximizing customer service levels (Lo et al. 2021). Erengüç et al. (1999) submitting a complete SCN design must meet three dimensions, namely from the supplier side, the manufacturing side and the buyer side.

Based on the background that has been conveyed that the high cost of materials and most of the material costs are paid to suppliers. Therefore, that special attention is needed regarding the selection of suppliers with appropriate criteria for cost optimization. Transportation planning by optimizing the transhipment model to get the optimal total cost of procurement. It should also be compared with the direct transport optimization analysis to test the results of the transhipment optimization of the total cost and time.

1.1. Objectives

The research objectives based on the problem formulation that have been mentioned are:

1. To get the best supplier against the specified criteria,
2. Optimal total procurement cost,
3. Comparison of total procurement costs and total lead time with direct transport analysis.

2. Literature Review

2.1. CRITIC Method

The important thing in the application of the multi-criteria decision-making (MCDM) method is to determine the weights for the criteria against the alternatives that will be ranked. This Criteria Importance Through Inter-Criteria Correlation (CRITIC) method was created by (Diakoulaki et al. 1995), applied to determine the weights on the criteria of a decision matrix. CRITIC is a method for determining the weight of the criteria that affect the severity of a conflict and contrast inherent in the framework of decision-making problems (Diakoulaki et al. 1995). The steps for implementing the CRITIC method were explained by (Kumari & Acherjee 2022) as follows.

Step 1: A decision matrix $A = [x_{ij}]m\ x\ n$ compiled by utilizing information about available alternatives. Where x_{ij} represents the performance of alternative i^{th} based on criteria j^{th}, m represents the number of alternatives chosen by the decision maker while n is the number of criteria used to determine the ranking of these alternatives.

Step 2: The initial decision matrix is normalized by the following equation to get the dimensionless values of the various criteria for comparison.

$$r_{ij} = \frac{x_{ij} - x_j^{min}}{x_j^{max} - x_j^{min}}$$

Where: $x_j^{max} = (x_{ij})$, $x_j^{min} = (x_{ij})$, dan $i = 1, 2, 3, \ldots, m.$

Step 3: After that, calculate the standard deviation and correlation between criteria. Then the w_j weight of criterion j^{th} is calculated by the following equation.

$$w_j = \frac{C_j}{\sum_{j'}^{m} C_{j'}}$$

Where,

$$C_j = \sigma_j \sum_{j=1}^{n} (1 - r_{jj'})$$

Where σ_j is standard deviation of the criterion j^{th} and $r_{jj'}$ is correlation coefficient between the j^{th} and the j'^{th} criterion.

Step 4: To find out the criteria that have been determined are consistent, needed Consistency Ratio $(CR) \leq 0.10$ to be able to meet a consistent matrix, with the calculation of the Consistency Index (CI) using the following equation (Kumar et al., 2019):

$$CI = \frac{\mu_{max} - n}{n - 1}$$

Step 5: Determine the Random Consistency Index (RI) according to the number of predetermined criteria.

Step 6: Calculate CR with the following equation:

$$CR = \frac{CI}{RI} \leq 0.10$$

2.2. EDAS Method

The Evaluation Based on Distance from Average Solution (EDAS) method was applied by Keshavarz Ghorabaee et al. (2017) to determine inventory classification. The advantages of EDAS compared to other classification methods are in its accurate efficiency and simpler mathematical calculations. In EDAS the assessment of alternatives depends on the distance of the individual alternatives from the standard solution about each criterion according to Keshavarz Ghorabaee et al. (2017). The calculation of the EDAS method was written by (Asante et al., 2020) with the following steps:

Step 1: From the decision matrix A, the average solution γ_j for each criterion is determined with the following equation:

$$\gamma_j = \frac{\sum_{i=1}^{m} x_{ij}}{n}$$

Step 2: Calculated the positive distance $\left(PD_{ij}\right)$ or the j^{th} beneficial criteria and also the negative distance $\left(ND_{ij}\right)$ for the j^{th} beneficial criteria from each alternative under each criterion.

$$PD_{ij} = \frac{max\ (0,\ (x_{ij} - \gamma_j)}{\gamma_j}$$

$$ND_{ij} = \frac{max\ (0,\ (\gamma_j - x_{ij})}{\gamma_j}$$

Step 3: Based on PD_{ij} and ND_{ij}, it is determined the aggregate distance for each alternative:

$$SP_i = \sum_{j=1}^{n} PD_{ij}$$

$$NP_i = \sum_{j=1}^{n} ND_{ij}$$

Step 4: SP_i and NP_i normalized by the following equation:

$$NSP_i = \frac{SP_i}{max_i SP_i}$$

$$NNP_i = 1 - \frac{NP_i}{max_i NP_i}$$

Step 5: The calculation of the assessment score for each alternative uses the following equation:

$$AS_i = \frac{1}{2}(NSP_i + NNP_i)$$

Step 6: From the calculation of the scores on the alternatives, the ranking for each alternative is determined.

2.3. Model Transhipment

There have been many previous studies that discuss the completion of transhipment. Transhipment here can also be called a transfer problem. Various studies have shown that alternative transfers between retailers improve supply chain performance in terms of costs, revenues and service levels (Naderi et al. 2020). Cavagnini et al. (2021) provide a complete review of the transhipment literature based on inventory systems, ordering and transhipment characteristics. There are 2 types of transhipment: emergency or reactive transhipment and preventive or proactive transhipment, which differ mainly in timing (Ahmadi et al. 2016). Proactive transhipment distributes inventory between retailers or warehouses before realizing demand, while reactive transhipment distributes remaining inventory between retailers or warehouses after demand is realized (Liao et al. 2020).

Fungsi Tujuan

$$Minimize\ z = \sum_{i=1}^{m} \sum_{l=1}^{p} b_{il} v_{il}$$

Where z is the total transportation cost, b_{il} represents the transportation cost from the i^{th} origin point based on the l^{th} destination point, m represents the number of selected origin points while p is the number of destination points. While v_{il} represents the volume of cargo transported from the i^{th} origin point based on the l^{th} destination point.

Batasan

$$\sum_{l=1}^{p} v_{il} \le P_i$$

for $i = 1, 2, \dots, m$

$$\sum_{i=1}^{m} v_{il} \ge D_l$$

for $l = 1, 2, \dots, p$

$$v_{il} \ge 0$$

for $i = 1, 2, \dots, m;\ l = 1, 2, \dots, p$

Where P_i represents the amount of supply from the i^{th} origin point, while D_l is the number of the demand from the l^{th} destination point or buyer.

3. Methods

The data that has been collected and presented in the matrix will be processed according to the stages of the research methodology that have been presented in the previous sub-chapter. Data processing will go through two stages, namely the supplier selection stage and the transportation optimization stage.

The selection of suppliers begins with the identification of criteria that have been determined by the study of the existing literature. Continued to determine the weight for each criterion. After obtaining the weights of each criterion, a consistency analysis is carried out to ensure that the matrix meets the requirements to be able to proceed to the next stage. After obtaining a consistent weight of criteria and decision matrix, the analysis is continued by determining the ranking for each supplier against each criterion.

The delivery of materials from the supplier's warehouse to the construction project site is simulated with a transhipment scheme, in which the mathematical model for this transhipment uses a mathematical model from previous research that has been redeveloped. The objective function of this model is to minimize the total transportation costs from the selected supplier's warehouse to the project site through a predetermined transhipment point.

4. Data Collection

In this study, to run the calculation model, it takes some data, both from secondary data searches and mathematical approaches. Adjustment to the CRITIC-EDAS method and linear programming for transhipment problems requires data such as supplier data, transhipment points and construction project sites. Total data from 21 suppliers ($S1 - S21$), 2 transshipment points ($T1 - T2$) and 4 construction project sites ($C1 - C4$) were collected from the PTXY database. In the first stage of analysis, the selection of suppliers begins with the identification of criteria. It was concluded from the literatures that had been reviewed obtained 7 criteria, namely: geographic location ($K1$ & $K2$); production capacity ($K3$), company equity ($K4$), company relationship ($K5$), product price ($K6$), and minimum purchase ($K7$). The following are the results of data collection from 21 suppliers to fill in the predetermined criteria (Table 1-3).

Table 1. Data Classification

Classification	Code	Number
Criteria	*K1 - K7*	7
Supplier	*S1 - S21*	21
Supplier’s Warehouse Location		
Jawa Timur	*S2, S3, S13, S15*	4
Jawa Barat	*S5, S16*	2
DKI Jakarta	*S8, S11, S19*	3
Banten	*S1, S4, S6, S7, S9, S12, S14, S18, S20, S21*	10
Sumatera	*S10, S17*	2
Transhipment Point	*T1, T2*	2
Construction Site	*C1, C2, C3, C4*	4

Table 2. Supplier Data Related to Criteria

Supplier	City	*K1*	*K2*	*K3*	*K4*	*K5*	*K6*	*K7*
S1	Cilegon	110.00	881.00	3,076.92	7,378,560,117.00	30	10,600.00	1,400.00
S2	Surabaya	782.00	6.00	1,153.85	1,009,652,000,000.00	49	10,550.00	900.00
S3	Sidoarjo	782.00	31.40	830.77	756,846,071,956.00	49	10,500.00	1,700.00
S4	Tangerang	35.50	813.00	153.85	1,000,000,000.00	10	10,290.00	1,300.00
S5	Bekasi	27.60	771.00	115.38	65,678,714,135.00	48	12,510.00	1,800.00
S6	Tangerang	35.50	813.00	96.15	10,000,000,000.00	51	12,430.00	1,200.00
S7	Serang	95.10	867.00	96.15	750,000,000,000.00	14	11,200.00	1,000.00
S8	Jakarta Timur	17.60	778.00	92.70	1,612,443,230,170.00	50	11,840.00	1,500.00
S9	Serang	95.10	867.00	115.38	3,135,838,710.00	18	11,620.00	1,300.00
S10	Medan	1,895.00	2,668.00	57.69	615,578,918,032.00	52	13,850.00	500.00
S11	Jakarta Timur	17.60	778.00	92.31	248,170,745,933.00	33	11,100.00	1,900.00
S12	Tangerang	35.50	813.00	115.38	39,034,949,026.00	3	12,060.00	700.00
S13	Surabaya	782.00	6.00	96.15	15,780,985,676.00	4	11,990.00	600.00

S14	Tangerang	35.50	813.00	115.38	900,000,000,000.00	11	12,860.00	1,300.00
S15	Gresik	798.00	20.00	1,153.85	200,530,316,637.00	46	11,890.00	700.00
S16	Bogor	78.60	824.00	96.15	20,590,570,336.00	9	11,100.00	1,000.00
S17	Batam	1,145.00	1,927.00	96.15	101,726,519,228.00	32	12,670.00	1,900.00
S18	Serang	95.10	867.00	553.85	229,382,995,906.00	9	12,840.00	500.00
S19	Jakarta Utara	5.90	785.00	2,307.69	25,000,000,000,000.00	6	11,010.00	700.00
S20	Serang	95.10	867.00	96.15	750,000,000,000.00	8	10,640.00	1,100.00
S21	Serang	95.10	867.00	115.38	4,869,352,214.00	8	11,870.00	1,100.00

5. Result and Discussion

Transportation optimization data processing with different supplier arrangements is carried out to deepen and test the results of the transportation optimization analysis of the transhipment model. The results of data processing with different supplier arrangements show that the transportation optimization of the transhipment model always has a lower total transportation cost than the direct transport model. However, in terms of purchasing costs, the comparison results are similar for the arrangement of 1 supplier, while the arrangement of 3 and 5 suppliers has the results of the purchase cost with the transhipment model being lower than the purchase cost with the direct transport model, while the arrangement of 10 and 21 suppliers has the results of the purchase cost with the transhipment model. higher than the purchase cost with the direct transport model. In the analysis of the arrangement of 3 suppliers, the purchase cost has a significant difference compared to the composition of the number of other suppliers, the difference reaches IDR 3,838,780,464.40 while the analysis of the number of other suppliers has a difference of not more than IDR 1,700,000,000.00.

In total procurement costs, the lowest procurement costs were obtained using the transportation optimization method of the transhipment model of 10 suppliers with a total procurement cost of IDR 103,145,979,785.50. Meanwhile, for the smallest lead time, the transportation optimization method of the direct transport model is obtained with an arrangement of 21 suppliers, the total lead time reaches 11 days.

5.1. Numerical Results

The results of the total cost and total lead time for the five supplier arrangements with the transhipment model were compared with the direct transport model. The following are the results of these calculations (table 3).

Table 3. Result Comparison between Transhipment and Direct Transport

Supplier	**Transhipment**		**Direct**	
	Biaya Pengadaan (IDR)	**Lead Time (hari)**	**Biaya Pengadaan (IDR)**	**Lead Time (hari)**
1	105,490,885,400.00	52	106,606,736,000.00	28
3	103,570,886,021.50	39	108,253,981,703.65	50
5	103,632,223,734.50	39	104,960,600,830.00	38
10	103,145,979,785.50	31	103,608,346,455.00	15
21	105,959,695,238.00	28	104,907,003,060.00	11

5.2. Graphical Results

The results of the comparison in the table above are presented in the following figure 1-3.

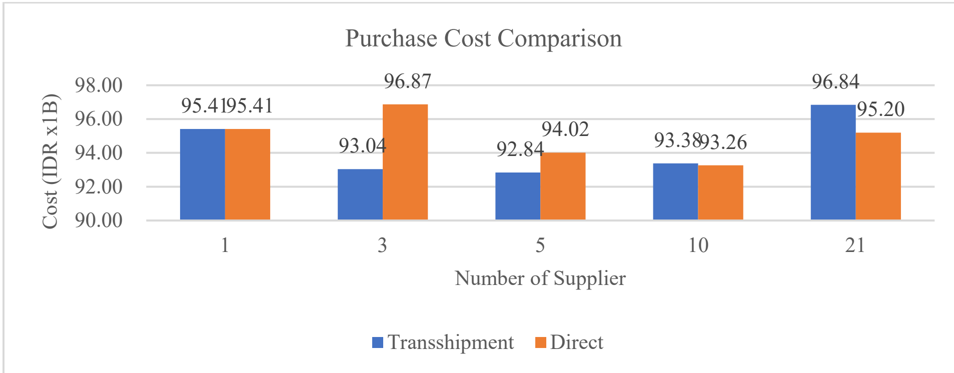

Figure 1. Purchase Cost Comparison

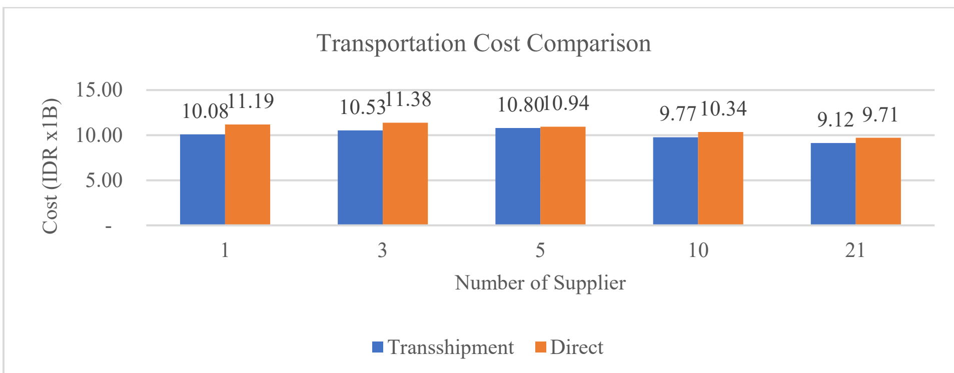

Figure 2. Transportation Cost Comparison

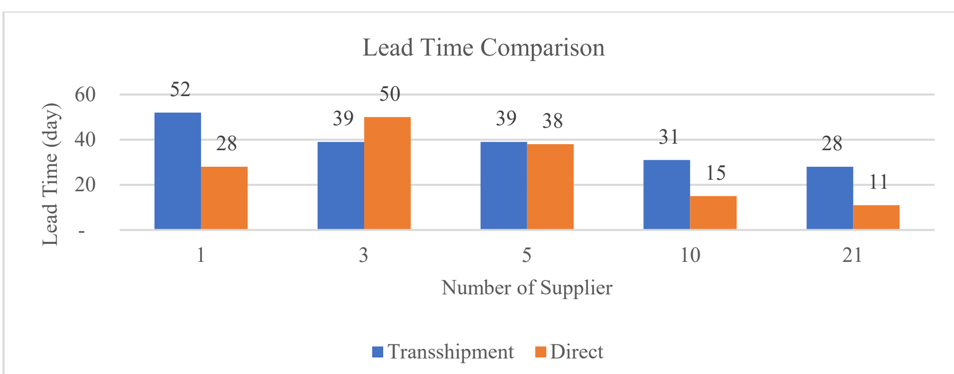

Figure 3. Lead Time Comparison

5.3. Proposed Improvement

The supplier selection uses a hybrid MCDM strategy which is applied sequentially by combining CRITIC and EDAS to get more effective results. Determination of the weights for each criterion from the data that has been collected using the CRITIC method starting with the normalization of the decision matrix (table 4-5).

Table 4. Weighted Criteria

K2	***K3***	***K4***	***K5***	***K6***	***K7***				
0.62	1.04	1.14	1.44	0.62	1.21	6.07	0.27	1.62	0.13
0.00	1.22	1.02	1.07	0.44	0.98	5.33	0.23	1.21	0.10
1.22	0.00	0.50	1.07	1.40	1.11	6.34	0.27	1.71	0.14
1.02	0.50	0.00	0.79	1.17	1.23	5.84	0.22	1.26	0.10
1.07	1.07	0.79	0.00	1.17	1.34	6.88	0.39	2.67	0.22
0.44	1.40	1.17	1.17	0.00	1.22	6.00	0.27	1.61	0.13
0.98	1.11	1.23	1.34	1.22	0.00	7.08	0.32	2.26	0.18

Table 5. Supplier Rank

Supplier	***SPi***	***SNi***	***N SPi***	***N SNi***	***ASi***	**Rank**
S1	0.85	0.11	0.39	0.90	0.64	2
S2	0.29	0.25	0.13	0.78	0.46	8
S3	0.29	0.23	0.13	0.80	0.47	5
S4	0.16	0.20	0.07	0.82	0.45	9
S5	0.23	0.21	0.11	0.81	0.46	7
S6	0.13	0.22	0.06	0.81	0.43	13
S7	0.10	0.20	0.05	0.83	0.44	11
S8	0.19	0.11	0.09	0.90	0.49	3
S9	0.12	0.22	0.05	0.81	0.43	12
S10	0.00	1.14	0.00	0.00	0.00	21
S11	0.26	0.20	0.12	0.83	0.47	4
S12	0.12	0.28	0.05	0.75	0.40	18
S13	0.10	0.48	0.04	0.58	0.31	19
S14	0.14	0.16	0.06	0.86	0.46	6
S15	0.28	0.34	0.13	0.70	0.41	17

S16	0.11	0.24	0.05	0.79	0.42	16
S17	0.12	0.67	0.06	0.42	0.24	20
S18	0.11	0.21	0.05	0.82	0.43	14
S19	2.19	0.07	1.00	0.94	0.97	1
S20	0.11	0.18	0.05	0.84	0.45	10
S21	0.09	0.23	0.04	0.80	0.42	15

5.4. Validation

After obtaining the weights of each criterion, a consistency analysis is carried out to ensure the weighting of the scale on a pair of choices does not deviate from other options so that the matrix has met the requirements to be able to proceed to the next stage of analysis. Consistency meets when $CR \leq 0.1$. Calculation of CR using equation (5). The results of the calculation of CI = 0.11 and RI = 1.32 for a matrix of size 7x7, so that CR = 0.09 is obtained which has met the consistency requirements.

6. Conclusion

Based on the research that has been done, it can be concluded that the results of data processing show the ranking of each supplier against each criterion affecting the final ranking. The analysis stage of supplier selection using CRITIC-EDAS with transportation optimization analysis of the transhipment model with an arrangement of 21 suppliers shows similar final results, where at the supplier selection analysis stage there are similarities in K3 criteria, relatively large production capacity and K6 criteria, relatively cheap product prices. The results of the optimization of the transhipment model of transportation with the composition of 21 suppliers also show that the two top-ranked suppliers are included in the three shipments with the highest volume. The criteria for K1, K2, K4, K5, and K7 show a less significant effect on the transportation optimization analysis of the transhipment model.

The transportation optimization of the transhipment model compared to the direct transport model in this study shows that the transhipment model is more efficient in terms of transportation costs. This is influenced by the lower transportation costs per unit of material due to the larger load capacity of the fleet used from the transhipment point to the construction project site. However, in terms of time, the transhipment model takes longer to complete the transportation of materials to the construction project site.

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Biographies

Naufal Diaz Aditia, is a Master Degree student in the field of Industrial Engineering at the Universitas Indonesia, Jakarta, Indonesia. He earned his bachelor degree in Ocean Engineering at Institute Teknologi Sepuluh Nopember (ITS), Surabaya, Indonesia. Currently he is in charge at a construction company in Indonesia from 2019 as a Procurement Officer. His current research is in operation research for a construction company for the completion of his Master Degree.

Dendi P Ishak, is a lecturer at the Industrial Engineering Department of Universitas Indonesia. He holds a Bachelor Engineering degree and a Master of Engineering Science degree in Industrial Engineering from Wayne State University USA. Mr. Dendi completed his Doctorate in Mechanical Engineering from Universiti Teknologi MARA Malaysia. His field interest in organizational behaviour and design, industrial project management, Safety Engineering and Management, and Maintenance Management System.