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Preface

Even though the COVID-19 pandemic has not abated yet, this edition of Industrial Analysis Journal volume 15 no 2 Agustus 2021 is still managed to publish. Thanks to continuous submission from contributors and hardwork of editor teams. This volume presents various fields of transportation and material sciences. Transportation engineering nowadays is among the priority programs in Indonesia, which emphasize in Infrastructures development. Material sciences are therefore very relevant in supporting this theme.

Research and assessment were conducted by various institutions researchers in those fields. In this edition, the journal publishes important and interesting papers related to transportation, such as . alysis Of Heat Release Rate In Engine Room Fires Of 300 Gt Ferry Ro-Ro Passenger By Using Water Mist System And CO_2 System, Hydrodynamic And Boussinesq Wave Modeling For The N219 Amphibious Aircraft Seaplane Dock Development Plan In Panjang Island, and Developing Supply Chain Network With Piecewise Linear Transportation Cost For A Small-And-Medium Enterprise In Cilegon.

In this editions are published also paper on materials engineering :. Relationship Between Safety Culture And The Safety Climate, Safety Behavior, And Safety Management, Microstructure And Oxidation Behavior Of The Oxide Dispersion Strengthened Stainless Steel 316L With Zirconia Dispersion and Assay And Graphite Furnace- Atomic Absorbance Spectrometry Accuracy For Palladium Content Analysis. The other paper are environment researchers : Demographic Characteristics Of Site Vicinity Area For Preparation In West Kalimantan NPP Site and The Effect Of Dimethyl Ether (DME) as LPG Substitution On Household Stove: Mixture Stability, Stove Efficiency, Fuel Consumption, and Materials Testing.

The editors always do their best to improve the quality of the Journal; especially now that we are heading towards an english language journal in order to increase the impact and citations. The next publication is scheduled on December 2021. As closing remarks, the editors always call for critics and suggestions to further improve this Journal.

The Editors

Majalah Ilmiah Pengkajian Industri
(Journal of Industrial Technology Assessments)

ANALYSIS OF HEAT RELEASE RATE IN ENGINE ROOM FIRES OF 300 GT FERRY RO-RO PASSENGER BY USING WATER MIST SYSTEM AND CO_2 SYSTEM

Wira Setiawan, Distyan Kotanjungan

Abstract

Based on statistical data in recent years, there are still quite several ship accidents due to fires, including on passenger ships. The water mist system is a fire suppression system that allows it to be used in the engine room with the advantage that it can keep the heat production rate low during the extinguishing process and can be operated earlier than the CO_2 system. The research is conducted by using a fire dynamic simulator in the engine room of a 300 GT ferry ro-ro passenger to compare the heat release rate of fire without an extinguishing system, an existing CO_2 system, and a water mist system. The result shows that the CO_2 fire suppression system reduces the heat release rate more rapidly to the decay phase at 375 seconds while the water mist takes more than 900 seconds. However, the fully developed phase of the water mist suppression system occurs more quickly than CO_2 because the sprinklers are activated shortly after a fire occurs. Unlike water mist, the CO_2 system is activated at 60 seconds so that the pre-combustion, growth, flashover, and fully developed phases are at the same HRR and time as the natural one.

Keywords: Heat Release Rate; Water mist System; CO_2 System; Fire on Ship; Fire Dynamics

THE EFFECT OF DIMETHYL ETHER (DME) AS LPG SUBSTITUTION ON HOUSEHOLD STOVE: MIXTURE STABILITY, STOVE EFFICIENCY, FUEL CONSUMPTION, AND MATERIALS TESTING

Galuh Wirama Murti, Unggul Priyanto, Imron Masfuri, Nesha Adelia

Abstract

DME has characteristics similar to LPG so that the storage and handling are not different from LPG. DME could be used as a solvent that can extract typical types of rubber/polymer material. The aims and objectives of this study are to determine the effect of blending DME/LPG ratios (100/0, 80/20, 50/50, 30/70, 20/80) on the stability of the DME/LPG mixture, the efficiency of the stove, and the fuel consumption. The highest efficiency of the stove with blending DME/LPG was 71.29% and was achieved by the LPG-DME stove with 50/50 DME/LPG. This result shows the stove design has an enormous effect on efficiency. The increasing DME ratio in the blending fuel can raise fuel consumption. The study also observes the effect of the blending on several stove accessories rubber materials. The study reveals that the usage of a DME/LPG with blend ratios between 20/80 - 30/70 does not require a replacement of any substitute materials but only requires minor modifications to the stove. However, at a higher DME composition, the use of the fuel needs to replace the seal that is resistant to DME.

Keywords : Dimethyl ether; LPG; stability; stove; the rubber material Received: 2021-05-03; Revised: 2021-07-19; Accepted: 2021-07-19

HYDRODYNAMIC AND BOUSSINESQ WAVE MODELING FOR THE N219 AMPHIBIOUS AIRCRAFT SEAPLANE DOCK DEVELOPMENT PLAN IN PANJANG ISLAND

Hanah Khoirunnisa, Mardi Wibowo, Wahyu Hendriyono, Khusnul Setia Wardani

Abstract

The flight test of N219 Amphibious aircraft will be targeted in 2023/2024 and it needs a seaplane dock. One of the potential locations for the seaplane dock is Panjang Island at Seribu Islands. This study aims to know the characteristic of hydrodynamic and wave conditions and to determine whether Panjang Island is suitable for the seaplane dock. This study uses a modelling method with MIKE 21 Flexible mesh (FM) Hydrodynamic-Spectral wave (HD-SW) module and MIKE 21 Boussinesq Wave (BW) module. The needed data are the bathymetry data were obtained from the Indonesian Navy Hydrographic and Oceanographic Center (Pushidrosal), tidal data, wave and wind data. The validation result between hydrodynamic modelling and Tidal model driver (TMD) is 92%. Current velocity has a range of 0.018-0.199 m/s during the west monsoon and 0.02-0.193 m/s during the east monsoon. The 50-year return period modelling resulted the maximum wave height between 1.139 to 1.474 m. Furthermore, the significant wave height has the range of 0.679 to 0.741 with the period of 13.45 seconds. In general, the current and wave conditions in Panjang Island is suitable for the construction of the seaplane dock, except that the dominant wave heights are still above the requirements.

Keywords : boussinesq wave; hydrodynamic modelling; spectral wave; N219A; seaplane dock

DEVELOPING SUPPLY CHAIN NETWORK WITH PIECEWISE LINEAR TRANSPORTATION COST FOR A SMALL-AND-MEDIUM ENTERPRISE IN CILEGON

Bobby Kurniawan, Ade Irman, Akbar Gunawan, Ani Umyati, Evi Febianti, Nuraida Wahyuni, Putro Ferro Ferdinant, Ratna Ekawati, Fellek Getu Tadesse

Abstract

This study proposed a supply chain network for determining suppliers' location in which the transportation costs are a piecewise linear function. The supply chain network consists of a production facility, suppliers, and customers. These types of costs are found in the fields of transportation, logistics, and purchasing discount. First, the supply chain network is formulated as the mixed-integer non-linear programming (MINLP) because piecewise linear transportation cost makes the model non-linear. Then, the model is transformed into a mixed-integer programming (MIP) model using the convex-combination method to overcome this nonlinearity. The model was used for solving the problem faced by a small and medium enterprise (SME) in Cilegon. The MIP was solved using the CPLEX software. Sensitivity analysis was carried to provide the SME with several alternatives in handling the suppliers' location problem.

Keywords : Supply chain network; piecewise linear function; convex-combination method; small and medium enterprise

RELATIONSHIP BETWEEN SAFETY CULTURE AND THE SAFETY CLIMATE, SAFETY BEHAVIOR, AND SAFETY MANAGEMENT

Dian Palupi Restuputri, M. Syahban Giraldi, Shanty Kusuma Dewi, Ilyas Masudin, Uci Yuliati

Abstract

This article aims to measure the application of occupational safety and health using Cooper's Reciprocal Safety Culture Model and Confirmatory Factor Analysis method. The objective function of this article is to find out the aspects of safety culture that have been implemented by companies. A questionnaire was circulated to staff on the company's production floor as part of this study.The results of the questionnaire recapitulation were then analyzed using the confirmatory factor analysis method. Based on the score calculation results and the category determination build on the questionnaire scores on each dimension of the safety culture applied to the Steel Company, the safety climate value of 55.58 is obtained, which is on a 'quite good' scale. The safety behavior value of 44, 89 is included on a 'quite good' scale, the safety management system value of 22.04 is on a 'poor' scale, and the safety culture value of 40.83 is on the 'quite good' scale. With these results, it is essential to make improvements to the safety culture in the company, especially in the dimensions of the safety management system, which is on the 'quite good' scale.

Keywords: Occupational Safety and Health; Safety Culture; Safety Climate; Safety Behavior

MICROSTRUCTURE AND OXIDATION BEHAVIOR OF THE OXIDE DISPERSION STRENGTHENED STAINLESS STEEL 316L WITH ZIRCONIA DISPERSION

Syahfandi Ahda, Rohmad Salam, Agus Sujatno, Diene Hairani, Nanda Shabrina, Sulistioso Giat, Bandriyana

Abstract

Synthesis of the oxide dispersion sODS steels was performed by dispersing 0.5 wt % zirconia to the stainless steel SS 316L by the powder metallurgy method. The ball milling process was carried out for pre-alloying the elements continued with the consolidation performed by the compaction and sintering process using the APS (Arc Plasma Sintering). Analysis of microstructure was performed by observing the morphology, identify the phase and evaluate the oxide distribution. An oxidation test was carried out at 700ºC for 8 hours using the MSB (Magnetic Suspension Balanced) apparatus to evaluate the primary oxidation curve. Relatively the same grain fineness consists of 2 dominant phases, so the presence of an austenitic phase and a ferritic phase has been analyzed from the X-Ray Diffraction pattern. The homogeneous distribution of zirconia was observed, followed by improvements in mechanical properties, which could be identified by hardness testing. The parabolic phenomenon oxidation curve was explained by the excellent high-temperature oxidation behavior of the ODS steel, followed by the formation of ZrO_2 oxide protective thin layer.

Keywords: ODS steel; zirconia; microstructure; oxidation; powder metallurgy

ASSAY AND GRAPHITE FURNACE- ATOMIC ABSORBANCE SPECTROMETRY ACCURACY FOR PALLADIUM CONTENT ANALYSIS

Ronaldo Irzon, **Kurnia**

Abstract

Palladium is a member of the expensive Platinum Group Metals as it is indispensable for various applications of modern technology. Due to the very small number of these elements in nature, high-sensitivity analytical methods and devices are required for accurate PGM measurement. The current study aims to determine the accuracy level of the Graphite Furnace-Atomic Absorbance Spectrometry device for palladium analysis after pre-concentration through the assaying process. The studied samples were two in-house standard reference samples with stream sediment and ultramafic rock matrices. Due to the lack of certified reference material containing certain palladium compositions, the degree of accuracy was tested by the spiking method. The detection limit for Pd in this study was 11.79 ppb. Pd content in the stream sediment (17 ppb) is much lower than of the ultramafic sample (290 ppb), implying PGM association to ultramafic rock naturally. Almost all measurements have good accuracy according to spike recovery between 80-120%. Inaccurate addition process and inappropriate calibration range most probably lead to inaccuracy.

Keywords: palladium; GF-AAS; assay; spiking

DEMOGRAPHIC CHARACTERISTICS OF SITE VICINITY AREA FOR PREPARATION IN WEST KALIMANTAN NPP SITE

Siti Alimah, Euis Etty Alhakim, Sunarko, Kurnia Anzhar, Mudjiono

Abstract

The potential risk of radioactive release to the environment and surrounding population can occur when there is a nuclear emergency, and nuclear preparedness planning is required for disaster mitigation. In preparedness planning, data is needed, one of which demographic characteristics. Demographic information in site preparation can produce appropriate and efficient policy formulations because the number and density of the population, as well as the susceptible population, are known. The method used is secondary data collection, data verification, data processing, mapping, and analysis. This study aims to determine the demographic characteristics of the site vicinity. The study results show that the population density in 5 km radius area is 177 people/km^2. In 2018, the total population was 5,199 people, the percentage of the male population was 50.3%, and the female population was 49.7%. The population aged ≥20 years was 63.4%, 5-19 years old was 29.7%, and aged 0-4 was 6.9%. The projected population in 2047 is 6,523 people. The assumption is that in the event of a nuclear emergency, the emergency response considers the susceptible population. Evacuation of residents related to the emergency response can be carried out through 2 routes, namely through the South Singkawang District to the West Singkawang area, which is about 30 km from the site or through the Sungai Raya District to the Sungai Kunyit area, which is of about 26 km from the site.

Keywords : Demographic; Site Vicinity; Nuclear Emergency; Evacuation

DEVELOPING SUPPLY CHAIN NETWORK WITH PIECEWISE LINEAR TRANSPORTATION COST FOR A SMALL-AND-MEDIUM ENTERPRISE IN CILEGON

Bobby Kurniawan[1], Ade Irman[1], Akbar Gunawan[1], Ani Umyati[1], Evi Febianti[1], Nuraida Wahyuni[1], Putro Ferro Ferdinant[1], Ratna Ekawati[1], Fellek Getu Tadesse[2]

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ABSTRACT

This study proposed a supply chain network for determining suppliers' location in which the transportation costs are a piecewise linear function. The supply chain network consists of a production facility, suppliers, and customers. These types of costs are found in the fields of transportation, logistics, and purchasing discount. First, the supply chain network is formulated as the mixed-integer non-linear programming (MINLP) because piecewise linear transportation cost makes the model non-linear. Then, the model is transformed into a mixed-integer programming (MIP) model using the convex-combination method to overcome this nonlinearity. The model was used for solving the problem faced by a small and medium enterprise (SME) in Cilegon. The MIP was solved using the CPLEX software. Sensitivity analysis was carried to provide the SME with several alternatives in handling the suppliers' location problem.

Keywords: Supply chain network; piecewise linear function; convex-combination method; small and medium enterprise
Received: 2021-05-07; Revised: 2021-07-22; Accepted: 2021-07-23

INTRODUCTION

This study aims to determine the problem of determining the location of the supplier of a Small-and-Medium Enterprise (SME) in the Cilegon area. With growing demand, the business owner feels the need to increase production capacity and open several distribution centers. Therefore, it is necessary to determine a location that can cover a large market and minimal shipping costs. A third party carries out the delivery of goods through a contract system. In this contract, a discount is applied for the number of goods sent. The discount makes SME chooses these third parties as business partners.

The problem is modeled into determining the distributor's location by considering the transportation costs of a piecewise linear function. Transportation costs in the form of a piecewise linear function are widely applied in the real world [1], [2]. For example, this function can be found in discounts on goods [3], [4]. The more the number of goods purchased by the consumer, the more significant the price reduction received.

This study is different from other studies, which assume that transportation costs are constant [5-12]. Conversely, the transportation costs in this study are not constant but a piecewise linear function. A piecewise linear function is a composite function consisting of more than one straight line (line segment). This function is linear for a particular domain, but overall, this function is not linear. Thus, the location determination model becomes non-linear [13]. As a result, this study's problem is more complicated than in previous studies [14].

Several studies have proposed several ways of dealing with nonlinearity. Lagrange decomposition is used to determine where a single location can cover multiple request locations [15]. A greedy adaptive algorithm was developed to determine the location of stochastic demand [16]. Holmberg proposed an approach based on Bender's decomposition to solve the location problem [17]. Other research used a dynamic programming approach to tackle the nonlinearity of the piecewise linear function [18]. A clustering technique was used to solve the warehouse location problem [19]. The branch-and-cut algorithm is proposed to solve the non-convex and non-linear model [20], [21].

In this study, the convex-combination method (CCM) is used to change the non-linear form to the linear form [22]. The CCM transforms the non-linear form into a linear form by reformulating the piecewise linear function into an integer constraint. After linearization was carried out by converting the problem into an integer-programming model, the CPLEX software was used to find the optimal solution. Furthermore, sensitivity analysis is used to determine total cost changes due to changes in several model parameters.

METHODS

Quantitative research methods are used in this research. First of all, the problem is formulated. In the next section, the general model for determining the location (facility location problem) is discussed. Furthermore, model development is used to solve problems. The piecewise linear function is discussed next. Finally, this section also discusses the design of numerical experiments.

Problem Formulation

The problem discussed in this study is the extension of the capacitated facility location problem. The formulation of the problem is as follows.

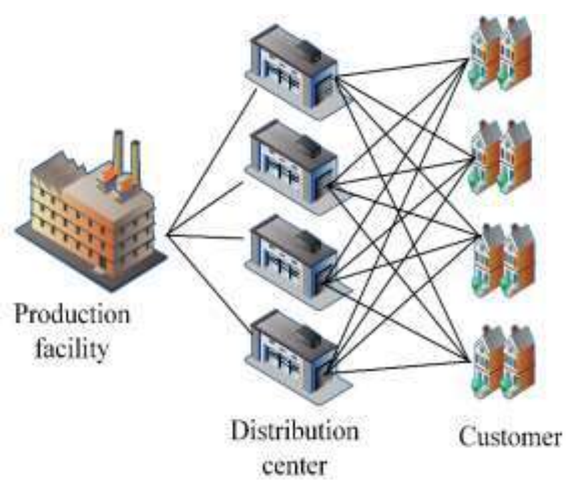

Figure 1. The proposed supply chain network of the SME

An SME in Cilegon has one production facility. With the increasing demand, the SME plans to open several distribution centers (DC) to distribute the goods. To open a DC requires a fixed investment fee. The goods stored in DC will fulfill requests from customers. Third-party transportation companies carry out transfers from a production facility to DC and shipments from DC to customers.

Based on the contract with the transportation company, shipping costs will be discounted according to the number of products sent. Discounts are categorized into several modes or types of discounts directly influenced by the number of goods transported. For example, suppose a transportation company offers three discount modes. The first mode is the transportation cost for one unit of product is IDR 100.00/km for the number of shipments between 0-10 units. The second mode is the transportation fee of IDR 75.00/km for 10-20 units shipments. The last mode is the transportation fee, which is IDR 50.00/km for more than 20 units. The SME conducts research to determine how many suppliers will be opened and the number of goods sent through these suppliers. **Figure 1** illustrates the supply chain network that the SME will make.

Mathematical model

The notations used to model the problem faced by the SME are as follows.

Index

i : Index of the production facility
j : Index of distribution center
k : Index of customer
l : Index of discount mode

Parameters

N : The number of production facilities
M : The number of distribution centers
K : The number of customers
L : The number of discount modes
a_{ijl} : The minimum quantity of products sent from production facility i to distribution center j using discount mode$l$
$a_{ij(l+1)}$: The maximum quantity of products sent from production facility i to distribution center j using discount mode$l$
λ_{ijl} : The weight of discount mode$l$ if used to deliver products from production facility i to distribution center j

c_{jkl} : The minimum quantity of products sent from distribution center j to customer k using discount model l
$c_{jk(l+1)}$: The maximum quantity of products sent from distribution center j to customer k using discount model l
μ_{jkl} : The weight of discount model l if used to deliver products from distribution center j to customer k
u_i : Production capacity of production facility i
v_j : Storage capacity of distribution center j
d_k : Demand of customer k
g_j : Investment fee to open distribution center j
f : Transportation cost function

Decision variables

x_j : 1 if distribution center j is open, 0 otherwise
y_{ij} : Product flow from production facility i to distribution center j
z_{jk} : Product flow from distribution center j to customer k
b_{ijl} : 1 if products are sent from production facility i to distribution center j using discount model l, 0 otherwise
e_{jkl} : 1 if products are sent from distribution center j to customer k using discount model l, 0 otherwise

The supply-chain network for determining the distributors' location with piecewise linear transportation costs is modeled as mixed integer non-linear programming (MINLP) as follows.

$$\min \sum_{i=1}^{i=N}\sum_{j=1}^{j=M} s_{ij} f(y_{ij}) + \sum_{j=1}^{j=M} g_j x_j + \sum_{j=1}^{j=M}\sum_{k=1}^{k=K} t_{jk} f(z_{jk}) \quad (1)$$

$s.t.$

$$\sum_{j=1}^{j=M} y_{ij} \le u_i, 1 \le i \le N \quad (2)$$

$$y_{ij} \le v_j x_j, 1 \le i \le N, 1 \le j \le M \quad (3)$$

$$\sum_{j=1}^{j=M} z_{jk} = d_k, 1 \le k \le K \quad (4)$$

$$\sum_{k=1}^{k=K} z_{jk} \le v_j x_j, 1 \le j \le M \quad (5)$$

$$\sum_{i=1}^{i=N}\sum_{j=1}^{j=M} y_{ij} = \sum_{j=1}^{j=M}\sum_{k=1}^{k=K} z_{jk} \quad (6)$$

Eq. (1) is the objective function that consists of three parts. The first term represents the transportation expenses for delivering goods from distribution centers to consumers. The second term is the fixed cost of opening a distribution center. Meanwhile, the third term is transportation cost for sending products from the production facility to distribution centers. In the first and second terms, the transportation cost $\boldsymbol{f}$ is a piecewise linear function. Eq. (2) states that the flow of products sent from the production facility to distribution centers does not exceed its capacity. Eq. (3) ensures that the production facility's product flow to the distribution centers does not exceed its storage capacity. Eq. (4) states that all distribution centers' flow is the same as consumer demand. Eq. (5) guarantees no product flow from a distribution center to the consumer if it is not opened. Eq. (6) guarantees that the total product flow from the production facility to the distribution centers equals the total product flow from the distribution centers to the consumer.

Piecewise Transportation Cost

Transportation cost depends on the number of products shipped. The transportation cost function is expressed as a piecewise linear function, where the function depends on the product transported. Let y_{ij} be the number of products transported from production facility i to distribution center j and $f(y_{ij})$ be the transportation cost. **Figure 2** illustrates the transportation costs from production facility i to distribution center j with three discount modes ($L = 3$).

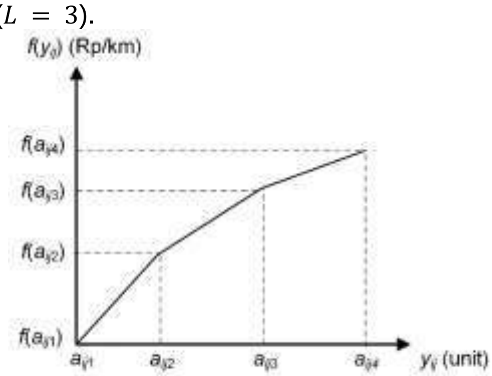

Figure 2. Piecewise transportation cost from production facility i to distribution j

From **Figure 2**, the transportation cost function is linear for each discount mode but not linear as a whole. Each discount mode is a straight line bounded by the minimum value and maximum value. The non-linear transportation cost function can be transformed into a linear form using the convex-combination method.

Suppose y_{ij} is in the first discount mode $(a_{ij1} \leq y_{ij} \leq a_{ij2})$, then y_{ij} can be expressed as $y_{ij} = \lambda_{ij1}a_{ij1} + (1-\lambda_{ij1})a_{ij2}$, with $0 \leq \lambda_{ij1} \leq 1$. However, y_{ij} can also be in the second and third discount modes, Therefore, y_{ij} can be generalized to $y_{ij} = \lambda_{ij1}a_{ij1} + (1-\lambda_{ij1})a_{ij2} + \lambda_{ij2}a_{ij2} + (1-\lambda_{ij2})a_{ij3} + \lambda_{ij3}a_{ij3} + (1-\lambda_{ij3})\, a_{ij4}$, $\lambda_{ijl} \leq 1$, and at most two adjacent λ_{ijl} can be positive. Thus, y_{ij} in general can be stated as follows.

$$\sum_{l=1}^{l=L+1} \lambda_{ijl}a_{ijl} = y_{ij}, 1 \leq i \leq N, 1 \leq j \leq M \quad (7)$$
$$\sum_{l=1}^{l=L+1} \lambda_{ijl} = 1, 1 \leq i \leq N, 1 \leq j \leq M \quad (8)$$
$$\lambda_{ijl} \leq b_{ij(l-1)} + b_{ijl}, 1 \leq i \leq N, 1 \leq j \leq M, 1 \leq l \leq L+1 \quad (9)$$
$$\sum_{l=1}^{l=L} b_{ijl} = 1, 1 \leq i \leq N, 1 \leq j \leq M \quad (10)$$

In the same way, $f(y_{ij})$ can be expressed as the convex combination of discount modes as follows.

$$\sum_{l=1}^{l=L+1} \lambda_{ijl} f(a_{ijl}) = f(y_{ij}), 1 \leq i \leq N, 1 \leq j \leq M \quad (11)$$

For the number of products and transportation costs from supplier j to customer k, the number of products shipped z_{jk} and the transportation costs $f(z_{jk})$ is carried out in the same way. Thus, the variables z_{jk} and $f(z_{jk})$ are stated as follows.

$$\sum_{l=1}^{l=L+1} \mu_{jkl}c_{jkl} = z_{jk}, 1 \leq j \leq M, 1 \leq k \leq K \quad (12)$$
$$\sum_{l=1}^{l=L+1} \mu_{jkl} = 1, 1 \leq j \leq M, 1 \leq k \leq K \quad (13)$$
$$\mu_{jkl} \leq e_{jk(l-1)} + e_{jkl}, 1 \leq j \leq M, 1 \leq k \leq K, 1 \leq l \leq L+1 \quad (14)$$
$$\sum_{l=1}^{l=L} e_{jkl} = 1, 1 \leq j \leq M, 1 \leq k \leq K \quad (15)$$
$$\sum_{l=1}^{l=L+1} \mu_{jkl} f(c_{jkl}) = f(z_{jk}), 1 \leq j \leq M, 1 \leq k \leq K \quad (16)$$

In the next step, we substitute y_{ij} in Eqs. (1)-(6) with Eq. (7), z_{jk} with Eq. (12), $f(y_{ij})$ with Eq. (11), $f(z_{jk})$ with Eq. (16) and augmented Eqs. (8)-(10) and (12)-(15) to the model. As a result, the supply chain model becomes as follows.

$$\min \sum_{i=1}^{i=N}\sum_{j=1}^{j=M}\sum_{l=1}^{l=L+1} s_{ij}\lambda_{ijl} f(a_{ijl}) + \sum_{j=1}^{j=M} g_j x_j + \sum_{j=1}^{j=M}\sum_{k=1}^{k=K}\sum_{l=1}^{l=L+1} t_{jk}\mu_{jkl} f(c_{jkl}) \quad (17)$$

$3s.t.$

$$\sum_{j=1}^{j=M}\sum_{l=1}^{l=L+1} \lambda_{ijl}a_{ijl} \leq u_i, 1 \leq i \leq N \quad (18)$$
$$\sum_{l=1}^{l=L+1} \lambda_{ijl}a_{ijl} \leq v_j x_j, 1 \leq i \leq N, 1 \leq j \leq M \quad (19)$$
$$\sum_{j=1}^{j=M}\sum_{l=1}^{l=L+1} \mu_{jkl}c_{jkl} = d_k, 1 \leq k \leq K \quad (20)$$
$$\sum_{k=1}^{k=K}\sum_{l=1}^{l=L+1} \mu_{jkl}c_{ijl} \leq v_j x_j, 1 \leq j \leq M \quad (21)$$
$$\sum_{i=1}^{i=N}\sum_{j=1}^{j=M}\sum_{l=1}^{l=L+1} \lambda_{ijl}a_{ijl} = \sum_{j=1}^{j=M}\sum_{k=1}^{k=K}\sum_{l=1}^{l=L+1} \mu_{jkl}c_{jkl} \quad (22)$$

Thus, the new model consists of Eqs. (17)-(22), (8)-(10), (13)-(15). The new model can be solved by CPLEX.

Data Collection

The data were collected by observation from the SME. The data collected include 1) production facility data, 2) distribution center data, 3) customer data. The data regarding the supply chain network are as follows. The number of production facilities is $N = 1$, the number of distribution centers $M = 4$, and the number of customers $K = 6$. The transportation company provides three discount modes $L = 3$ with the transportation cost function (in thousands of IDR per km) in Eq. (23).

$$f(q) = \begin{cases} 25 + 0.25q, 0 \leq q \leq 100 \\ 500 + 0.15q, 100 \leq q \leq 200 \\ 850 + 0.1, 200 \leq q \leq 300 \end{cases} \quad (23)$$

The production capacity per month of the production facility is 1000 units per month. Meanwhile, the demand from all customers is around 500 units. The data regarding suppliers are presented in **Table 1**. The data consists of distance from the production facility, investment cost to open distribution center, and the storage capacity.

Table 1. Distribution center data

Location	Distance from production facility (km)	Investment cost (000 IDR)	Storage capacity (unit)
P1	14	200,000	200
P2	30	150,000	200
P3	38	100,000	150
P4	36	75,000	100

Figure 3. The map of the supply chain network

Figure 3 depicts the locations of the production facility (FP), distribution centers (P1-P4), and customers (C1-C6). The location of FP is located around the Merak area. The location of distribution centers are Cilegon (P1), Taktakan (P2), Mancak (P3), and Pontang (P4). Currently, there are four locations as the candidate for distribution centers.

Table 2 shows the customer data that consists of its location and demand. The demand is obtained from SME's forecasting.

The locations of customers are Kragilan (C1), Balaraja (C2), Cikande (C3), Binung (C4), Pandeglang (C5), and Cipait (C6). The distance from the distribution center and customer are shown in **Table 3**.

Table 2. Customer data

No	Location	Demand (unit)
1	C1 (Kragilan)	62
2	C2 (Balaraja)	115
3	C3 (Ciaknde)	181
4	C4 (Binung)	29
5	C5 (Pandeglang)	73
6	C6 (Cipait)	23

Table 3. Distance matrix from distribution center to customers (km)

Dist.	Customers					
center	C1	C2	C3	C4	C5	C6
P1	30	46	40	41	38	33
P2	21	41	33	37	33	23
P3	42	66	54	57	46	18
P4	26	46	37	38	36	31

Solution Method

Once the mathematical model has been developed and data has been collected, we seek the solution to the problem using CPLEX software. First, the model (Eqs. (17)-(22), (8)-(10), (13)-(15)) are coded using OPL modelling language and the data collected are inputted as parameters. Then, we solve the code using CPLEX software. The code and CPLEX software are running on a hexa-core computer using 8 GB of RAM.

RESULTS AND DISCUSSION

Table 4 presents the results from the CPLEX software. The results showed that P1, P2, and P4 are opened as distribution centers, whereas location P3 is not opened. The production facility sends 183 units of product to P1, 200 units to P2, and 100 units to P4. Distribution center P1 sends 100 units to C2, ten units to C4, and 73 units to C5. P2 sends 62 units of product to C1, 15 units of it to C2, 100 units of it to C3, and 23 units to C6. Finally, P4 sent 81 units of products to C3 and 19 units of products to C4. The total cost required is IDR 458,254,250. The computation time required is 0.05 seconds.

Table 4. Optimal product flow (unit)

Dist. center	Customers C1	C2	C3	C4	C5	C6
P1	0	100	0	10	73	0
P2	62	15	100	0	0	23
P3	0	0	0	0	0	0
P4	0	0	81	19	0	0

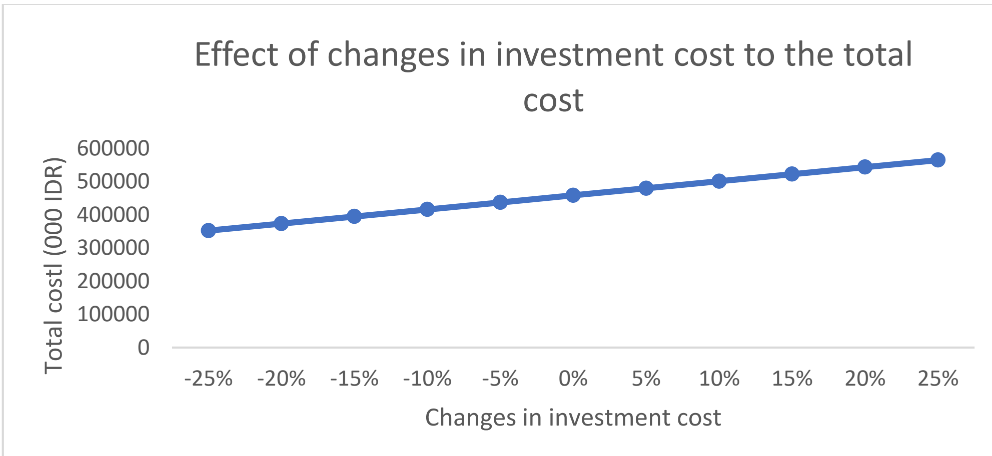

Figure 4. Effect of investment cost to the total cost

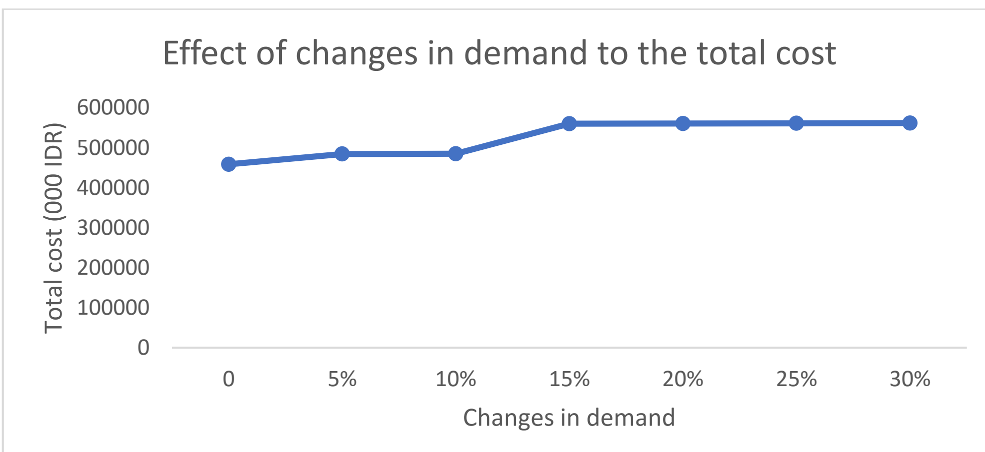

Figure 5. Effect of demand on the total cost

Next, sensitivity analysis is performed to investigate the effect of changes in investment cost to open a distribution center and customer demand on the total cost. The investment costs used in the sensitivity analysis range from -25%-25%. Meanwhile, the demand used as a sensitivity analysis ranges from 0-30%. For example, the investment cost at location P1 is IDR 200,000,000. So, if the investment cost is reduced by 25%, the investment cost becomes IDR 150,000,000.00. This value is then used as a parameter. CPLEX is used to find solutions using the new investment value. The same way is conducted for demand. The results of the sensitivity analysis are then presented in **Figure 4** and **Figure 5**.

Figure 4 shows the effect of changes in investment costs on total costs. From **Figure 4**, the result obtained is a tendency that the graph obtained is a straight line. We can see in the second term of equation (18) that transportation costs are a linear function. Therefore, an increase or decrease in investment costs will result in a linear change in total costs.

On the other hand, it is different from the effect of demand on total costs, as shown in **Figure 5**. An increase in demand up to 10% graph tends to rise flat. At a 15% increase in demand, total costs increase substantially. It can be explained as follows. The customer demand is 483 units (data in **Table 2**). When the demand increase is less than 15%, the total demand is 483 * 1.15 < 555 units. The demand for less than 555 units can still be fulfilled by three distribution centers (P1, P2, and P4). However, the demand after passing the threshold of 555 units can only be fulfilled if all suppliers are open. Therefore, the increase in total costs of the 15% increase in demand was mainly due to increased investment costs. After a 15% increase, total cost increases occurred, but the increases tended to be flat.

CONCLUSION

This study developed a supply chain network model to determine the location of distribution centers from an SME in Cilegon. The model is different from other studies due to the non-linear transportation costs. Therefore, the model is transformed into a linear model with the convex-combination method. The model was solved using the CPLEX software.

From the results obtained, the optimal result is to open three suppliers from four possible locations. In addition, the results provide optimal product flow from the production facility to the distribution center and product flow from distribution to customers. According to sensitivity analysis, changes in investment costs against total costs tend to be linear. Meanwhile, changes in demand for total costs are not linear, depending on the supplier's capacity. This research can be developed by considering vehicle emissions to investigate the trade-offs between economic and environmental benefits.

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