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Combining Total Cost of Ownership and Integer Programming for 3PL Order Allocation in PT. X

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ABSTRACT

Managing multiple third-party logistics providers (3PLs) for export shipments presents a complex challenge for large manufacturers like PT. X, involving both explicit and implicit costs that impact overall efficiency and cost-effectiveness. This study aims to develop an optimal 3PL order allocation model for PT. X's export operations by integrating Total Cost of Ownership (TCO) to capture comprehensive costs and Integer Programming (IP) to minimize these total costs. A case study approach was employed, utilizing data from PT. X, including 3PL quotations, operational records, and quality performance metrics. The TCO framework incorporated both explicit costs (e.g., shipment and service fees) and implicit costs (e.g., management and quality failures). An IP model was then formulated to allocate orders across five 3PLs while adhering to operational constraints on minimum and maximum volumes per 3PL and shipping liner. The combined TCO-IP model achieved a cost saving of Rp 1.52 billion (4.57%) compared to PT. X's previous allocation method. Sensitivity analysis revealed that implicit costs (communication and quality), while captured by TCO, had an insignificant impact on the overall allocation due to their small proportion in the total cost structure. The research demonstrates the practical value of combining TCO and IP for strategic logistics decision-making, enabling significant cost savings. It suggests that for PT. X, minimizing explicit costs is the primary driver of optimal 3PL allocation, though monitoring implicit costs remains important.

KEYWORDS *Total Cost of Ownership, Integer Programming, 3PL*

INTRODUCTION

International trade is a crucial factor in modern society since every nation has the right to obtain the best products from every corner of the world. Indonesia as a nation is also involved in international trade and has continuously maintained an export-import surplus for 56 months until December 2024 (Kementerian Perdagangan, 2025). The automotive sector plays a huge role in Indonesian exports, contributing up to USD 10 billion or equivalent to 4.45% of total Indonesian exports from January to November 2024 (BPS, 2024). In Indonesia, the automotive sector creates jobs and drives technological development (Waluyo, 2024).

Supply Chain Management has a positive influence on increasing the competitiveness of a company, customer satisfaction, and financial performance (Abusalma et al., 2024; Maaz & Ahmad, 2022; Tukamuhabwa et al., 2023). Transportation strategy is one of the crucial factors in the supply chain decision area (Hugos, 2024). Efficient logistics management may help the supply chain achieve maximum competitiveness (Dadzie & Richard, 2025). Indonesian competitiveness in the logistics sector is fifth in Southeast Asia and 61st in the world due to the lack of policy integration in government institutions (Iskandar & Arifin, 2023; World Bank, 2023). Due to the complexity in the logistics aspect, companies need experts such as third-party logistics providers, called 3PLs (Vlachos & Polichronidou, 2022).

Freight forwarders, or 3PLs, play a crucial role in the delivery of goods by representing the shipper to manage multiple logistics tasks (Sugiono et al., 2023; Wirjodirdjo et al., 2021). A 3PL provides services such as packing, storage, and item distribution to the end customer (Valashiya & Luke, 2023). A carrier such as a shipping liner is an entity that owns several ships that operate on routine schedules between multiple destinations (Christiansen et al., 2020).

The global logistics industry faces increasing challenges in cost optimization and service quality management. European automotive manufacturers like Volkswagen and BMW have implemented sophisticated 3PL management systems to handle complex multi-destination shipments, achieving 8-12% cost reductions through mathematical optimization approaches (Schmidt et al., 2023). Similarly, Japanese companies such as Toyota have demonstrated that integrated cost-based supplier selection can reduce logistics costs by 15-20% while maintaining service quality standards (Nakamura & Tanaka, 2022). In the North American context, General Motors has successfully applied hybrid TCO-mathematical programming approaches for 3PL allocation, resulting in annual savings of $50-80 million across their supply chain operations (Johnson & Williams, 2023).

3PL selection is not easy due to the many criteria to consider (Jovčić & Průša, 2021). Outsourced versus in-house problems have attracted researchers to develop robust decision analysis models to solve them (Kandil et al., 2022). Integration with suppliers is one of the crucial parts to consider for companies seeking to increase supply chain responsiveness (Jiang et al., 2023). However, companies need to manage their relationships with suppliers due to the higher bullwhip effect and internal know-how circulating outside the company (Hou et al., 2023; Lin et al., 2024).

Taherdoost and Brard (2019) explain six categories of methods for supplier selection: (1) Cluster analysis such as fuzzy logic; (2) Categorical methods such as Analytical Hierarchy Process and Analytic Network Process; (3) Cost methods based on Activity-Based Costing (ABC) and Total Cost of Ownership (TCO); (4) Mathematical programming such as linear programming; (5) Artificial Intelligence (AI) such as case-based reasoning and Artificial Neural Networks. AI can identify company needs in the supplier selection process (Guida et al., 2023); (6) Combined methods such as mathematical programming and TCO. The combined method can bring a more holistic view of a phenomenon, better result validity, answers to ambiguous questions, and increased managerial contribution (Grant et al., 2023).

Recent studies have increasingly focused on integrating cost-based approaches with mathematical optimization for logistics decision-making. Zhang et al. (2024) demonstrated that combining Activity-Based Costing with linear programming in Chinese manufacturing companies achieved 12-18% cost reductions compared to traditional supplier selection methods. Park and Lee (2023) applied the TCO framework integrated with multi-objective programming for Korean automotive exporters, resulting in improved cost visibility and 8-15% logistics cost savings. Additionally, Rodriguez and Silva (2024) showed that hybrid TCO-integer programming approaches in Brazilian manufacturing firms not only reduced costs by 10-20% but also improved supplier relationship management and service quality metrics.

TCO is a complex method that requires the buyer to determine the costs that are considered important for acquisition, ownership, use, and disposal of goods and services such as ordering, quality checking, transport, receiving, rejection, replacement, downtime, scrapping, etc. (Ellram, 1995). There are two approaches for measuring TCO: dollar-based and value-based (Ellram, 1995). Implementation of TCO is still relevant today with plenty of research using TCO for applications such as car ownership decision-making (Sutcu, 2020), global location decisions (Woldt et al., 2024), and automation of therapeutic drug monitoring (Settanni et al., 2021).

There are six key activities that contribute to TCO (Ellram & Maltz, 1995): (1) Management related to the evaluation, promotion, and development of employees; (2) Delivery related to shipment, late fulfillment, and correction of incorrect deliveries; (3) Service related to installation, maintenance, quality guarantee, and other problem-solving; (4) Communication related to forecasts, order communication, and payment; (5) Price related to quantity, quality level, terms of delivery, etc.; (6) Quality related to the assessment of quality, rejection rate, and scrapping of rejected items.

Linear programming is a quantitative optimization approach recognized as one of the key methods in operational research due to its ability to provide the most optimum solution to achieve a goal in real-life scenarios (Golden et al., 2024; Kunwar & Sapkota, 2022). There are several attributes to be considered when developing linear programming, such as having a single objective function, having one or more constraints to achieve the objective function, and having several alternatives to solve the problem; the objective function and constraints are linearly formed (no powers, roots, etc. in the formula), and there are mathematical relationships between the objective function and constraints that are constant over the research period (Render, 2018).

Integer programming (IP) has similar characteristics to linear programming, except that some or all variables must be integers (Render, 2018). There are four simple steps to develop an optimization model (Evans, 2016): (1) Identify the decision variables, which are unknown values to seek such as production quantity, fund allocation, etc.; (2) Identify the objective function, which involves maximizing or minimizing a value; (3) Identify the related constraints to form the solution; (4) Write down the objective function and constraints in mathematical formulas.

The novelty of combining TCO and IP is especially relevant to *PT. X's* complex multi-destination export operations, where traditional cost-based approaches fail to capture the intricate relationships between explicit shipping costs and implicit operational costs across multiple 3PL providers. This integration addresses a significant gap in prior literature, which typically treats cost analysis and allocation optimization as separate problems rather than integrated decision-making frameworks. The combined approach enables simultaneous consideration of comprehensive cost structures and optimal allocation decisions, providing more realistic and actionable insights for automotive exporters managing complex international logistics networks.

The implications of this research extend to both industry and academia. For industry practitioners, the study provides a replicable framework for automotive and manufacturing companies seeking to optimize their 3PL selection and allocation processes while maintaining transparency in cost structures. For academic researchers, this work contributes to the growing body of literature on hybrid optimization approaches in supply chain management, demonstrating how traditional cost accounting methods can be effectively integrated with mathematical programming to solve complex logistics problems in emerging market contexts.

RESEARCH METHOD

This research employs an explanatory case study design utilizing a mixed-method approach that combines quantitative optimization modeling with qualitative business process analysis. The research follows a structured three-phase methodology designed to address *PT. X's* 3PL allocation challenges through systematic integration of Total Cost of Ownership analysis with Integer Programming optimization. This research offers a combination of TCO and IP to overcome *PT. X's* challenge in order allocation to 3PLs. TCO is expected to bring a broader view of cost estimation for *PT. X* in their relationship with each 3PL. IP is expected to present the most efficient order allocation for each 3PL to minimize costs.

This research attempts to solve the 3PL selection for order allocation problem with a combined method implementation of TCO and integer programming. First, the case study that exists in *PT. X* will be explained based on the business process described by *PT. X's* management. Second, the translation of the TCO component activities from Ellram & Maltz (1995) is conducted based on *PT. X's* operations. Third, the IP model based on the steps explained by Evans (2016) is designed based on the conditions in the first step to minimize the overall TCO for *PT. X*.

Data collection instruments included structured interview protocols based on Ellram & Maltz's (1995) TCO framework, cost documentation templates for explicit cost capture, and operational performance tracking sheets for implicit cost measurement. Primary data were collected through semi-structured interviews with *PT. X's* export operation supervisors, 3PL sourcing managers, export shipment managers, and the general manager of export business, ensuring comprehensive stakeholder perspectives on operational requirements and constraints.

Data validation processes included triangulation of cost data from multiple sources (3PL quotations, internal accounting records, operational logs), member checking with key informants to verify business process descriptions, and sensitivity testing of model assumptions to ensure robustness of optimization results. The research adhered to ethical guidelines through informed consent procedures, confidentiality agreements to protect proprietary business information, and transparent disclosure of research objectives to all participants. Datasets, indices, and parameters used to develop mathematical formulas are explained in the following lists:

a : AHM export model AHM & destination, $a \in A$
b : 3PL in AHM, $b \in B$
c : *liner*, $c \in C$
A : all export model & destination in AHM
B : all 3PLs in AHM
C : all liners used by AHM
l_b : carrying cost for each 3PL for 40 feet container
m_b : carrying cost for each 3PL for 20 feet container

n_b : service cost for each 3PL for shipment of one lot of export model
o_b : communication cost for each 3PL per container
s_a : number of 40 feet container needed for each model & destination
t_a : number of 40 feet container needed for each model & destination
p_{abc} : shipment cost for each 3PL based on destination and liner for 40 feet container
q_{abc} : shipment cost for each 3PL based on destination and liner for 20 feet container
r_b : quality cost for each 3PL in TEUs
u_b : minimum volume allowed for each 3PL in *TEUs*
v_b : maximum volume allowed for each 3PL in *TEUs*
w_c : minimum volume allowed for each liner in *TEUs*
y_c : maximum volume allowed for each liner in *TEUs*

For further analysis, sensitivity analysis will be conducted on the implicit cost that might be considered changeable over time. The sensitivity analysis will use the price increase of implicit cost component by 100%, 500% and 1.000%. Huge range used in sensitivity analysis is to understand how order allocation is affected by significant increases in the implicit cost.

RESULT AND DISCUSSION

3PL Operation in PT. X

Model for export in PT. X is varied, starting from Completely Built Up (CBU) and Completely Knock Down (CKD). Every model has a dedicated destination and lot size. All export models always use standard shipping containers of 20 feet and 40 feet. PT. X and the customer agreed that PT. X manages the shipment until it reaches the port where the customer will conduct the custom process or formally called the Port of Destination (POD). To send the item to POD, PT. X and the customer has agreed to use a certain liner. The shipment is managed per every lot size shipped. Table 1 shows the export volume, lot size, destination, liners, and how many standard containers of 20 feet and 40 feet needed for every lot shipment.

Table 1. Export Volume of PT. X

Model	Destination	Forecast Quantity (Unit/Set)	Lot Size (Unit/Set)	Number or Shipment (Lot)	40 *Feet* Standard Container Need / Lot	20 *Feet* Standard Container Need / Lot
CBU01	DD	336	48	7	1	0
CBU02	DD	66.320	40	1.658	1	0
	EE	2.920	40	73	1	0
	FF	3.640	40	91	1	0
CBU03	AA	48	48	1	1	0
CBU04	CC	544	34	16	1	0
CBU05	HH	6.144	48	128	1	0
	II	18.480	48	385	1	0
CKD01	DD	31.500	500	63	3	1
CKD02	DD	240.000	300	800	1	0
CKD03	HH	19.200	640	30	1	0
CKD04	CC	6.000	200	30	0	1
CKD05	CC	5.400	200	27	2	1
CKD06	CC	12.600	200	63	2	0
CKD07	CC	14.000	200	70	1	0
CKD08	CC	6.600	300	22	0	1

Model	Destination	Forecast Quantity (Unit/Set)	Lot Size (Unit/Set)	Number or Shipment (Lot)	40 *Feet* Standard Container Need / Lot	20 *Feet* Standard Container Need / Lot
CKD09	CC	13.100	100	131	1	1
CKD10	CC	1.300	50	26	1	0
CKD11	BB	15.100	100	151	2	0
CKD12	GG	300	100	3	0	1
CKD13	GG	900	100	9	2	0
CKD14	GG	13.500	100	135	1	0
CKD15	GG	300	100	3	2	1

To manage the export shipments, PT. X use 5 3PLs to run their export operation. Multiple 3PLs is used to manage concentration risk in single 3PL. Appointed 3PL has several tasks to manage the export shipment such as: (1) Space booking to liner; (2) Procuring the standard container and the truck for container movement. (3) Manage physical export process start from PT. X's warehouse, movement to port of loading, until the shipment reached the POD.

TCO Implementation

Based on (Ellram & Maltz, 1995), there are six key activities on TCO that should be considered. To understand TCO key activities and PT. X operation, discussion with key persons in PT. X such as the PIC and managers for 3PL management was conducted. To generate cost breakdown in TCO, data from PT. X is collected, such as quotation from 3PL, manpower rate and quality cost estimation. The following list explains the breakdown of the key activities in PT. X:

1. Management cost: PT. X treated all the 3PLs with the same treatment, regardless of their allotment. PT. X has a dedicated person in charge (PIC) to manage the relationship with the 3PLs for regular evaluation and order allocation. To determine management cost, the wage of the PIC will be spread among 3PLs and estimated to be Rp40.000.000 per 3PL.
2. Delivery cost: PT. X needs the container that keeps all the export items to be moved from the warehouse to the Port of Loading (POL). Every container needs a truck to move the container. To fulfill this need, each 3PL provides the trucking for each container with their own pricing, as shown in Table 2.

Table 2 Delivery Pricing for Each 3PL for One Container (in Rupiah)

Type of Container	3PL 01	3PL 02	3PL 03	3PL 04	3PL 05
40 *Feet*	2.250.000	2.400.000	2.300.000	2.200.000	2.200.000
20 *Feet*	1.950.000	2.300.000	2.150.000	2.000.000	2.000.000

3. Service cost: each 3PL represents PT. X to manage the physical movements of goods from PT. X's warehouse until it reached POD. There are several documentations such as the Bill of Lading (B/L) and Certificate of Origination (COO), handling fee, and handing fee that need to be managed and become a cost factor from each 3PL. Table 3 represents the service cost for each 3PL for every lot shipment.

Table 3 Service Pricing for Each 3PL for every lot shipment (in Rupiah)

Component	3PL 01	3PL 02	3PL 03	3PL 04	3PL 05
B/L	150.000	150.000	150.000	150.000	100.000
COO	90.000	90.000	250.000	100.000	210.000
Handling Fee	250.000	200.000	230.000	200.000	199.000
Admin Fee	-	150.000	150.000	-	-
Total	**490.000**	**590.000**	**780.000**	**450.000**	**509.000**

4. Communication cost: Daily operation communication with each 3PL is conducted with internet communication such as e-mail or instant messages application. This cost is deemed insignificant in this era. But the emphasize come higher to the responsiveness of each 3PL to manage communication with PT. X. The longer the 3PL response the communication, the cost will be higher due to manpower idle to wait for communication response. Therefore, the communication cost comes from the wage of the manpower time waiting time for communication response for every container shipped regardless of the type of container used and shown in Table 4.

Table 4 Communication Cost for Each 3PL for Every Container Shipped (in Rupiah)

3PL 01	3PL 02	3PL 03	3PL 04	3PL 05
26.042	20.833	31.250	26.042	31.250

5. Shipment cost: This cost is derived from the definition of price cost. every container needs to be moved from POL to POD. Currently, PT. X just use one POL. For every POD, there is at least one liner to be used. Each 3PL might or might not provide the service to certain POD or liner. Table 4 presents the shipment cost for each 3PL for managing the shipment from POL to POD with the liner option for every standard container of 40 feet and 20 feet in USD currency. N/A means the 3PL does not provide the service to certain POL and with that liner. For further cost calculation, the exchange rate was set to be Rp15.900/USD.

Table 5 Shipment Cost for Each 3PL (in USD)

POD	Liner	Standard Container 40 Feet (USD)					Standard Container 20 Feet				
		3PL 01	3PL 02	3PL 03	3PL 04	3PL 05	3PL 01	3PL 02	3PL 03	3PL 04	3PL 05
AA	**ABC**	N/A	1.103	1.132	N/A	1.022	N/A	847	868	N/A	756
BB	**ABC**	297	413	282	N/A	212	356	337	341	N/A	273
CC	**ABC**	287	358	287	N/A	212	281	282	281	N/A	207
DD	**DEF**	415	495	450	440	N/A	260	345	295	288	N/A
DD	**ABC**	247	238	227	N/A	163	176	162	158	N/A	100
EE	**ABC**	297	333	297	N/A	217	281	257	254	N/A	196
FF	**DEF**	505	495	495	485	N/A	305	295	295	285	N/A
GG	**DEF**	325	445	445	435	N/A	210	245	245	235	N/A
HH	**DEF**	405	395	395	385	N/A	255	245	245	235	N/A
HH	**GHI**	570	N/A	N/A	570	N/A	320	N/A	N/A	328	N/A
II	**DEF**	455	445	455	435	N/A	275	265	270	255	N/A
II	**GHI**	80	N/A	N/A	150	N/A	70	N/A	N/A	150	N/A

6. Quality cost: when managing daily operations, each 3PL might make some mistakes such as late container availability, incorrect container, sub-par container quality, incorrect export documentation, etc. This mistake comes down with the estimation cost that PT. X should bear. Table 6 contains the estimation of quality cost for each 3PL in Twenty-Feet Equivalent Unit (TEUs) from the previous period of assessment. For the 40-feet standard container, it counted as 2 TEUs and the 20-feet standard container count as one TEUs.

Table 6 Quality Cost for Each 3PL in TEUs

		Number of Mistake in Previous Period					**Cost Estimation per Mistake**
		3PL 01	**3PL 02**	**3PL 03**	**3PL 04**	**3PL 05**	
Detail	Incorrect Container	2	0	0	0	7	5.000.000
	Incorrect Documentation	1	8	1	0	5	5.000.000
	Late Documentation	0	0	0	0	2	10.000.000
	Billing Issue	0	0	0	1	2	2.500.000
	Sub-par Container Quality	0	0	0	2	6	7.500.000
	Late Container Availability	0	0	0	0	6	7.500.000
	Confidentiality	0	1	0	0	0	2.000.000
Cost Calculation	Total Quality Cost	15.000.000	42.000.000	5.000.000	17.500.000	175.000.000	
	Previous Period Volume (*TEUs*)	6.689	4.544	1.035	618	5.334	
	Average Quality Cost (*TEUs*)	2.242	9.243	4.831	28.317	32.808	

Integer Programming Implementation

PT. X having internal mechanisms to manage how much each 3PL and liner can manage export shipment. The main reason is to manage concentration risk in export shipment, giving protection to small scale 3PL, and manage shipment flexibility in time on needs. Table 7 contains the volume allowed to be managed by each liner and Table 8 contains the volume allowed to be managed by each 3PL. The volume is in a certain range to accommodate the need of export models that have different needs.

Table 7 Volume Allowed by Each Liner (TEUs)

Liner	Minimum Volume (*TEUs*)	Maximum Volume (*TEUs*)
ABC	4.956	5.066
DEF	3.202	3.312
GHI	439	614

Table 8 Volume Allowed by Each 3PL (TEUs)

Component	Volume (*TEUs*)				
	3PL 01	3PL 02	3PL 03	3PL 04	3PL 05
Minimum Volume	2.600	1.050	500	800	3.600
Maximum Volume	2.700	1.150	550	850	3.700

IP is designed to integrate all the TCO cost components that are already explained previously and develop using the mathematical formula (Evans, 2016). The development of integer programming is explained below:

1. Decision variable: how much lot shipment is managed by each 3PL.

$$X_{abc} = \{\geq 1,\ if\ lot\ export\ shipment\ of\ model\ and\ destination\ a\ is\ manages\ by 3PL\ b\ with\ liner\ c\ 0,\ if\ else$$

2. Objective function: minimize the TCO bear by PT. X.

$$Minimum \left\{ \sum_{a} \sum_{b} \sum_{c} [X_{abc} * [s_a(l_b + p_{abc} + o_b + (r_b * 2)) + t_a(m_b + q_{abc} + o_b + r_b) + n_b]] + \sum_{b} k_b \right\}$$

For the quality cost calculation of the 40-feet standard container, r_b needs to be doubled since the value of r_b is in TEUs.

3. Constraints:
   a. Shipment allotted to 3PLs for each export model must be integer.
   $X_{i,j,k} = integer$
   b. The total of allotment for each model should be the same as the total lot that must be shipped.

$$\sum_{b} \sum_{c} X_{abc} = X_a, \forall\ a \in A$$

   c. The volume allotted to each 3PL must be between the allowed range that PT. X arrange.

$$u_b \leq \sum_{a} \sum_{c} X_{abc} * (s_a * 2 + t_a) \leq v_b, \forall\ b \in B$$

   d. The volume allotted to each liner must be between the allowed range that PT. X arrange.

$$w_c < \sum_{a} \sum_{b} X_{abc} * (s_a * 2 + t_a) < y_c, \forall\, c \in C$$

To analyze the integer programming, the modelling use Microsoft Excel with additional add-ins of OpenSolver. The result of the order allocation based on integer programming can be found in Table 9. In Table 9, the allotment of every model is an integer and the total lot that is allotted for every model is the same as indicated in Table 1. Therefore, constraints point a and b are fulfilled. Tables 10 and 11 consist of a comparison of the volume allotted to each 3PL and each liner. Based on the checking, the volume allotted is still on the range that is allowed by PT. X. Therefore, constraints point c and d are fulfilled.

Based on PT. X's record, the total cost for order allocation for each 3PL that was estimated before there was any systematic approach and not including any implicit cost was Rp33.252.899.466. Based on the cost recapitulation in Table 12, Total Cost of Ownership that PT. X must bear is Rp31.730.939.929. Therefore, there is saving at a minimum of Rp1.521.959.537 or around 4,57% that PT. X can be benefited from the order allocation that is determined by the designed method.

To investigate further regarding the influence of the implicit cost that existed in the 3PL order allocation in PT. X, the communication cost and quality cost is chosen to be analyzed. The reason to choose both cost components is due to variability when companies may have different approaches in communication and quality cost calculation. The sensitivity analysis is conducted in an extreme way of increasing each cost to 100%, 500%, and 1.000% respectively.

Figure 1 and 1 show the cost component movement from the sensitivity analysis of the communication and quality costs. In both figures, there is no significant movement of other cost component that is changed due to additional of communication and quality cost. This means that there is no significant change of order allocation even the communication and quality cost increase significantly.

Table 9 Result of Order Allocation based on Integer Programming

Model	**Desti-nation**	***Liner***	**3PL 01**	**3PL 02**	**3PL 03**	**3PL 04**	**3PL 05**	**Total Lot / *Liner***	**Total Volume (*TEUs*)**	**Total Lot / Model**
CBU01	DD	ABC	-	-	-	-	-	-	-	7
		DEF	1	-	-	6	-	7	14	
CBU02	DD	ABC	-	378	-	-	976	1.354	2.708	1.658
		DEF	81	-	-	223	-	304	608	
	EE	ABC	-	-	-	-	73	73	146	73
	FF	DEF	-	68	-	23	-	91	182	91
CBU03	AA	ABC	-	-	-	-	1	1	2	1
CBU04	CC	ABC	-	-	-	-	16	16	32	16
	HH	DEF	-	-	-	128	-	128	256	128

Model	Desti-nation	*Liner*	3PL 01	3PL 02	3PL 03	3PL 04	3PL 05	Total Lot / *Liner*	Total Volume (*TEUs*)	Total Lot / Model
		GHI	-	-	-	-	-	-	-	
CBU05	II	DEF	-	79	-	-	-	79	158	385
		GHI	306	-	-	-	-	306	612	
CKD01	DD	ABC	-	-	63	-	-	63	441	63
		DEF	-	-	-	-	-	-	-	
CKD02	DD	ABC	-	-	-	-	-	-	-	800
		DEF	800	-	-	-	-	800	1.600	
CKD03	HH	DEF	-	-	-	30	-	30	60	30
		GHI	-	-	-	-	-	-	-	
KD04	CC	ABC	-	-	-	-	30	30	30	30
KD05	CC	ABC	-	-	-	-	27	27	135	27
KD06	CC	ABC	-	-	-	-	63	63	252	63
CKD07	CC	ABC	-	-	-	-	70	70	140	70
KD08	CC	ABC	-	-	-	-	22	22	22	22
CKD09	CC	ABC	-	-	-	-	131	131	393	131
KD10	CC	ABC	-	-	-	-	26	26	52	26
KD11	BB	ABC	-	-	15	-	136	151	604	151
KD12	GG	DEF	3	-	-	-	-	3	3	3
CKD13	GG	DEF	9	-	-	-	-	9	36	9
CKD14	GG	DEF	135	-	-	-	-	135	270	135
CKD15	GG	DEF	3	-	-	-	-	3	15	3

Table 10 Comparison of Actual Allotment for Each 3PL with Allowed Range of Volume

3PL	3PL 01	3PL 02	3PL 03	3PL 04	3PL 05
Actual Volume (TEUs)	2.700	1.050	501	820	3.700
Minimum Volume (TEUs)	2.600	1.050	500	800	3.600
Maximum Volume (TEUs)	2.700	1.150	550	850	3.700
Checking	Yes	Yes	Yes	Yes	Yes

Table 11 Comparison of Actual Allotment for Each Liner with Allowed Range of Volume

Liner	Actual Volume (*TEUs*)	Minimum Volume (*TEUs*)	Maximum Volume (*TEUs*)	Checking
ABC	4.957	4.956	5.066	Yes
DEF	3.202	3.202	3.312	Yes
GHI	612	439	614	Yes

Table 12 Recapitulation of TCO Component for Each 3PL

Cost Component	Total Cost					
	3PL 01	3PL 02	3PL 03	3PL 04	3PL 05	Total
Carrying	7.050.775.500	2.524.586.100	974.940.300	2.746.645.500	5.831.499.900	9.128.447.300
Shipment	3.042.450.000	1.260.000.000	639.150.000	902.000.000	4.259.000.000	10.102.600.000
Service	655.620.000	309.750.000	60.840.000	184.500.000	799.639.000	2.010.349.000
Communication	35.234.375	10.937.500	8.812.500	10.677.083	61.093.750	126.755.208
Quality	6.053.400	9.705.150	2.420.331	23.219.940	121.389.600	162.788.421
Management	40.000.000	40.000.000	40.000.000	40.000.000	40.000.000	200.000.000
Total	**10.830.133.275**	**4.154.978.750**	**1.726.163.131**	**3.907.042.523**	**11.112.622.250**	**31.730.939.929**

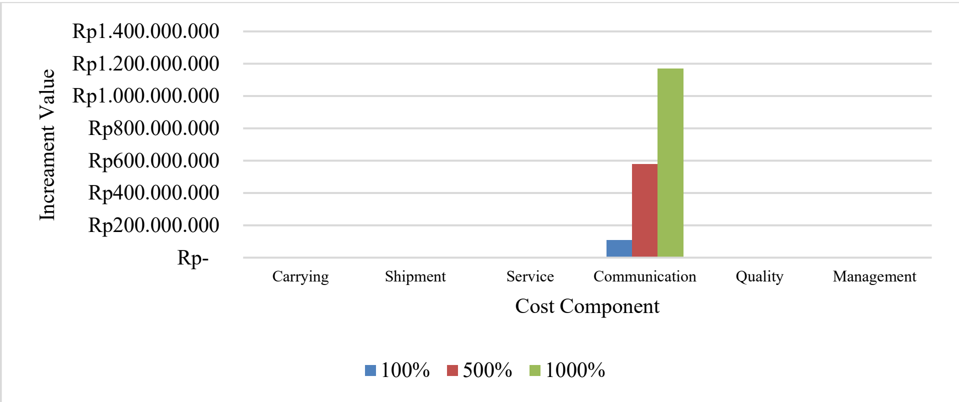

Figure 1 Cost Component Movement from Sensitivity Analysis of Communication Cost

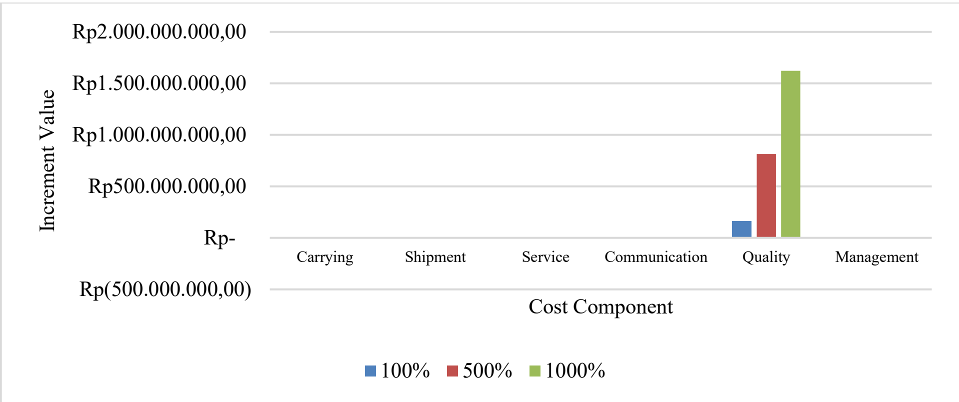

Figure 2 Cost Component Movement from Sensitivity Analysis of Quality Cost

The IP contribution in solving PT. X's problem is huge. In the percentage figure, saving about 5% might not be a significant figure. However, when the figure converts to monetary value, the value of saving is more than Rp1,5 billion, a large sum of money that PT. X can increase the profitability of the company or choose to reduce cost to customers.

TCO also provides guidance to PT. X regarding detailed activities to measure in term of the cost of 3PL involvement in the export operation of PT. X, including the implicit cost that might not considered before. However, from the sensitivity analysis, a drastic change of the communication and quality costs are not able to change order allocation significantly. If we look closer, the increase of 1.000% for communication and quality cost is just 3,55% and 4,86% of the total cost, respectively. This means that in PT. X's case, the contribution of communication and quality cost is not significant to influence the overall order allocation process.

CONCLUSION

The combination of TCO and Integer Programming is undoubtedly able to provide a positive impact on the decision-making process of order allocation to 3PLs in *PT. X*. TCO provides a contribution by giving a framework about what costs *PT. X* must face when managing export shipments with each 3PL. On the other hand, IP provides the contribution of delivering the best order allocation for *PT. X*. Each method complements the other to solve the problem that *PT. X* has with their order allocation. This research is limited only to the export-related services that are used by *PT. X*. If the supplier has a broader range of products that can be offered, the complexity of the order allocation would be higher. This research also assumed that all 3PLs can fulfill orders from *PT. X*. However, there might be cases where the supplier cannot fulfill orders from the buyer. For future research, higher implicit cost contribution in TCO should be conducted to examine how implicit costs have a greater influence in shaping order allocation to suppliers.

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