An Optimization Model for Single-Warehouse Multi-Agents Distribution Network Problems under Varying of Transportation Facilities: *A Case Study*

Yuniaristanto[1], Alfin Nuriya Fauziati[2], Muh. Hisjam[3] and Wahyudi Sutopo[4]
Laboratory of Logistics System and Business, Department of Industrial Engineering
University of Sebelas Maret, Surakarta, INDONESIA
Ir. Sutami 36A, Kentingan, Surakarta, Post Code 57126, Telp/Fax. (0271) 632110.
E-mail addresses: utan@uns.ac.id [1], fauziati@yahoo.com[2],
hisjam@uns.ac.id[3], and sutopo@uns.ac.id[4]

Abstract. *The transportation cost of goods is the highest day-to-day operational cost associated with the food industry sector. A company may be able to reduce logistics cost and simultaneously improve service level by optimizing of distribution network. In reality, a company faces problems considering capacitated transportation facilities and time constraint of delivery. In this paper, we develop a new model of order fulfillment physical distribution to minimize transportation cost under limited of transportation facilities. The first step is defined problem description. After that, we formulate a integer linear programming model for the single-warehouse, multiple-agents considering varying of transportation facilities in multi-period shipment planning. We analyze problems faced by company when should decide policy of distribution due to varying of transportation facilities in volume, type of vehicle, delivery cost, lead time and ownership of facilities. We assumed transportation costs are modeled with a linear term in the objective function. Then, we solve the model with Microsoft Excel Solver 8.0 Version. Finally, we analyze the results with considering amount of transportation facilities, volume usage and total transportation cost.*

Keywords: *physical distribution, shipment planning, integer linear programming, transportation cost, transportation facilities.*

1. INTRODUCTION

Distribution network enables product distribute from location where the product is produced to consumer or end-user locations which frequently limited by distance (Chopra and Meindl, 2004). In doing transportation activity, the shipper must not deliver its products by transportation facilities owned. A difference of institution, business type, and governmental regulation causing transportation management requires the best performance for distributing their products. They collaborate with intermediary like forwarders and third-party logistics providers (Pujawan, 2005).

At this paper, research object is a food company with distribution network which spread over all Indonesia. Tiga Pilar Sejahtera Company headquartered in Sragen produces many varieties of food like dry noodles, rice noodles, instant noodles, instant rice noodles, snack and candy for Indonesian market. Tiga Pilar Sejahtera (TPS) Company want we help them to develop product transportation and distribution model using mathematical programming. Mathematical programming has been applied frequently and successfully to a wide variety of distribution and transportation problems for a variety of industries. For example, Smith et. al. (2001) use linear programming to develop a tool that Delta and Pine Land Company could use to derive a more economical strategy for distributing cottonseed to its customers; Camm et. al. (1997) use integer programming and network optimization models to improve Procter & Gamble's distribution system; Arntzen et. al. (1995) use mixed-integer linear programming to determine Digital Equipment Corporation's distribution strategy; and Martin et. al. (1993) use linear programming to assist in distribution operations for Libbey-Owens-Ford. The minimization of total transportation and holding costs on logistic networks has been studied by Jin and Muriel (2005). The objective is to decide when and how many units to ship from supplier to warehouse and from warehouse to retailers so as to minimize total transportation and holding costs over the finite horizon without any shortages.

TPS distributes its products in two echelons distribution systems that are from warehouse to several distributors. The purpose of formulating and optimizing the food distribution model is to provide TPS with a means for comparing their strategy for moving food through their distribution network with the optimized strategy derived from the formulated model. Therefore, the first objective of the project was to establish the scope of the model by identifying the aspects of TPS distribution that would be studied. The second objective was to define the decision variables, parameters, constraints, and performance measures necessary for formulating a model of TPS food distribution operations. The third objective was to formulate a mathematical programming model of the distribution activities. The fourth objective was to identify software for solving the defined mathematical programming model. And final objective was to analyze the optimal distribution of food determined for the model to identify improvements to the current distribution strategy used by TPS. TPS staff assisted in establishing the problem definition; defining the model's decision variables, parameters, constraints, and performance measures; validating the model formulation; providing input parameters for the model; and analyzing test scenarios.

2. PROBLEM DESCRIPTION

The scope of the distribution network can depict as Figure 1. TPS produces many varieties of food are classified in 10 product families and 88 product items. Transportation vehicles used consist of two types that are truck owned by company (*shipper*) and truck from third-party logistics providers (*carriers*) with differences of volume and distribution area. There are around 36 carriers becoming company partner.

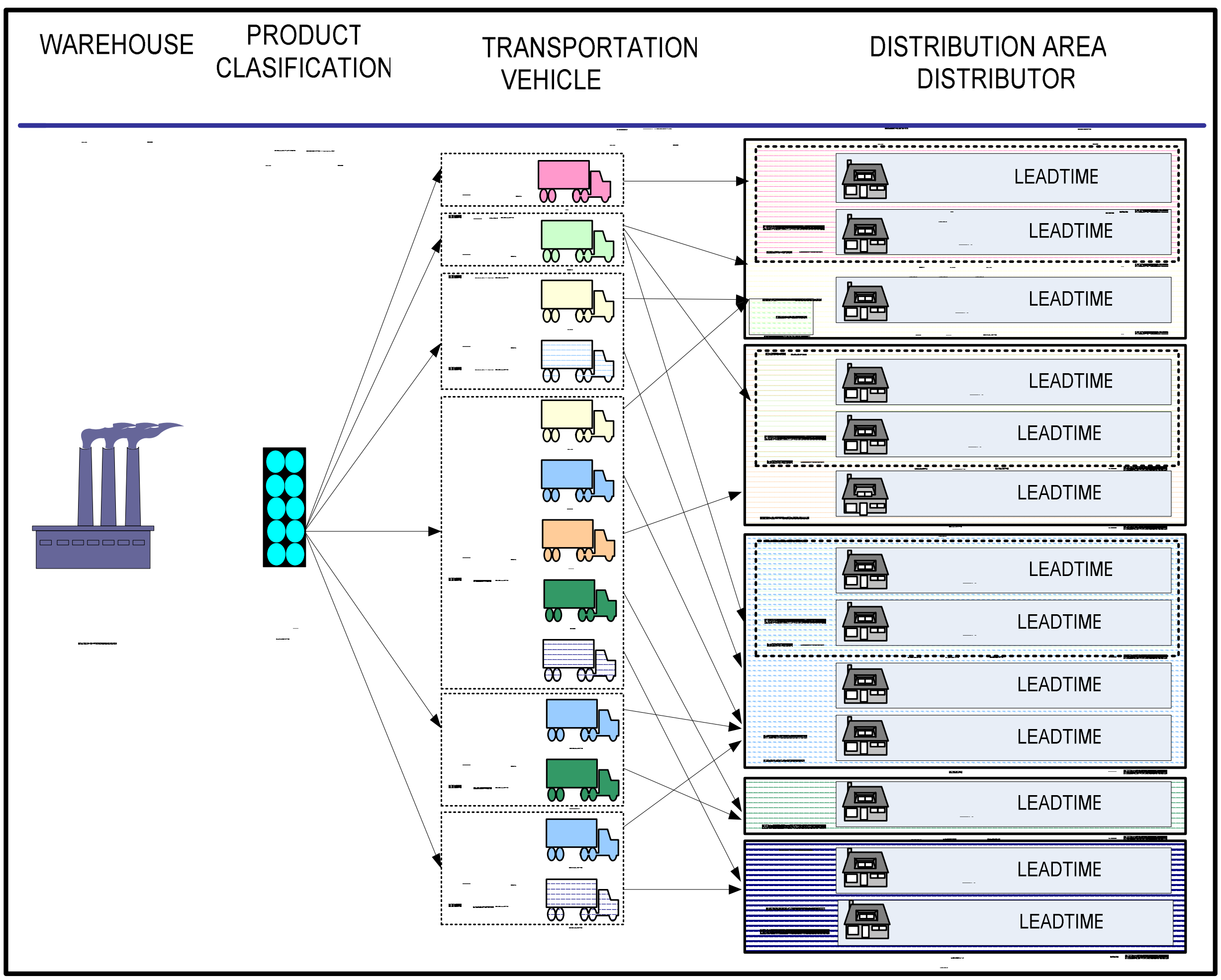

Figure 1: Illustration of Company Distribution Network

TPS classifies their transportation vehicles become thirteen classes by considering truck volume in meter cubic, ownership and destination point (distributor location). Two categories is property of TPS, while the others are property of the carrier companies. The company has two-echelon distribution network that consist of one warehouse and 59 distributors divided in five distribution areas. Demand quantities are based on forecasting methods that established by TPS.

The distribution of goods is a dynamic activity. Therefore, the activities captured by the model must be indexed over time. The model must take into consideration the planning horizon of interest to TPS. A planning horizon was used for four weeks. Lead-time delivery each distributor is dependent on distance between distributors and company warehouse.

As illustrated earlier, this study is primarily concerned with reducing total transportation cost in single-warehouse multi-agent distribution network by considering delivery lead time and capacitated transportation facilities. We have to decide product amount will be delivered to each distributor and number of transportation facilities will be assigned to each distributor.

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3. MODEL FORMULATION

We formulate the problem above in Integer Linear Programming model. Assumptions considered by this model are:

- Number of trucks always available,
- Number of distributors is constant,
- Quantity of daily demand is known in advance,
- Delivery cost is constant along time,
- Delivery lead time is deterministic and static

While none of these assumptions are perfectly valid, we agreed that they were necessary for one of two reasons. First, it was agreed that a simpler model will be beneficial for this study. Second, valid data sources necessary for relaxing these assumptions did not exist. The model developed in this paper use the following notations:

Decision variables:

- X_{ijk} : number of trucks *i* are assigned to distributor *j* on day *k*,

Parameters:

- C_{ijk} : delivery cost for truck category *i* to distributor *j* on day *k*,
- D_{jk}: demand of distributor *j* on day *k*,
- q_i : volume of truck- *i* (m^3) ,
- t_i : loading tolerance for truck- *i*,
- T_{ik}: number of truck- *i* available ,
- *i* : index for truck category (1, ..,13)
- *j* : index for distributor (1, 2...59)
- *k* : index for day (1,2...6)

Objective Function:

This model is aimed to minimize variable transportation cost as follow:

$$Z_{\min} = \sum_{k \in K} \sum_{j \in J} \sum_{i \in I} x_{ijk} c_{ijk} \tag{1}$$

Subject to

a. Number of trucks constraint

$$\frac{x_{i,1,k}}{2} + \sum_{j=2}^{12} x_{i,j,k} \le T_{ik}, \quad i = 1,3,5; \forall k \tag{2}$$

$$\frac{x_{2,1,k}}{2} + \sum_{j=2}^{26} x_{2jk} + \sum_{j=28}^{46} x_{2jk} + \sum_{j=18}^{26} x_{2jk-1} + \sum_{j=42}^{46} x_{2jk-1} \le T_{2k}; \quad \forall k \tag{3}$$

$$\sum_{j=28}^{50} x_{ijk} + \sum_{j=42}^{50} x_{ijk-1} + x_{i,50,k-2} + x_{i,50,k-3} \le T_{ik}, \quad i = 4,6,10,12; \forall k \tag{4}$$

$$\sum_{j=13}^{27} x_{7jk} + \sum_{j=13}^{27} x_{7jk-1} \le T_{7k}, \quad \forall k \tag{5}$$

$$\sum_{j=51}^{55} x_{ijk} + \sum_{j=51}^{55} x_{ijk-1} \le T_{ik}, \quad i = 8,11; \forall k \tag{6}$$

$$\sum_{j=56}^{59} x_{ijk} + \sum_{j=56}^{59} x_{ijk-1} + \sum_{j=56}^{59} x_{ijk-2} + x_{i,59k-3} + x_{i,59,k-4} \le T_{ik}, \quad i = 9,13; \forall k \tag{7}$$

b. Truck volume constraint

$$\sum_{i \in I} x_{ijk}(q_i - t_i) \ge D_{jk}, \quad \forall i, j, k \tag{8}$$

c. Allocation decision constraint

$$x_{ijk} \ge 0, \quad \forall i, j, k \tag{9}$$

$$x_{ijk} = \text{integer} \quad \forall i, j, k \tag{10}$$

Equation (1) is objective function that minimizes the sum of the costs to distribute goods from warehouse to distributor-*j* using truck-*i* during *k* days. Constraint set equation (2)-(7) represents the number of truck class-*i* assigned to deliver products to distributor area on day-k are not permitted exceeds number of truck available by considering delivery lead time. Constraint set equation (8) ensures that all the demand of distributor-*j* day-*k* is balanced by total volume of product that has been transported from warehouse. Constraint equation (9) enforces the non-negativity restriction on the decision variables used in this model. Constraint set equation (10) enforces the integer number of the decision variables

4. NUMERICAL RESULT AND ANALYSIS

Data collected as inputs in data processing and analyzing are:

(i) **Truck data.** Data about truck classification by considering ownership of truck, truck volume, number of truck available, and delivery coverage. This data needed to knows number of vehicles which can be assigned to deliver product to distributor.

Table 1: Truck Classification

Class(*i*)	Owner	Volume	Area	Available
1	Company	9,5m^3	d<100	8
2	Company	14m^3	d<600	10
3	Carrier	14m^3	Central Java	13
4	Carrier	14m^3	East Java	10
5	Carrier	28m^3	Central Java	101
6	Carrier	28m^3	East Java	91
7	Carrier	28m^3	West Java	97
8	Carrier	28m^3	Jabotabek	49
9	Carrier	28m^3	Outside Java	190
10	Carrier	34m^3	East Java	14
11	Carrier	34m^3	Jabotabek	204
12	Carrier	46m^3	East Java	100
13	Carrier	46m^3	Outside Java	22

(ii) **Distributor data.** Data distributor covers distributor name and addresses, traveled distance from warehouse, and delivery lead time required to distribute the product.

(iii) **Product Demand data.** Demand data of product each 59 distributors that spread over in all Indonesia during four weeks. Distributors demand has daily time phased.

(iv) **Components of Transportation cost.** Transportation cost is cost arising as result of existence of distribution activity of product. Transportation cost for company's trucks and carrier's trucks have different components. Transportation cost for company's truck consists of two cost types, that is:

- **Fixed cost.** Fixed cost is expense spent for transportation activity, and this cost is not influenced by number of deliveries. Fixed cost consisted of three cost components that is expense of depreciation, insurance, and driver salary.
- **Variable cost.** Variable cost depends on number of truck used for delivery and expense of delivering goods to every distributor. Variable cost consisted of some components that are: administration; food allowance, addition of fee, fuel cost and maintenance cost

Meanwhile variable transportation cost for carrier's truck is calculated based on truck rent expenses per km.

After data is input into Microsoft Excel Solver 8.0, these data is processed to determine decision variables value. The optimization result can be seen at table. 2.

a. Total transportation cost

At first week, transportation cost is equal to Rp 335,469,612. Transportation cost for second week is equal to Rp 346,798,097. Transportation cost for third week is equal to Rp 328,253,714. Transportation cost for fourth week is equal to Rp 305,105,357. So total transportation cost for January is Rp 1,315,626,780. Summary of weekly transportation cost in planning period is shown at Table 2.

Table 2: Summary of weekly transportation cost (Rp)

	Week 1	Week 2	Week 3	Week 4
fixed cost	4,688,750	4,688,750	4,688,750	4,688,750
variable cost				
Monday	60,263,349	39,806,659	63,074,601	46,391,947
Tuesday	45,311,410	43,274,114	52,648,624	60,079,138
Wednesday	57,302,837	35,441,563	47,198,640	60,180,892
Thursday	63,427,437	60,380,524	55,587,914	45,047,657
Friday	40,363,082	70,127,000	49,503,630	42,406,777
Saturday	64,112,747	93,079,486	55,551,555	46,310,196
Total	335,469,612	346,798,097	328,253,714	305,105,357
Total Transportation cost			**Rp 1,315,626,780**	

b. Allocation of Trucks

The allocation of trucks for delivering to all distributors during January can be described as follow:

- Number of truck class 1 for distributor area in radius less than 100km is 204 trucks.
- Number of truck class 2 for distributor area in radius less than 600km is 142 trucks.

- Number of truck class 3 for central java area is 202 trucks.
- Number of truck class 4 for outside java area is 11 trucks.
- Number of truck class 5 for central java area is 179 trucks.
- Number of truck class 6 for east java area is 150 trucks.
- Number of truck class 7 for west java area is 208 trucks.
- Number of truck class 8 for jabotabek area is 31 trucks.
- Number of truck class 9 for outside java area is 7 trucks.
- Number of truck class 10 for east java area is 28 trucks.
- Number of truck class 11 for jabotabek area is 19 trucks.
- Number of truck class 12 for east java area is 38 trucks.
- Number of truck class 13 for outside java area is 27 trucks.

The summary of vehicle should be assigned is shown at Tables 3.

Table 3: Summary of Trucks Allocation

	9.5m^3	14m^3	14m^3		28m^3					34m^3		46m^3	
	s<100	s<600	Central java	Outside java	Central java	East java	West java	Jabo tabek	Outside java	East java	Jabo tabek	East java	Outside java
Monday	21	10	3	1	8	4	8	0	0	3	3	2	1
Tuesday	20	1	1	0	6	7	12	0	0	1	0	1	1
Wednesday	8	10	6	1	8	6	9	2	0	0	1	3	1
Thursday	8	1	8	1	8	4	12	2	1	2	0	2	1
Friday	7	9	5	0	8	5	4	1	1	1	1	1	0
Saturday	8	2	7	1	8	9	13	1	0	1	2	2	0
Total	**72**	**33**	**30**	**4**	**46**	**35**	**58**	**6**	**2**	**8**	**7**	**11**	**4**
Monday	8	10	12	0	8	6	5	0	0	0	2	0	1
Tuesday	8	0	5	0	8	5	9	0	0	1	1	1	1
Wednesday	8	10	13	0	8	2	5	0	0	1	1	1	0
Thursday	6	0	3	0	8	6	15	1	0	4	1	0	2
Friday	7	10	9	0	5	8	9	2	0	1	1	6	2
Saturday	8	9	18	0	8	13	17	2	1	4	1	1	1
Total	**45**	**39**	**60**	**0**	**45**	**40**	**60**	**5**	**1**	**11**	**7**	**9**	**7**
Monday	8	10	15	0	8	8	7	2	0	1	0	3	2
Tuesday	3	1	9	0	5	7	11	0	1	0	1	1	2
Wednesday	8	9	7	1	8	3	7	1	0	1	0	1	2
Thursday	8	1	2	1	8	10	8	1	0	1	1	1	2
Friday	8	9	3	1	8	6	5	1	0	1	1	1	2
Saturday	8	3	14	2	8	6	6	3	0	1	0	1	1
Total	**43**	**33**	**50**	**5**	**45**	**40**	**44**	**8**	**1**	**5**	**3**	**8**	**11**
Monday	8	10	9	0	8	6	5	2	0	0	0	0	2
Tuesday	5	1	17	1	6	7	12	2	0	0	0	1	1
Wednesday	8	9	18	0	8	8	5	3	1	0	1	2	2
Thursday	7	5	3	0	5	4	10	3	1	3	0	0	0
Friday	8	7	3	1	8	5	8	1	0	1	1	2	0
Saturday	8	5	12	0	8	5	6	1	1	0	0	5	0
Total	**44**	**37**	**62**	**2**	**43**	**35**	**46**	**12**	**3**	**4**	**2**	**10**	**5**
Total trucks	**204**	**142**	**202**	**11**	**179**	**150**	**208**	**31**	**7**	**28**	**19**	**38**	**27**

c. Remains of volume

Remains of volume are calculated with decay of load volume with demand volume loaded. At first week, load volume remain is 1,002.177 m^3. The remains of load volume for second week is 1,127.253 m^3. The Remains of load volume for third week is 1,104.735 m^3. The Remains of load volume for fourth week is 1,101.864 m^3. So, the total remains of load volume for January is 4,336.029 m^3. The summary remains of volume overall of visible is showed at Tables 4.

Table 4: Summary remains of volume

	Week 1	Week 2	Week 3	Week 4
Monday	188.465	136.705	249.051	160.619
Tuesday	175.358	95.011	227.656	247.505
Wednesday	152.329	127.433	129.495	185.176
Thursday	148.932	174.469	185.876	129.222
Friday	130.783	158.335	140.728	161.990
Saturday	206.309	435.300	171.929	217.352
Total	1,002.177	1,127.253	1,104.735	1,101.864
Total Remains of volume (m3)				4,336.029

By considering the truck volume and truck ownership, we could make comparison of number of deliveries between company data and research result (see Table. 5). Number of deliveries truck sized 9.5m^3 increases equal to 163 deliveries, company's truck sized 14m^3 decreases equal to 243 deliveries, carrier's truck sized 14m^3 decreases equal to 97 deliveries, truck sized 28m^3 decreases equal to 27 deliveries, truck sized 34m^3 decreases equal to 46 deliveries, and truck sized 46m^3 increases equal to 42 deliveries.

Table 5: Comparison of number of deliveries based on company data and research result

Truck volume	Company	This research	delta
9.5m^3	136	299	163
14m^3 (TPS)	831	588	-243
14m^3 (carrier)	238	141	-97
28m^3	228	201	-27
34m^3	90	44	-46
46m^3	24	66	42
Total	1547	1339	-208

From result of calculation allocation of trucks, knowable of volume utility reached. Volume utility is obtained by dividing demand loaded with total trucks load volume applied. Based on company data, obtained volume utility equal to 63%, while based on calculation this research is obtained volume utility equal to 76% or there is improvement equal to 13%.

Tables 5: Comparison of Volume Ratio (m^3)

Truck volume	Company	Research	Dev
9.5m^3	1,904	4,186	2,282
14m^3 (TPS)	23,268	16,464	-6,804
14m^3 (carrier)	3,332	1,974	-1,358
28m^3	2,166	1,909.5	-256.5
34m^3	3,060	1,496	-1,564
46m^3	1,104	3,036	1,932
Total	34,834	29,065.5	-5,768.5
Demand	22,088.04	22,088.04	
Volume usage	63%	76%	13%

From calculation which has been conducted, total transportation cost which must be spent based on this research is equal to Rp 1,315,626,780. Compared with company policy which must spent total transportation cost Rp. 2,060,605,248, so we can reduce total cost about Rp. 744,978,468 or 36%.

In this project, we also design a tool which facilitates counting of truck allocation for TPS's delivery manager. This tool developed in MS-Excel with designing *user interface* that facilitates user make truck allocation decision using *Microsoft Excel Solver 8.0.* This tool also provided menu to change model parameters that are number of trucks and components of transportation costs.

5. CONCLUSION

This paper provides A Model for Single-Warehouse Multi-Agents Distribution Network Problems under Varying of Transportation Facilities. Our numerical results show that the transportation cost under limited of transportation facilities proposed by this model is cheaper then current system. For that, we recommend the company as follows:

a. Recommendation which can be given to the company is to allocate number of truck required weekly and daily like shown at the Tables 3.
b. Total required truck to distribute the products on this model is 1,339 or around 13.4% lower than company required.
c. Volume utility of all trucks based on this model is equal to 76%, or around 13% higher than the company system.
d. Transportation total cost based on this model is equal to Rp 1,315,626,780 or around 36% lower than company system.

The contribution of this research is an approach to problems involving single-warehouse, multiple-agents considering varying of transportation facilities in multi-period shipment planning. We obtained optimal transportation cost by decided the number of each truck types should be assigned to deliver company's product going to their distributor for a weekly schedule in a monthly planning. For further research, this model could be extended to other characteristics of transportation problems, in examples: with transportation cost discounts, considering maintenance cost, consider loading/unloading cost.

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AUTHORS' BIOGRAPHIES

YUNIARISTANTO is a lecturer in Department of Industrial Engineering, Faculty of technology, University of Sebelas Maret. He obtained his Bachelor's degree in Industrial Engineering from Sepuluh Nopember Institute of Technology and Master's degree in Industrial Engineering from Bandung Institute of Technology. His research interest is at production scheduling, logistic management and supply chain planning. He has published many papers in several national journals.

A.N. FAUZIATI is a student in Department of Industrial Engineering, Faculty of technology, University of Sebelas Maret. She is an assistant in Laboratory of Logistics System and Business.

M. HISJAM is a lecturer in Department of Industrial Engineering, Faculty of technology, University of Sebelas Maret. He obtained his Bachelor's degree in Agricultural Industrial Engineering from University of Gajah Mada and Master's degree in Industrial Engineering from Bandung Institute of Technology. His research interest is at logistics information system, decision support system, logistic and supply chain development. He has published many papers in several national journals.

W. SUTOPO is a lecturer in Department of Industrial Engineering, Faculty of technology, University of Sebelas Maret. He obtained his Bachelor's degree in Industrial Engineering from Bandung Institute of Technology and Master's degree in Management Scince from University of Indonesia. His research interest is at logistic and supply chain development. He has published many papers in several national journals.