Determining Optimum Route and Load Transfers in a Multiple Route-based Flat Rate Transportation Problem

Ketut Gita Ayu, Nike Septivani and Verola Lollyta
Department of Industrial Engineering
Bina Nusantara University
Jakarta, 11480, Indonesia

Abstract

In automotive manufacturing industry, a synergized continuous improvement is a must to ensure products are designed and produced according to the specification with short cycle time, best quality yet low cost. A case study is conducted in a joint venture spare part manufacturing company which employs direct shipping and milk run logistic systems to pick up parts from their suppliers. In order to minimize the damages occurred on the parts happened during transport, the company together with one of its suppliers changed the transport case from basket pallet to part-specific dunnage which required company to reevaluate the effectiveness of their current logistic systems. The objective of the study is to develop an ILP model in response to this change. The problem is deterministic with multiple pallet sizes required by the suppliers and available truck types. It is further complicated by the multiple route-based flat rates offered by the logistic firm depending on type of truck chosen by the company. The model finds the optimum route, load transfer, and number of required trucks of each type so that the cost is minimized. Result indicates that the developed model allow company to stay competitive by saving up to 20.5% on transportation cost.

Keywords

Deterministic, integer linear programming, route-based flat rate

1. Introduction

Supply chain management focuses on the collaboration between entities in the supply chain to improve their overall performance by achieving an integrated value chain with the help of information technologies and systems (Okada 2012). In fact, effectively managed supply chain relationships through flexibility, information sharing, visibility of effort, performance of each party, and fairness in distributing costs and benefits foster cooperation and trust that facilitate coordination in supply chain (Chopra 2004).

2. Problem Description

A study is conducted in a Japanese joint venture manufacturing company in Indonesia. The company picks up parts from four different suppliers (ATI, IMN, TMI, and ADW) in which three out of them are located in the same industrial district area (see Figure 1:).

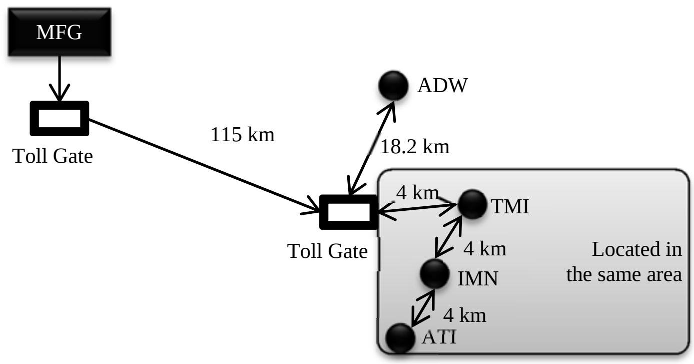

Figure 1: Company's and suppliers' location

Parts from ADW are picked up using direct shipping while parts from the remaining three suppliers (TMI, IMN, and ATI) are picked up using milk run system. Each supplier has their own pallet size which can complicate the pallet arrangement inside a truck.

Last year, in order to minimize the damages occurred on the parts during transport process, the company together with one of the suppliers (ATI) changed the transport case from basket pallet to part-specific dunnage (Baudin 2004) for body caliper and support mounting. As part of the agreement, the company is required to pay fifty percent of the initial investment only. The change on the transport case did reduce the defect occurrences during the transport process; however, it required double handling for unpacking and packing into the production lines. Improvement on the warehouse layout is then performed to eliminate the double handling and it managed to save the company over IDR 230 million a year. The change also required the company to reevaluate the current logistics systems used to pick up parts from their suppliers. Syncrum Logistics, a third party logistics (3PL) used by the company, offered three types of trucks with three different flat rates depending on the pick-up location.

Integer linear programming (ILP) will be used to solve this type of transportation problem with objective to determine the optimum route, load transfer, and number of required trucks so that the cost is minimized. Finding the optimum number of trucks along with its route and quantity carried in each truck for each type of supplier becomes an important issue for this company in order to stay competitive.

3. Literature Review

There are four major drivers that determine the performance of a supply chain: facilities, inventory, transportation, and information where all of them are correlated. Mode of transportation, route and network selection, in-house or outsource, and overall trade-off between responsiveness and efficiency are the key components of transportation (Chopra 2004). In principle, managing a transportation system raises several decision problems which are greatly influenced by the nature of the operational constraints. As a result, transportation planning and management problems come in a large number of variants where some are common, while others have a specific transportation model (Ghiani 2004). The common decision problem at the operational level is determining the optimum number of vehicles used and its schedules with the least-cost routing of goods over a transportation services network from the origins to the destinations. Ghiani (2004) claimed that from a mathematical point of view, this assignment problem can be cast as network flow problems which include transportation problem.

3.1 Route and Network Selection

Chopra (2004) stated that there are various transportation network designs with its own strengths and weaknesses such as direct shipping network, direct shipping network with milk runs, all shipments via central DC, shipping via DC using milk runs, and tailored network. Direct shipping eliminates intermediate warehouse and simplifies the operation and coordination, although it may incur high transportation cost in some extent. Rodrigue (2006) claims transaction costs, friction of space, and shipment are the three important cost components in the assessment of the related transportation cost.

The high cost can be reduced by adapting milk runs into direct shipping network. All shipments via central DC option allows crossdocking which allow product flows faster in the supply, however it requires a significant degree of coordination and synchronization between the incoming and outgoing shipment. It also has possibility to have high transportation cost and adapting milk run can overcome this high cost. Tailored network, on the other hand, uses combination of various transportation network designs and in return gives the highest coordination complexity (Chopra 2004).

3.2 Optimization Model

The modeling process starts with establishment of the objectives and system constraints. Involving factors which cannot be changed for various reasons must also be specified as system constraints. Upon completion of the study, performance must be measured in order to determine whether or not the objectives are met (Murphy 2004). Common goal in logistics is to minimize the overall cost while meeting some other requirements. Thus, Jacobs et al. (2011) believed that action ought to be taken only if some action at one stage will give large cost saving in overall, not in a subset. However, this approach can be challenging because of the significant fixed costs of the systems and material handling costs which account for a major part of manufacturing costs, in which all of these impact production scheduling flexibility (Sharp et al. 2006).

Goal programming, tree search methods, and dynamic programming, among others are efficient solution procedures which can be utilized to deal with large, complex problem frequently encountered in logistics network design. Yet, Ballou (1999) claimed that the most promising of this class is the integer linear programming (ILP) approach due to its ability to handle fixed costs in an optimal way. The argument is supported by Desai (2012) who showed that a novel linear programming for the approximation of the dynamic programming relaxes the restriction to lower bounding approximations in an appropriate fashion while remaining computationally tractable.

The application of ILP is broad. As an example, Billings (2005) formulates and solves an ILP that prescribes a minimum-cost load-and-unload schedule for U.S. Navy ships subject to constraints on ship availability and port capabilities. These constraints are similar to the constraints in our model that describes truck capacity and availability. Another example on the application of ILP is in modeling and solving crew assignment problem while complying with a variety of work regulations and collective agreements (Zeghal 2006), airline crew pairing (AhmadBeygi 2009), fleet assignment in Turkish Airlines (Ozdemir 2012), cement split delivery vehicle routing problem with an heterogeneous fleet of vehicles and customer demands larger than the vehicle capacity (Hertz 2012), and many others.

Although it is quite appealing, Winston (2003) and Rardin (1997) agreed that integer programming requires longer solution times compared to linear programming which can be bothersome. Yet, this issue to some extent can be solved by utilizing optimization software. Everingham et al. (2008) utilize a large-scale LP solver in Microsoft Excel to optimize their model and similar implementation method will be used in this paper. In addition, the interpretation and the formulation of integer programming is not an easy task because it has implicit logical meanings in some of the variables and constraints (Yeom 1996).

4. Preliminaries

4.1 Transport Case

ATI switched the transport case from basket pallet to part-specific dunnage. One dunnage can hold up to 4 pieces or equivalent to 2 units (or sets). Total sixty dunnages can be stacked on a 110 x 80 x 105 cm pallet which is equivalent to 240 pieces per pallet. Before the change, the amount of pieces per pallet were varies from 26 to 480. The remaining three suppliers remain using their current specified pallet size. The different pallet types used by the four suppliers can be seen in Table 1: Pallet size used by suppliers.

Table 1: Pallet size used by suppliers

Supplier	Pallet Dimension			Pallet Type
	Length (cm)	Width (cm)	Height (cm)	
ATI	110	80	105	ATI
TMI	110	110	125	TMI
IMN	110	110	97	Standard

ADW	110	110	97	Standard

4.2 Pallet Requirement

Let demand of part *i* at month *t* to be picked up from supplier *j* is denoted as d_{itj} and there are *n* days in month *t* where *n* may varies month to month. In calculating the number of pallets required daily for each supplier, fluid model is used because it is the most accurate downstream where smaller units are moved and can be realized easily. Fluid model treats each stock keeping unit (sku) as incompressible, continuously divisible fluid (Bartholdi 2011). Applying fluid model, the number of pallets required in each day for each supplier is computed by summing up the daily demand of part *i* from supplier *j*. Assuming demand does not vary much between days, total pallets required to be picked up from each supplier in one day, D_j, is computed by finding the maximum daily demand from the previous four months as can be seen in equation (1). Total parts required to be picked up from each supplier is summarized in Table 2: Demand on parts from each supplier.

$$D_j = \max\left\{\sum_i \frac{d_{itj}}{n}, \forall t\right\} \tag{1}$$

Table 2: Demand on parts from each supplier

Supplier	No. Pallets	Pallet Type
ATI	60	ATI
TMI	27	TMI
IMN	16	Standard
ADW	2	Standard

4.3 Truck Size, Cost, and Capacity

The company utilizes trucks provided Syncrum Logistics, to pick up parts from suppliers. Syncrum Logistics offers three types of trucks with three different flat rates depending on the selected route. The rates are varied depending on whether parts are picked up from suppliers located within the industrial district area, outside the industrial district area, or combined. The flat rates include toll fare, manpower, gasoline, as well as truck maintenance cost. See Table 3: Truck sizes and costs for the inside dimension of the three types of truck along with its cost per route.

Table 3: Truck sizes and costs

Truck Type	Length (cm)	Width (cm)	Height (cm)	Route 1 MFG–District–MFG	Route 2 MFG–District–ADW–MFG	Route 3 MFG–ADW–MFG
A	730	220	215	IDR 720,000	IDR 740,000	IDR 770,000
B	480	160	160	IDR 585,000	IDR 605,000	IDR 635,000
C	880	220	215	IDR 885,000	IDR 905,000	IDR 935,000

Getting more parts unto a pallet and more pallets into a truck reduces the transportation cost borne by the company. Given the pallet dimension, an analysis is conducted to find the optimum pallet count and arrangement inside each truck. Each pallet can be arranged in two possible ways: pallet width against truck inner width (pwtw) and pallet width against truck inner length (pwtl). For ATI supplier, the maximum number of pallets can be placed inside truck type A and C are obtained when pallet width is used against the inner truck length (pwtl). On the contrary, matching pallet length with the inner truck length for truck type B, gives the maximum number of pallets can be carried at one time. Pallet arrangement inside three different types of truck shows indifference for the remaining two pallet types used by the three suppliers (TMI, IMN, and ADW). Assuming a truck is dedicated to carry pallets from one supplier only, the maximum number of pallets can be carried by each type of truck can be seen in the following Table 4: .

Table 4: Truck capacity based on the pallet arrangement

Pallet Type	A Truck		B Truck		C Truck	
	pwtw	pwtl	pwtw	pwtl	pwtw	pwtl
ATI	24	**36**	**8**	6	32	**44**
TMI	12	12	4	4	16	16
Standard	24	24	4	4	32	32

5. ILP Model Formulation

The objective of the model is to minimize the route based flat rate cost borne by the company subject to the constraints of satisfying the demand on parts from each supplier.

5.1 Parameters

Define, supplier *j = {ATI, TMI, IMN, ADW}*, and truck type *k = {A, B, C}*

D_j = number of pallets required to be picked up from supplier *j* with values listed in Table 2: Demand on parts from each supplier = {60, 27, 16, 2}

l_j = length of pallet used by supplier *j* with values defined in Table 1: Pallet size used by suppliers = {110, 110, 110, 110}

w_j = width of pallet used by supplier *j* with values defined in Table 1: Pallet size used by suppliers = {80, 110, 110, 110}

L_k = truck type *k* length with values defined in Table 3: Truck sizes and costs = {730, 480, 880}

P_{ki} = cost of leasing truck type *k* with values defined in Table 3: Truck sizes and costs

Pseudocode to compute $\boldsymbol{P_{ki}}$

Let: l = pick up location = {district, district-ADW, ADW}

P_{kl} = cost to use truck type k to pick up parts from supplier located in area (see Table 3: Truck sizes and costs)

$$y_{kij} = \begin{cases} 1, \text{ if truck type } k \text{ number } i \text{ carried pallets from supplier } j \\ 0, \text{ otherwise} \end{cases}$$

First, assign binary number to determine whether or not truck number *i* of type *k* carried pallets from supplier *j*

do {
for all *j* and *i* **do**
  if $A_{ij} > 0$ then $y_{Aij} = 1$
  else $y_{Aij} = 0$
  end if
for all *j* and *i* **do**
  if $B_{ij} > 0$ then $y_{Bij} = 1$
  else $y_{Bij} = 0$
  end if
for all *j* and *i* **do**
  if $C_{ij} > 0$ then $y_{Cij} = 1$
  else $y_{Cij} = 0$
  end if}

Now, assign the associated price according to the truck type *k* and pick up location *l*.

do {
for all *i* and *k* **do**
  if $y_{kij=ADW} = 0$ then $P_{ki} = P_{k1}$
  else if $\sum_{j=ATI,TMI,IMN} y_{Aij} = 0$ then $P_{ki} = P_{k3}$
  else $P_{ki} = P_{k2}$
  end if}

Summing up the multiplication of assigned truck cost, $\boldsymbol{P_{ki}}$**,** to binary decision variables, A_i, B_i, and C_i will give the objective function (2) of the model.

5.2 Variables

$$\text{truck } A_i = \begin{cases} 1, \text{ if truck type A number } i \text{ is used} \\ 0, \text{ otherwise} \end{cases}$$
$$\text{truck } B_i = \begin{cases} 1, \text{ if truck type B number } i \text{ is used} \\ 0, \text{ otherwise} \end{cases}$$
$$\text{truck } C_i = \begin{cases} 1, \text{ if truck type C number } i \text{ is used} \\ 0, \text{ otherwise} \end{cases}$$

A_{ij}= amount of pallets picked up from supplier *j* using truck type A number *i*
B_{ij}= amount of pallets picked up from supplier *j* using truck type B number *i*
C_{ij}= amount of pallets picked up from supplier *j* using truck type C number *i*

5.3 Objective

$$\text{minimize} \qquad \sum_i P_{Ai}A_i + \sum_i P_{Bi}B_i + \sum_i P_{Ci}C_i \tag{2}$$

5.4 Constraints

$$4\sum_i A_{ij} + 2\sum_i B_{ij} + 4\sum_i C_{ij} \geq D_j, j = \text{ATI (pallet requirement)} \tag{3}$$
$$2\sum_i A_{ij} + \sum_i B_{ij} + 2\sum_i C_{ij} \geq D_j, \forall j = \text{TMI (pallet requirement)} \tag{4}$$
$$4\sum_i A_{ij} + \sum_i B_{ij} + 4\sum_i C_{ij} \geq D_j, \forall j = \text{IMN, ADW (pallet requirement)} \tag{5}$$
$$\sum_j A_{ij}w_j \leq L_A A_i, \forall i \text{ (maximum inside length in truck A)} \tag{6}$$
$$\sum_j B_{ij}l_j \leq L_B B_i, \forall i \text{ (maximum inside length in truck B)} \tag{7}$$
$$\sum_j C_{ij}w_j \leq L_C C_i, \forall i \text{ (maximum inside length in truck C)} \tag{8}$$
$$A_{ij}, B_{ij}, C_{ij} \geq 0 \tag{9}$$
$$A_{ij}, B_{ij}, C_{ij} \text{ INT} \tag{10}$$
$$A_i, B_i, C_i \text{ BINARY} \tag{11}$$

Constraint (3), (4), and (5) guarantee all parts demand requirement from each supplier to be fully satisfied. The constants used in these constraints are explained as follows. The maximum layer of each type of pallet can be put in each type of truck is computed by rounding down the result obtained by dividing the truck inner height with each type of pallet height (see Table 5: Maximum stacks). Stacking pallets from different suppliers may increase space utilization, yet it may also increase the difficulty in pallet retrieval. Thus, this model assumes no pallet from different suppliers can be stacked on top of each other.

Table 5: Maximum stacks in a truck

Truck Type	Height (cm)	Pallet Height (cm)				Maximum Stack			
		ATI	TMI	IMN	ADW	ATI	TMI	IMN	ADW
A	215	105	125	97	97	2	1	2	2
B	160					1	1	1	1
C	215					2	1	2	2

Table 6: Maximum number of shows the maximum number of rows in each type of truck is computed by dividing pallet width with inner truck width for all suppliers except ATI. Pallet length is used as the dividing factor for ATI supplier in order to increase space utilization.

Table 6: Maximum number of rows of pallets in a truck

Truck Type	Width (cm)	Pallet Width (cm)				Max no. pallet per truck width			
		ATI*	TMI	IMN	ADW	ATI	TMI	IMN	ADW
A	220					2	2	2	2
B	160	110	110	110	110	2	1	1	1
C	220					2	2	2	2

Multiplying these two numbers (stacks and rows) give the constants used in constraint (3), (4), and (5) representing the total number of pallets per pallet length for each supplier using truck type *k* (see Table 7: Pallet Multiplier for each Column in a Truck).

Table 7: Pallet Multiplier for each Column in a Truck

Truck Type	Width (cm)	Multiplier			
		ATI	TMI	IMN	ADW
A	220	4	2	4	4
B	160	2	1	1	1
C	220	4	2	4	4

Constraint (6), (7), and (8) ensure the total pallets' length do not exceed the inner length of truck type A, B, and C. Total pallets' length is calculated by multiplying the number of pallets per row with pallet width from supplier *j* (for truck type A and C) or with pallet length from supplier *j* (for truck type B). The remaining constraints (9) and (10) require decision variables are positive and integer, while constraint (11) requires decision variables to be binary.

6. Computational Result

The model finds the optimal solution to be using three trucks type C (route: ATI, TMI, and TMI-IMN-ADW) and two trucks types A (route: ATI-TMI and ATI-TMI-IMN) with total cost of IDR 4,115,000 per day to pick up parts from four different suppliers. The pallets composition inside each truck and space utilization level of each truck can be seen in Table 8: Optimal Truck Route and Pallet Arrangement. Small deviation appeared on the number of pallets picked up from ADW supplier, which stated as four pallets while we only required two pallets. This difference is due to the simplification done in the modeling when counting the number of pallets can be carried per pallet length. Total of four pallets can be carried per each ADW pallet length because one pallet length is equivalent to two rows of two pallets stacked. However, this variance is not significant. In fact, it allows tolerance for the company when the total number of pallets to be carried from ADW fluctuates.

Table 8: Optimal Truck Route and Pallet Arrangement

Truck type and no.	ATI	TMI	IMN	ADW	Utilization
A1	24	4	-	-	96%
A2	4	2	4	-	41%
C1	-	6	12	4	88%
C2	-	16	-	-	100%
C3	32	-	-	-	100%
Total pallets picked up	60	28	16	4	
Demand	60	28	16	2	

Prior the change of transport case from basket pallet to part-specific dunnage, company has to pick up parts using direct shipping network for supplier located outside industrial district (ADW) and milk run for suppliers located within the district (ATI, TMI, and IMN). The new transportation system finds the optimum solution which allows company to save up to 20.5% in transportation cost alone (see Figure 2: Transportation Cost Comparison).

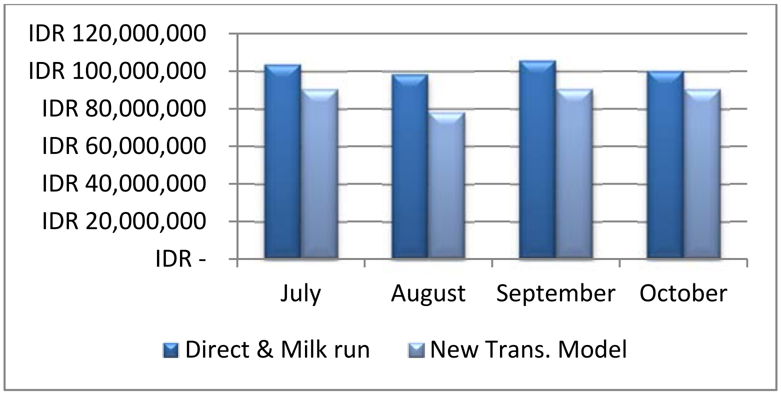

Figure 2: Transportation Cost Comparison

7. Conclusion and Further Works

Multiple flat rates and types of transportation mode, nowadays, are offered by 3PL companies to increase vehicle utilization level and reducing possibility of deadhead. These multiple rates and vehicle types expand company's possible choices yet complicates the decision making process because company will have to ensure that the rate variation will give significant benefit to the company in the overall. The ILP model constructed in this paper can be used as an answer to these issues commonly faced by companies hiring 3PL for transportation. The model utilizes approximation to determine the average demand in order to reduce the complexity and increase tractability of the problem and solve it as a deterministic model. The ILP model finds the optimum route, pallets composition, and number of required trucks in a minimum cost incurred given the multiple flat rates according to the route chosen and types of vehicle used and suppliers' pallet size and demand. Solver with GRG nonlinear method is used as computational tool to find the optimal solution.

This model can also be used to solve similar cases with multiple suppliers and route-based flat rates. However, as the number of suppliers, types of truck, and flat rates increase, longer solution times will be required. We are in the process of developing a more generic ILP model to solve similar problems as part of our future research plan.

References

AhmadBeygi, S., and Weir, M., An integer programming approach to generating airline crew pairings, *Computer & Operations Research*, vol. 36, no. 4, pp. 1284-1298, 2009.

Ballou, R., *Business Logistics Management*, 4th Edition, Prentice Hall, New Jersey, 1999.

Bartholdi, J, and Hackman, S., *Warehouse and Distribution Science*, Available: www.warehouse-science.com, August 21, 2011

Baudin, M., Packaging and returnable containers, Available: http://www.iienet2.org/uploadedfiles/IIE/Technical_Resources/Archives/lean1022.pdf, September 3, 2004.

Billings, R., Scheduling ammunition loading and unloading for U.S. Navy ships in San Diego, *Technical report*, Naval Postgraduate School, Monterey, 2005.

Chopra, S, and Meindl, P., *Supply Chain Management: Strategy, Planning and Operation*, 2nd Edition, Prentice Hall, New Jersey, 2004.

Desai, V., Farias, V., and Moallemi, C., Approximate dynamic programming via a smoothed linear program, *Operations Research*, vol. 60, no. 3, pp. 655-674, 2012.

Everingham, K., et al., Operations research enhances supply chain management at the U.S. Coast Guard aircraft repair and supply center, *Interfaces*, vol. 38, no. 1, pp. 61-75, 2008.

Ghiani, G., Laporte, G, and Musmanno, R., *Introduction to Logistics Systems Planning and Control*, 1st Edition, Wiley, England, 2004

Hertz, A., Uldry, M., and Widmer, M., Integer linear programming models for a cement delivery problem, *Innovative Application of OR*, vol. 222, no. 3, pp. 623-631, 2012.

Jacobs, F., et al., *Manufacturing Planning & Control*, 6th Edition, McGraw-Hill, Singapore, 2011.

Murphy, Jr., Paul, R., and Wood, D., *Contemporary Logistics*, 8th Edition, Prentice Hall, New Jersey, 2004.

Okada, Yosuke, Competition and productivity in Japanese manufacturing industries, *Journal of the Japanese and International Economies*, vol. 19, no. 4, pp. 586-616, 2005.

Ozdemir, Y, Basligil, H., and Sarsenov, B., A large scale integer linear programming to the daily fleet assignment problem: a case study in Turkey, *World Conference on Business, Economics, and Management (BEM-2012)*, May 4-6, Antalya, Turkey, pp. 849-853, 2012.

Rardin, R., *Optimization in Operation Research*, 1st Edition, Prentice Hall, New Jersey, 1997.

Rodrigue, J., Comtois, C., and Slack, B., The geography of transport systems, Routledge, New York, 2006.

Sharp, G., et al., Material transports system design in manufacturing, Available: www.iienet2.org/uploadedfiles/IIE/Technical_Resources/Archives/614.pdf, August 15, 2006.

Winston, W., and Venkataramanan, M. *Operation Research Volume One: Introduction to Mathematical Programming*, 4th Edition, Thomson Learning, 2003. (4)

Yeom, K., and Lee, J., Logical representation of integer programming models, *Decision Support Systems*, vol. 18, no. 3-4, pp. 227-251, 1996.

Zeghal, F., and Minoux, M., Modeling and solving a crew assignment problem in air transportation, *Discrete Optimization*, Discrete Optimization, vol. 175, no. 1, pp. 187-209, 2006

Biography

Ketut Gita Ayu is a faculty in Industrial Engineering at Bina Nusantara University. She earned both B.S. and M.S. in Industrial Engineering at Georgia Institute of Technology, Atlanta, GA. She has published journals and conference papers. Her research interests mostly related to warehousing, logistic, optimization, and green industry. Her current research is designing shuttle bus system for campus residence hall. She is a member of IIE and SEMS.

Nike Septivani is a faculty in Industrial Engineering at Bina Nusantara University. She earned her B.S. in Industrial Engineering at Institut Teknologi Indonesia and Master of Management in Marketing Management in Universitas Pelita Harapan, Indonesia. She has taught production planning and inventory related courses and published conference papers. Her research interests include production process, material planning, and lean strategy.

Verola Lollyta is an Industrial Engineering student at Bina Nusantara University.