# Production and Distribution Model in Cement Industry to Minimize Supply Chain Costs

**Muhammad Reza Nooranda and Iwan Vanany**
Department of Industrial Engineering
Institut Teknologi Sepuluh Nopember
Surabaya, Indonesia
noorandareza@gmail.com, vanany@ie.its.ac.id

## Abstract
This study aims to develop a distribution optimization model for bulk and package products of cement industry from cement plant until the store customers in Java and Bali market regions area. In distribution model, 2 cement plants, 5 packing plants, 6 virtual distribution centers, and 128 market areas are included. The transportation mode types are ships and trucks. Linear programming will be used to develop proposed distribution optimization model. The main objective of proposed model is to minimize supply chain costs of production and distribution system in this case study. The improvement recommendation also will be declared to reduce supply chain costs from plant until customers. The implication practices of this study is the supply chain manager could plan and manage the production and distribution of bags and bulks cement product from cement plant until customers that has minimizing supply chain costs. As for the potential reduction in supply chain costs, it can save up to Rp49.6 Billion if existing allocation compared to optimal allocation and also recommendation to stop operation of packing plant due to low production utility.

## Keywords
Distribution System, Cement Industri, Supply Chain

## 1. Introduction
Supply Chain Management is an important concept in the world of business and logistics, especially that experienced by companies that work together to create product distribution to reach the final consumer. The first time a product is provided by the manufacturer or factory, then the distribution of products is continued by the distributor to the agent and the last is the consumer (Pujawan and Geraldin 2009). Companies always strive to increase value through efficient supply chain management, and one of the easiest ways to increase value is through increasing volume while reducing waste through reducing operating costs.

One of cement companies in Indonesia owns and manages all cement plants from production to distribution process. One of cement distribution is from the sales area in area A and has supply facilities in the form of a cement plants, packing plants, grinding plants, sea ports, and virtual distribution centers. Cement distribution in area A uses ships and trucks for transportation modes. Ships are used to transport bulk cement from cement plants to the packing plants as a transshipment facility. Meanwhile, trucks are used to transport bag and bulk cement from cement plants, packing plants, distribution centers to the marketing districts.

In existing condition, the company makes deliveries through direct shipping and through distribution center facilities, packing plants and cement plants. Deliveries are made through the cement plants to the packing plants, distribution centers and marketing districts. Bag cement is delivered from the cement plant to the virtual distribution center as a transshipment facility. Meanwhile, bulk cement is delivered from the cement plant to the packing plant . Bag and bulk cement delivery is also carried out directly from cement plants to marketing districts. Cement delivered from virtual distribution centers and packing plants to marketing districts are bag and bulk cement.

Distribution problems that occur are the lack of management of distribution costs due to ineffective allocation of cement distribution and lack of collaboration and coordination between departments involved in production and distribution to monitor and evaluate costs arising from cement allocation to each marketing district, which creates a burden on cement distribution cost in area A reached almost 14% or equivalent to 2.19 Trillion Rupiah of the Company's Principal Expenses in 2018.

This study is more focused on distribution problem bag and bulk cement products in area A. The improvement of the distribution system is expected to reduce supply chain costs so as to increase company profits. This study seeks to create a distribution system optimization model to reduce the company's operating expenses and increase company revenue as well by using linear programming methods. The purpose of this study are to construct mathematical linear programming models in the distribution of cement delivery from several supply facilities (cement plants, packing plants, and virtual distribution centers) in the marketing areas A; produce optimal supply chain costs by designing distribution system optimization models to minimize existing supply chain costs and fulfill service levels to customers; and provide some recommendations for improvement of the cement distribution system for the marketing areas A.

## 2. Literature Review

### 2.1. Supply Chain Optimization

Supply Chain Management is an approach used to achieve a more efficient integration of various organizations from suppliers, manufactures, distributors, retailers, and customers in terms of goods produced in the right amount, at the right time and at the right place with the aim of achieving the cost of the overall system is minimum and also reaches service level. Supply Chain Management receives considerable attention because supply chain is an integral part of the company's strategy and is the most expensive activity in almost every company. For manufacturing and service companies, supply chain costs have a large proportion as a percentage of sales. Therefore, an effective strategy is needed. The supply chain provides a great opportunity to reduce costs and increase profits (Tsiakis et al. 2001)0.

A comprehensive work models supply chain networks under demand uncertainty focusing on the production and transportation issues (Tsiakis et al. 2001)0. model for multi-echelon supply chain networks, integrating components associated with production, facility location and distribution along side with financial and business issues, plant utilisation, and plant maintenance for strategic planning (Tsiakis and Papageorgiou 2008).

The solution to optimizing has been widely used in problems that exist within the supply chain scope, whether using heuristic or linear programming methods. Problems that are widely discussed in the literature also vary, such as discussing the problem of network optimization model, gravity location model, and aggregate planning using linear programming methods. The problems of transportation models, transshipment, and allocation models are using same method as well. Supply chain optimization will not be separated from the objective function of maximizing profits, or minimizing costs.

### 2.2. Supply Chain Costs

The terms 'supply chain costs' and 'logistical costs' are often used in the world of academics and literature. Therefore, it is not surprising that sometimes there are misunderstandings in the definition of both. But according to the definition of Supply Chain Management that has a broader scope than Logistics Management, supply chain costs are defined as all costs incurred related to activities in the supply chain of a company or organization including logistics costs associated with distribution, transportation, and warehousing costs (Pettersson and Segerstedt 2013).

Supply chain costs can be divided into five categories: production costs; transportation costs; warehousing costs; inventory costs; and internal material handling costs. Supply chain costs are divided into five main fields plus one sixth field that applies to supply chains where installation costs are a necessary part of the sale price. The six fields are as follows: production costs; administration expenses; warehouse costs; distribution costs; cost of capital; installation costs (Pettersson and Segerstedt 2013). Production costs include direct materials, direct labor and overhead production costs. Administrative costs include all costs related to administration, such as fees for paying people who handle customer orders and people who buy materials.

### 2.3. Mathematical Model of Transshipment Problems

Transshipment problem allows shipping between supply points and between demand points, and it may also contain delivery points of goods through which goods can be sent on their way from the supply point to the demand point. Transshipment problems can be solved by several linear modeling, namely linear programming (Liu 2011). The general formulation of linear programming for transshipment models has the following characteristics:

min Z =

$$\sum_{i=1}^{m} \sum_{j=1}^{n} C_{ij} X_{ij}^{P} + \sum_{j=1}^{n} \sum_{k=1}^{l} C_{jk} X_{jk}^{R}$$

s.t. $X_{i1}^{P} + X_{i2}^{P} + \cdots + X_{ij}^{P} \leq Q_{i}^{P}, (i = 1, 2, \dots, m)$ (1) (Supply constrains)

$X_{1k}^{R} + X_{2k}^{R} + \cdots + X_{jk}^{R} \geq D_{k}^{P}, (k = 1, 2, \dots, l)$ (2) (Demand constrains)

$\sum_{i=1}^{m} X_{ij}^{P} - \sum_{k=1}^{l} X_{jk}^{R} = 0, (j = 1,2, \dots, n)$ (3) (Transshipment constrains)

$X_{ij}^{P} \geq 0, (i = 1,2, \dots, m\ ;\ j = 1,2, \dots, n)$ (4) (Non-negativity constrains)

$X_{jk}^{R} \geq 0, (j = 1,2, \dots, n\ ;\ k = 1,2, \dots, l)$ (5) (Non-negativity constrains)

## 3. Research Methodology

In this research methodology, there are five steps taken to resolve the problems in this research. The first step is collecting data consist of supply facilities, district demand, and costs at the supply facility. Supply facilities identify where production facilities are located, i.e. cement plant, packing plants, and virtual distribution center. as well as data collection of supply capabilities in the peak season months. Supply facilities in this study consist of 13 supply facilities. Cement plant is a plant that processes the activity from mining process to become a clinker product, and then is grinded into a final cement product. Packing plant is where cement packaging process takes place. Virtual distribution center is a weighing facility and has no storage capacity. District demand, namely discussing where the marketing district of this cement company in area A and the volume of requests in each of these districts. The number of districts has been distributed with 128 districts spread across area A. Costs at the supply facility, namely costs arising from each supply facility, including costs of production, shipping, transportation, administration, and fixed cost. The second step is constructing mathematical model by linear programming for transshipment problems. The third step is developing optimization model using LINGO software. The fourth step is verifying and validating model. The verification process is performed to ensure that the model is already built right in LINGO model and generate the value of the objective function. The validation process is performed by comparing the result of optimization with LINGO software to the result obtain from the real system. If both systems do not show significant different, meaning that the model is already valid and able to represent real system. The fifth step is comparing the existing supply chain costs to the optimal supply chain costs.

## 4. Proposed Optimization Model

An optimization model for the transshipment problem is formulated in this paper. This model will reveal that the effort necessary to implement specific solutions by producing optimal supply chain costs. The formula of linear programming model in this study is based on a general model of transshipment problems by considering the supply capability of each supply facility, the demand in each district in the form of bulk cement and bag cements, and types of costs.

**Index**

Index in the problem of bag and bulk cement transshipment models are as follow:

*i* = Cement Product Type *i*, *i* = 1,2 (bag and bulk cement)
*j* = Cement Plant *j*, *j* = 1,2
*k* = Packing Plant *j*, *j* = 1,2,…,5
*l* = Virtual Distribution Center *l*, *l* = 1,2,…,6
*m* = Marketing District *m*, *m* = 1,2,…,128

**Decision Variables**

Decision variables in the problem of bag and bulk cement transshipment models are as follow:

$x_{ijk}$ = The volume of cement *i* sent from the cement plant *j* to the packing plant *k*
$x_{ijl}$ = The volume of cement *i* sent from the cement plant *j* to the virtual distribution center *l*

$x_{ijm}$ = The volume of cement *i* sent from the cement plant *j* to the marketing district *m*
$x_{ikm}$ = The volume of cement *i* sent from the packing plant *k* to the marketing district *m*
$x_{ilm}$ = The volume of cement *i* sent from the virtual distribution center *l* to the marketing district *m*

**Parameter**

(1) Production capacity
$cp_{ij}$ = Production capacity of cement *i* from the cement plant *j*
$cp_{ik}$ = Production capacity of cement *i* from the packing plant *k*

(2) Cement demand
$d_{im}$ = Demand of cement *i* in the marketing district *k*

(3) Fixed cost
$c_k^F$ = Fixed cost of the packing plant *k* in a month

(4) Production cost
$c_{ij}^P$ = Production cost of cement *i* per ton in the cement plant *j*
$c_{ik}^P$ = Production cost of cement *i* per ton in the packing plant *k*

(5) Shipping cost
$c_{jk}^K$ = Shipping cost from the cement plant *j* to the packing plant *k*
$c_{jl}^K$ = Shipping cost from the cement plant *j* to the virtual distribution center *l*

(6) Transportation cost
$c_{jm}^T$ = Transportation cost from the cement plant *j* to the marketing district *m*
$c_{km}^T$ = Transportation cost from the packing plant *k* to the marketing district *m*
$c_{lm}^T$ = Transportation cost from the virtual distribution center *l* to the marketing district *m*

(7) Administration cost
$c_{jm}^D$ = Administration cost from the cement plant *j* to the marketing district *m*
$c_{km}^D$ = Administration cost from the packing plant *k* to the marketing district *m*
$c_{lm}^D$ = Administration cost from the virtual distribution center *l* to the marketing district *m*

**Objective Function**

The purpose of this transshipment problem is to minimize the overall supply chain costs that arise, with the objective function as follow:
In this model, total cost constrains more factors as discussed below:

- Fixed cost
  Fixed cost if the packing plant *k* operates

$$\sum_{k=1}^{5} c_k^F Y_k + \sum_{k=1}^{5} c_k^F (1 - Y_k) \tag{1}$$

- Production cost
  Production costs of the volume of cement *i* produced at each cement plant *j* and packing plant *k*.

$$\sum_{i=1}^{2} \sum_{j=1}^{2} \sum_{k=1}^{5} x_{ijk}\, c_{ij}^P + \sum_{i=1}^{2} \sum_{j=1}^{2} \sum_{l=1}^{6} x_{ijl}\, c_{ij}^P + \sum_{i=1}^{2} \sum_{j=1}^{2} \sum_{m=1}^{128} x_{ijm}\, c_{ij}^P + \sum_{i=1}^{2} \sum_{k=1}^{5} \sum_{m=1}^{128} x_{ikm}\, c_{ik}^P \tag{2}$$

- Shipping cost
  Shipping costs of the volume of cement *i* produced from the cement plant *j* to the packing plant *k* and virtual distribution center *l*.

$$\sum_{i=1}^{2} \sum_{j=1}^{2} \sum_{k=1}^{128} (x_{ijk}\, c_{jk}^K) + \sum_{i=1}^{2} \sum_{j=1}^{2} \sum_{l=1}^{6} (x_{ijl}\, c_{jl}^K) \tag{3}$$

- Transportation cost
  Transportation costs of the volume of cement *i* sent from the cement plant *j*, packing plant *k* and virtual distribution center *l* to the marketing district *m*.

(4)

$$\sum_{i=1}^{2}\sum_{j=1}^{2}\sum_{m=1}^{128}(x_{ijm}\,c_{jm}^{T})+\sum_{i=1}^{2}\sum_{k=1}^{5}\sum_{m=1}^{128}(x_{ikm}\,c_{km}^{T})+\sum_{i=1}^{2}\sum_{l=1}^{6}\sum_{m=1}^{128}(x_{ilm}\,c_{lm}^{T})$$

- Administration cost
  Administration costs of the volume of cement *i* sent from the cement plant *j*, packing plant *k* and virtual distribution center *l* to the marketing district *m*.

$$\sum_{i=1}^{2}\sum_{j=1}^{2}\sum_{m=1}^{128}(x_{ijm}\,c_{jm}^{D})+\sum_{i=1}^{2}\sum_{k=1}^{5}\sum_{m=1}^{128}(x_{ikm}\,c_{km}^{D})+\sum_{i=1}^{2}\sum_{l=1}^{6}\sum_{m=1}^{128}(x_{ilm}\,c_{lm}^{D}) \quad (5)$$

Summarizing the discussed objective functions above, the complete linear programming model can be expressed by following:
Min Z = (Total fixed costs) + (Total production costs) + (Total shipping costs) + (Total transportation costs) + (Total administration costs)

$$\text{Min } Z = \sum_{k=1}^{5} c_k^F Y_k+\sum_{k=1}^{5} c_k^F(1-Y_k)+\sum_{i=1}^{2}\sum_{j=1}^{2}\sum_{k=1}^{5} x_{ijk}\,c_{ij}^{P}+\sum_{i=1}^{2}\sum_{j=1}^{2}\sum_{l=1}^{6} x_{ijl}\,c_{ij}^{P}+\sum_{i=1}^{2}\sum_{j=1}^{2}\sum_{m=1}^{128} x_{ijm}\,c_{ij}^{P}$$
$$+\sum_{i=1}^{2}\sum_{k=1}^{5}\sum_{m=1}^{128} x_{ikm}\,c_{ik}^{P}+\sum_{i=1}^{2}\sum_{j=1}^{2}\sum_{k=1}^{128} x_{ijk}\,c_{jk}^{K}+\sum_{i=1}^{2}\sum_{j=1}^{2}\sum_{l=1}^{6} x_{ijl}\,c_{jl}^{K}+\sum_{i=1}^{2}\sum_{j=1}^{2}\sum_{m=1}^{128} x_{ijm}\,c_{jm}^{T}$$
$$+\sum_{i=1}^{2}\sum_{k=1}^{5}\sum_{m=1}^{128} x_{ikm}\,c_{km}^{T}+\sum_{i=1}^{2}\sum_{l=1}^{6}\sum_{m=1}^{128} x_{ilm}\,c_{lm}^{T}+\sum_{i=1}^{2}\sum_{j=1}^{2}\sum_{m=1}^{128} x_{ijm}\,c_{jm}^{D}+\sum_{i=1}^{2}\sum_{k=1}^{5}\sum_{m=1}^{128} x_{ikm}\,c_{km}^{D}$$
$$+\sum_{i=1}^{2}\sum_{l=1}^{6}\sum_{m=1}^{128} x_{ilm}\,c_{lm}^{D} \quad (6)$$

**Constraints**

(1) Cement production capacity
Sum of the volume of cement *i* produced from the cement plant *j* sent to the packing plant *k*, the volume of cement *i* produced from the cement plant *j* to the virtual distribution center *l* and the volume of cement *i* produced from the cement plant *j* to the marketing district *m* must be less than or equal to production capacity at each cement plant *j*.

$$\sum_{k=1}^{5} x_{ijk}+\sum_{l=1}^{6} x_{ijl}+\sum_{m=1}^{128} x_{ijm}\le cp_{ij}\,,\ \forall_i\,,\ \forall_j \quad (7)$$

On the other hand, the volume of cement *i* sent to the packing plant *k* operates from the cement plant *j* must be less than or equal to production capacity at each packing plant *k*.

$$\sum_{j=1}^{2} x_{ijk}\le cp_{ik}Y_k\,,\ \forall_i\,,\ \forall_k \quad (8)$$

(2) Cement demand

Sum of the volume of cement *i* sent to the marketing district *m* from the cement plant *j*, the packing plant *k* and the virtual distribution center *l* must be greater than or equal to cement demand at each marketing district *m*.

$$\sum_{j=1}^{2} x_{ijm} + \sum_{k=1}^{5} x_{ikm} + \sum_{l=1}^{6} x_{ilm} \geq d_{im} , \forall_i , \forall_m \quad (9)$$

(3) Transshipment balance
The volume of cement *i* sent to the packing plant *k* from the cement plant *j* must be equal the volume of cement *i* sent from the packing plant *k* to the marketing district *m*.

$$\sum_{j=1}^{2} x_{ijk} = \sum_{m=1}^{128} x_{ikm} , \forall_i , \forall_k \quad (10)$$

On the other hand, the volume of cement *i* sent to the virtual distribution center *l* from the cement plant *j* must be equal the volume of cement *i* sent from the virtual distribution center *l* to the marketing district *m*.

$$\sum_{j=1}^{2} x_{ijl} = \sum_{m=1}^{128} x_{ilm} , \forall_i , \forall_l \quad (11)$$

(4) Non-negativity constraints
Ensure that all decision variables must be greater than zero

$$x_{ijk} , x_{ijl} , x_{ijm} , x_{ikm}, x_{ilm} \geq 0 \quad (12)$$

(5) Binary constraints
Ensure that the decision variable for the packing plant *k* must be a binary number

$$Y_k \in \{0,1\}, \forall_k \in K \quad (13)$$

## 5. Results and Discussions

The LINGO model has been made consists of 2467 variables. With that large number of variables, LINGO can solve and produce optimal solutions. The allocation of supply facility to a sales district, that is undefined or constrained by a field, is given a large number of constants so that the solution formed does not choose the allocation and the solution becomes feasible. Before performing optimization process using LINGO, the supply chain costs for the existing allocation of input data are calculated so that the existing supply chain costs will be compared to the optimal supply chain costs later.

From the existing condition allocation, the supply chain costs Rp954,387,451,702. The optimal allocation results obtained supply chain costs of Rp904,783,313,635. It shows that by optimization procedure, the company is able to reduce costs up to Rp49.6 Billion, or by 5.2% (Table 1). From the optimization result, it also shows that there is a shift in the source of supply for the marketing districts, which is briefly presented in Table 2.

Table 1. Comparison of existing supply chain costs and optimal supply chain costs.

| **Cost Type** | **Existing Supply Chain Costs** | **Optimal Supply Chain Costs** | **Reduce Costs** | **Percentage** |
|---|---:|---:|---:|---:|
| **Fixed Cost** | Rp4,841,947,800 | Rp4,841,947,800 | Rp0 | 0.0% |
| **Production Cost** | Rp673,766,879,829 | Rp655,381,041,759 | (Rp18,385,838,070) | (2.7%) |
| **Shipping Cost** | Rp35,089,908,372 | Rp24,034,535,711 | (Rp11,055,372,661) | (31.5%) |
| **Transportation Cost** | Rp201,717,701,499 | Rp181,612,945,267 | (Rp20,104,756,232) | (10.0%) |
| **Administration Cost** | Rp38,971,014,202 | Rp38,912,843,098 | (Rp58,171,104) | (0.1%) |
| **Total Cost** | **Rp954,387,451,702** | **Rp904,783,313,635** | **(Rp49,604,138,067)** | **(5.2%)** |

Table 2. Optimal allocation.

| **No** | **Marketing District** | **Existing Allocation** | **Optimal Allocation** |
|---|---|---|---|
| **1** | M1 | Bag : CP 1 | Bag : CP 1 |
| | | Bulk : CP 1 | Bulk : CP 1 |
| **2** | M2 | Bag : CP 1 | Bag : CP 1 |
| | | Bulk : CP 1 | Bulk : CP 1 |
| **3** | M3 | Bag : CP 1, CP 2 | Bag : CP 2 |
| | | Bulk : CP 1 | Bulk : CP 2 |
| **4** | M4 | Bag : CP 1, CP 2 | Bag : CP 1 |
| | | Bulk : CP 1 | Bulk : CP 1 |
| **5** | M5 | Bag : PP 3, PP 4 | Bag : CP 1, PP 4 |
| | | Bulk : CP 1, PP 4 | Bulk : PP 4 |
| **6** | M6 | Bag : CP 1, PP 5, Virtual DC 3 | Bag : CP 1 |
| | | Bulk : CP 1, PP 5 | Bulk : CP 1 |

In addition to producing a decision to supply from a supply facility to a marketing district, it can also be seen from the results of optimization that the volume allocation can change. For example, in allocation for bag cement, the optimal allocation of supply facility CP 1 has changed. Cement allocation from CP 1 to M1 and M2 are constant, CP 1 to M3 is decreased, and CP 1 to M4-M6 are increased.

From the optimal allocation result, the production utility of each supply facility to the marketing district has a different percentage (Table 3). PP 2 has the highest production utility by 100%, while PP 5 has the lowest production utility by 21%. So, PP 5 includes an unproductive packing plant and is recommended to stop operating.

Table 3. Optimal production utility of supply facilities.

| Supply Facilities | Cement Plant | | Packing Plant | | | | |
|---|---|---|---|---|---|---|---|
| Production Capacity | CP1 | CP2 | PP1 | PP2 | PP3 | PP4 | PP5 |
| Total Production Capacity | 1300000 | 250000 | 35000 | 15000 | 30000 | 40000 | 50000 |
| Total Capacity Used | 1158430 | 220633 | 30506 | 15000 | 28083 | 27310 | 10461 |
| Production Utility | **89%** | **88%** | **87%** | **100%** | **94%** | **68%** | **21%** |

From the optimal allocation, the supply chain costs Rp904,783,313,635. If PP 5 stops operating, the optimal supply chain costs becomes Rp900,532,141,072 or reduced cost up to Rp4.25 Billion or by 0.5% from previous optimal supply chain costs (Table 4). In addition to producing cost reduction, the production utility of each supply facility to the marketing district is changing. CP 1 increased production utility by 1%. Table 5 shows New Optimal Production Utility of Supply Facilities.

Table 4. Comparison of optimal supply chain costs and new optimal supply chain costs.

| **Cost Type** | **Previous Optimal Supply Chain Costs** | **New Optimal Supply Chain Costs** | **Reduce Costs** | **Percentage** |
|---|---|---|---|---|
| **Fixed Cost** | Rp4,841,947,800 | Rp4,841,947,800 | Rp0 | 0% |
| **Production Cost** | Rp655,381,041,759 | Rp651,125,716,179 | (Rp4,255,325,580) | (0.6%) |
| **Shipping Cost** | Rp24,034,535,711 | Rp21,656,750,411 | (Rp2,377,785,300) | (9.9%) |
| **Transportation Cost** | Rp181,612,945,267 | Rp183,994,883,584 | Rp2,381,938,317 | 1.3% |
| **Administration Cost** | Rp38,912,843,098 | Rp38,912,843,098 | Rp0 | 0% |
| **Total Cost** | **Rp904,783,313,635** | **Rp900,532,141,072** | **(Rp4,251,172,563)** | **(0.5%)** |

Table 5. New optimal production utility of supply facilities.

| Supply Facilities / Production Capacity | Cement Plant | | Packing Plant | | | | |
|---|---|---|---|---|---|---|---|
| | CP1 | CP2 | PP1 | PP2 | PP3 | PP4 | PP5 |
| Total Production Capacity | 1300000 | 250000 | 35000 | 15000 | 30000 | 40000 | 0 |
| Total Capacity Used | 1168891 | 220633 | 30506 | 15000 | 28083 | 27310 | 0 |
| Production Utility | **90%** | **88%** | **87%** | **100%** | **94%** | **68%** | **0%** |

## 6. Conclusion

This study has identified cost types in production and distribution model for cement industry. The most affecting decision variable in optimization models making to reduce supply chain cost is the volume of cement that is delivered from the cement plant to the packing plant. Meanwhile, the most affecting constraint is the transshipment balance. The optimization model produced two results. First is supply chain costs reduction from the existing condition allocation. Second is recommendation to stop operation of packing plant due to low production utility. Therefore, there will be supply chain costs decreasing and production utilities increasing at certain facilities. There is also a change on bag and bulk cement volume allocation from supply facilities to marketing districts. The limitations of this study that this study does not consider lead time, terrain difficulties, and truck availability. Lead time is not used in this study because it tends to be relatively fixed. Terrain difficulties is not used in this study because cannot be controlled by the company. Therefore, it is very possible to include them at future research.

## References

Pujawan, I.N., and Geraldin, L.H., House of risk: a model for proactive supply chain risk management, *Bus. Process Manag. J.*, Emerald, 2009 Nov 6, vol. 15, no. 6, 953–967, 2009

Liu, J., *Supply Chain Management and Transport Logistics*, 1st edition, Routledge, London, 2011.

Pettersson, A.I., and Segerstedt, A., Measuring supply chain cost, *Int. J. Prod. Econ*., Elsevier BV, 2013 Jun, vol. 143, no. 2, pp. 357–363, 2013.

Tsiakis, P., Shah, N., and Pantelides, C.C., Design of multi-echelon supply chain networks under demand uncertainty, *Ind. Eng. Chem. Res.,* American Chemical Society (ACS), 2001 Aug, vol. 40, no. 16, pp. 3585–3604, 2001

Tsiakis, P., and Papageorgiou, L.G., Optimal production allocation and distribution supply chain networks, *Int. J. Prod. Econ*., Elsevier BV, 2008 Feb, vol. 111, no. 2, pp. 468–483, 2008