HEURISTIC SOLUTION OF LOCATION MODEL OF
STATE-OWNED COMPANY DISTRIBUTION SYSTEM

Sutanto SOEHODHO
Professor in Transportation
Department of Civil Engineering,
Faculty of Engineering,
University of Indonesia
Kampus UI Depok 16424.
Ph: 021-7270029
Email : ssoehodho@yahoo.com

Nahry YUSUF
Doctoral Student
Department of Civil Engineering,
Faculty of Engineering,
University of Indonesia
Kampus UI Depok 16424.
Ph: 021-7270029
Email : nahry@eng.ui.ac.id

Abstract: This study is a part of series of research on distribution system of state-owned company. It concerns with the determination of locations of warehouses of Public Service Obligation State-owned Company (PSO-SOC) distribution system. This paper will be focused on the heuristic solution of the proposed model. The original (mathematical) model takes form of Minimum Concave-cost Multicommodity Flow (MCMF) problem. The solution is approached by Network Representation, in which all of the components of the original model are represented in the form of dummy links and nodes which are added to the original network. Then, the original problem is replaced by the problem of MCMF of the Network Representation. Due to the complexity of solution of such MCMF problem, our solution is approached by bi-level programming. Primal-dual algorithm and heuristic algorithm associated to the searching of Destination Spanning Tree are employed to solve such bi-level programming. An illustrative example is presented to explain the mechanism of the bi-level programming.

Key Words: Location model, Minimum Concave-cost Multicommodity Flow problem, bilevel programming.

1. INTRODUCTION

Research works on determining location of distribution facilities have been done for many years. Most of them are dealing with private company of which its orientation is merely on profit maximization. In Indonesia, there exists the State-Owned Company (SOC) which is called Public Service Obligation (PSO)-SOC. PSO SOC has the obligation to serve the entire demand on public commodities or services. Its working orientation is not for profit but for security of supply. The PSO SOC’s are still permitted to conduct their own programs beyond their main task but it is undertaken under limitation and controlling of the government.

From the identification on distribution system of one of Indonesia PSO-SOC’s which deals with production and distribution of public commodities we note some important issues (Soehodho et al., 2008), as follows:
1. The company under consideration is a group of companies that consists of one holding company and five affiliated companies. Each of companies (included the holding company itself) carries out the operational of its own plant and its distribution process independently. Those companies are managed separately and there is no regulation that integrates those companies in their logistical process.
2. Unit production costs are not uniform among the plants. It is due to the different price of the raw material and it is also affected by the variability in the operation performance of production machines.

3. There exists product differentiation. Such product differentiation implies that products are not differentiated merely on type (material) of product, but they are also differentiated based on the type of user of the products. There are two types of users, those are public (subsidized) demand and commercial one. Both of them are different in term of selling price and demand satisfaction. Subsidized prices are determined by the government, while the commercial ones are set by the company. Naturally, the commercial prices are higher than the subsidized ones. At the other side, subsidized demands have the privilege to be fully satisfied regardless the profit that the company may take from them.

4. In order to ensure the subsidized products reach the customers in respectable time and place, government regulates the distribution channel of such products from the point of production to the point of final customer, that is retailer.

Such characteristic of PSO-SOC bring the notion to enhance the earlier location models for the purpose of taking into account special role of state-owned company.

2. LITERATURE REVIEW

In this section, some papers are reviewed to map out the preceding research works related to location model.

Hodder and Jucker develop uncapacitated plant location model with profit maximization as its objective (Hodder, et al., 1986). They consider selling price of the product in market and also the cost which is included production and transportation expenses and treated both of them in one term namely cost of serving market. Fixed cost of opening plant is included in the model in addition. They consider a single-period model with a number of markets and potential plant location.

Perl and Daskin propose location model to determine the number, size and locations of the Distribution Centers and the allocation of customers to them so as to minimize the total system cost (Perl et al., 1985). The problem is basically one of finding the optimal balance between warehousing and transportation costs. Warehousing costs include both fixed and variable costs, while the transportation costs consist of the trunking and delivery costs. Perl and Daskin’s state of the art is a methodology for determining Distribution Center location which represents delivery costs more accurately. The delivery cost in the Distribution Center location problem depends on vehicle routing. The objective function of their model is to minimize the sum of fixed warehousing cost, trunking cost, variable warehousing cost and delivery cost.

Nozick and Turnquist’s contribution on the development of location model is the inclusion of inventory cost within a fixed-charge facility location model (Nozick et al., 1998). A basic premise that inventory costs (in particular, the safety stock required to provide a desired level of service when demand is uncertain) should be considered together with other facility operation and transportation costs in determining the optimal number of Distribution Centers and their locations. The fixed-charge facility location model is an effective tool for analysis of how many Distribution Centers should be built and where they should be located.

Continuing their research on Location Model, Nozick and Turnquist proposed modeling approach that provides an integrated view of inventory costs, transportation costs and service levels when making Distribution Center location decision (Nozick et al.,2001). They believe that integration of
inventory costs into the location model is an important step for overall cost minimization, but it still needs to deal with customer responsiveness in the distribution system. The previous model that they developed is extended by incorporating multiple objective, those are minimization cost and maximizing service coverage.

Ricciardi, Tadei & Grosso determine the optimal location and size of a set of intermediate facilities in order to minimize the expected total generalized transportation cost, that is the generalized transportation cost of a freight unit from an origin to a destination passing through a facility (Ricciardi et al., 2002). The throughput cost represents operational cost of loading and unloading and holding inventory as well.

Lin in his dissertation carries out a research in which its goals of developing a location model for multi-product and multi-echelon distribution systems where there are significant economies of scale in the transportation movements (Lin, 2002). He integrates the location model with a multi-product multi-echelon inventory allocation model for finished goods. The objective function of his model is to minimize transportation cost, facility fixed-cost as well as the inventory cost and penalty cost. The concerns of the model are long-term decision on facility investments and selection of transportation channels and tactical decisions on inventory allocation rather than day-to-day operational decisions.

Dupont (Dupont, 2008) introduces location model, in which the global cost incurred for each established facility is a concave function of the quantity delivered by this facility. He introduce some properties of an optimal solution and derive heuristic algorithms and a branch and bound method from these properties. He propose uncapacitated facility location problem (UFLP) which characterized by single commodity and single stage network.

All of those research works make use of binary variable [0,1] to decide whether one facility should be open or not.

3. MODEL FORMULATION

In order to take into account the characteristics of PSO-SOC as stated in chapter 1, we propose that the distribution system of the affiliated companies are integrated in one systems and it can be coordinated by the holding company. Furthermore, we propose location model which deals with production cost, transportation cost, fixed cost of facility, as well as revenue as its variables (Soehodho et al., 2009). Those variables are considered for the following rationale. When the total plant capacity is more than the total demand, the holding company has to designate production allocation to each plant, and in such situation one or more plants must be in under capacity (not operated in full capacity). When the holding company only considers the distribution cost, it may lose the efficiency on logistics as a whole system, particularly if the cost of production is not in accordance with the efficiency in the level of distribution cost.

In case of over demand, all the plants must be fully operated. In such case, the holding company must decide which commercial demands that should be satisfied in order to attain the maximum profit of the company. Since the selling price of commercial products is different among each other, hence the selling price becomes important variable to be included in this optimization.

In order to improve the existing system, we propose three stage distribution network which consists of set of plants, consolidation centers, distribution centers and retailers. The transportation cost
between plant and consolidation centers, as well as consolidation centers and distribution centers follow the principle of economies of scale. Such principle illustrates that the average cost per unit of flow per unit of distance is changed as the quantity transferred changes (Lin, 2002). This principle leads to the situation in which the consolidation center may not be utilized and the product from the plant delivered to the distribution center directly. Figure 1 shows an example of proposed distribution network.

Figure 1. An example of physical distribution network

The above explanation leads to the formulation of proposed location model as follows:

\[
\min Z(X_c, Y_d, \alpha_{p(m)c}, \beta_{cdm}, \gamma_{drm}, \delta_{p(n)d}) = \\
\sum_{p \in P} \sum_{c \in C} u_{pc} \Phi_{pc} \left[ \sum_{m \in M} \alpha_{p(m)c} \right] + \sum_{c \in C} \sum_{d \in D} v_{cd} \Psi_{cd} \left[ \sum_{m \in M} \beta_{cdm} \right] + \sum_{p \in P} \sum_{d \in D} z_{pd} \xi_{pd} \left[ \sum_{m \in M} \delta_{p(n)d} \right] + \\
\sum_{d \in D} \sum_{r \in R} w_{dr} \left( \gamma_{drm} + \delta_{p(n)d} \right) + \sum_{p \in P} \sum_{m \in M} \sum_{c \in C} \alpha_{p(m)c} + \sum_{d \in D} \sum_{m \in M} \delta_{p(n)d} \left[ \lambda_{p(n)m} \right] + \sum_{c \in C} \lambda_{C_d} + \sum_{d \in D} \gamma_{drm} \Phi_{pm}
\]

subject to:

\[
\sum_{p \in P} \alpha_{p(m)c} = \sum_{d \in D} \beta_{cdm}, \quad \forall c \in C, \forall m \in M
\]  

\[
\sum_{c \in C} \beta_{cdm} + \sum_{p \in P} \delta_{p(n)d} = \sum_{r \in R} \gamma_{drm}, \quad \forall d \in D, \forall m \in M
\]  

\[
\gamma_{drm} = \lambda_{rm}, \quad \forall r \in R, \forall m \in M
\]  

\[
\gamma_{drm} \leq \lambda_{rm}, \quad \forall r \in R, \forall m \in M
\]  

\[
\gamma_{drm} \leq Y_d \lambda_{rm}, \quad \forall d \in D, \forall r \in R, \forall m \in M
\]  

\[
\sum_{p \in P} \alpha_{p(m)c} \leq X \cdot \sum_{r \in R} \lambda_{rm}, \quad \forall c \in C, \forall m \in M
\]  

\[
\sum_{c \in C} \alpha_{p(m)c} + \sum_{d \in D} \delta_{p(n)d} \leq C p_{p(m)}, \quad \forall p \in P, \forall m \in M
\]  

\[
\alpha_{p(m)c} \geq 0, \quad \forall p \in P, \forall c \in C, \forall m \in M
\]  

\[
\beta_{cdm} \geq 0, \quad \forall c \in C, \forall d \in D, \forall m \in M
\]
\[ \gamma_{d,m} \geq 0, \quad \forall d \in D, \forall r \in R, \forall m \in M \]  \hspace{2cm} (11)

\[ \delta_{p(m),d} \geq 0, \quad \forall p \in P, \forall d \in D, \forall m \in M \]  \hspace{2cm} (12)

\[ X_c = [0,1], \quad \forall c \in C \]  \hspace{2cm} (13)

\[ Y_d = [0,1], \quad \forall d \in D \]  \hspace{2cm} (14)

Subscripts:
- \( p \) : indicate the Plants
- \( c \) : indicate the Consolidation Centers
- \( d \) : indicate the Distribution Centers
- \( r \) : indicate the Retailers
- \( m \) : indicate the Products
- \( p(m) \) : indicate the plant \( p \in P \) that produces product-\( m \)

Sets:
- \( P \) : Set of plants
- \( C \) : Set of consolidation centers
- \( D \) : Set of distribution centers
- \( R \) : Set of retailers
- \( M \) : Set of products
- \( M' \in M \) : Set of subsidy (public) products
- \( M'' \in M \) : Set of commercial products

Decision Variables:
- \( X_c = 1 \) if Consolidation Center - \( c \) is opened , 0 otherwise
- \( Y_d = 1 \) if Distribution Center - \( d \) is opened , 0 otherwise
- \( \alpha_{p(m),c} \) is quantity of product-\( m \) that flow from Plant \( p(m) \) to Consolidation Center-\( c \)
- \( \beta_{c,d,m} \) is quantity of product-\( m \) that flow from Consolidation Center-\( c \) to Distribution Center-\( d \)
- \( \gamma_{d,m} \) is quantity of product - \( m \) that flow from Distribution Center-\( d \) to Retailer-\( r \)
- \( \delta_{p(m),d} \) is quantity of product - \( m \) that flow from Plant \( p(m) \) to Distribution Center-\( d \)

Input Parameters:
- \( \rho_{r,m} \) is the selling price of the product-\( m \) at retailer - \( r \)
- \( u_{pc} \) is the distance from Plant-\( p \) to Consolidation Center-\( c \)
- \( v_{cd} \) is the distance Consolidation Center-\( c \) to Distribution Center-\( d \)
- \( w_{dr} \) is the distance from Distribution Center-\( d \) to Retailer-\( r \)
- \( z_{pd} \) is the distance from Plant \( p(m) \) to Distribution Center-\( d \)
- \( FC_c \) is fixed cost of facility of Consolidation Center - \( c \)
- \( FD_d \) is fixed cost of facility of Distributor Center - \( d \)
- \( \omega_{d,m} \) is per-mile cost to ship a unit of product-\( m \) from Distribution Center-\( d \) to Retailer-\( r \)
- \( \lambda_{r,m} \) is demand of product-\( m \) in Retailer-\( r \)
- \( Cp_{p(m)} \) is the capacity of plant-\( p \) to produce product-\( m \)

Input Functions:
- \( \Phi_{pc} \), \( \forall p \in P, \forall c \in C \) : is the cost per mile for transporting product-\( m \) from Plan-\( p \) to Consolidation Center-\( c \) (a concave function of total volume)
- \( \Psi_{cd} \), \( \forall c \in C, \forall d \in D \) : is the cost per mile for transporting product-\( m \) from Consolidation Center-\( c \) to Distribution Center-\( d \) (a concave function of total volume)
- \( \zeta_{pd} \), \( \forall p \in P, \forall d \in D \) : is the cost per mile for transporting product-\( m \) from Plan-\( p \) to Distribution Center-\( c \) (a concave function of total volume)
- \( \eta_{p,m} \), \( \forall p \in P \) : is the cost per ton for producing product-\( m \) in plant-\( p \)
4. MODEL SOLUTION

From the mathematical model of equation (1)–(14) we can conclude that our proposed model takes form of Minimum Concave cost Multicommodity Flow (MCMF) problem. Such a concave function is employed due to consideration of economies of scale in production cost and transportation cost between plant, consolidation centers and distribution centers.

Zangwill (Zangwill, 1968) argue that although concave functions can be minimized by an exhaustive search of all the extreme points of the convex feasible region, such an approach is impractical for all but the simplest of problems. Gallo (Gallo, 1980) proposes that there is a one-to-one correspondence between the set of extreme flows and Destination Spanning Tree, where the root is source node, each terminal node is a destination, and the remaining destinations (if any) appear as intermediate nodes. He found that the problem of minimum concave cost network flow is based on an implicit enumeration of the elements of Destination Spanning Tree.

In order to solve our MCMF problem, we make use Gallo’s theorems and algorithm, which are dealing with the problem of finding Destination Spanning Tree. Since such problem is highly related to the network structure, we exploit Network Representation (NR) to represent and solve the proposed mathematical model. Network Representation is developed by adding some dummy links and nodes into the original network, in which cost function of those dummy links are designated to represent production cost, transportation cost, fixed cost of facility, as well as revenue. An example of NR is shown in figure 2. Such NR represents the MCMF problem of network in figure 1.

Unit cost function of a production link in figure 2 represents the unit cost of production of certain product which is associated to such link. Hence, we categorize such kind of link as product-exclusive link. This type of link is also utilized in representing revenue. Unit cost of a revenue link is associated to selling price of certain product. Furthermore, we assume that the unit cost of transporting any type of product is similar. Hence, the transportation link is dedicated to all products. This assumption is used for the fixed cost of facility link also. The cost associated to fixed cost of facility link refers to cost of building of the associated warehouse. The nodes of NR are valued as their flow requirement. Node $P_{i,m}$ is valued by the capacity of plant-$i$ on producing product-$m$, meanwhile node $R_{i,m}$ is valued by the demand on product-$m$ in retailer-$i$. The flow requirements of the intermediate nodes are set as zero.

From the developed NR, now we can simplify the equation (1)–(14) as follows:

$$\text{min } Z(x_{ijm}) = \sum_{i \in I} \sum_{j \in J} \sum_{m \in M} \varphi_{ijm}(x_{ijm})$$ (15)

subject to:

$$\sum_{i} x_{ilm} - \sum_{j} x_{ijm} = q_{lm} \forall l \in N, \forall m \in M$$ (16)

$$x_{ijm} \geq 0 \forall (i,j) \in A, \forall m \in M$$ (17)

where $x_{ijm}$ : flow on link $i$–$j$ of product $m$ (as decision variable)

$\varphi_{ijm}(.) \forall (i,j) \in A, \forall m \in M$ : link cost function of link $i$–$j$ of product-$m$

$q_{li}$ : flow requirement of node-$i$

$N$ : set of nodes of Network Representation

$A$ : set of links of Network Representation

$M$ : set of products
Since all the link cost functions of NR are functions of flow of the associated link, we can simplify the equation 1 into equation 15. Moreover, constraints in equation (2)~(14) could be simplify into equation (15)~(17). Flow conservation constraints in equation (2) ~ (8) could be replaced by equation (16) due to the valuation of node flow requirement as explained above. Equation (4) ~ (5) which are related to the demand satisfaction of subsidized and commercial product respectively are represented by the mechanism of the so called Excess Supply/Demand control links of NR.

Excess supply control links are added to the NR in case of total production capacity of all plants is larger than total demands. Each of the excess supply control links is connected to dummy retailer $R_m^\prime$ which is associated to certain product. Cost function of the excess supply control link could be an arbitrary number which represents cost to eliminate some amount of product-$m$ in plant-$p$ due to excess supply.

In case of total capacity is lesser than total demand, we add excess demand control link. Each of the excess demand control links is connected to dummy plant which is associated to certain product. Cost function of the excess demand control link represents cost of “unsatisfied demand” on product-$m$ in retailer-$r$ due to the excess of demand. In order to prioritize the subsidized demand, we set extremely high unit cost function to the links of excess demand control links that

Figure 2. An example of Network Representation

Notes :
- Production Link
- Transportation Link
- Revenue Link
- Excess Supply Control Link
- Excess Demand Control Link

$P_{im}$ : Plant – $i$ associated to product - $m$
$P_i$ : Plant – $i$
$CC_i$ : Consolidation Center – $i$
$CC_i^\prime$ : Dummy node of Consolidation Center – $i$
$DC_i$ : Distribution Center – $i$
$DC_i^\prime$ : Dummy node of Distribution Center – $i$
$R_i$ : Retailer – $i$
$R_{im}$ : Retailer – $i$ associated to product-$m$
$R_{m}^\prime$ : Dummy Retailer associated to product–$m$
$P_{m}^\prime$ : Dummy Plant associated to product – $m$
associated to subsidized product. It means that such a high “unsatisfied-demand cost” will avoid unfulfillment of public demand. Both of excess supply and demand control links and its associated dummy retailer or plant are depicted in figure 2.

The existence of flow requirement of dummy retailer or dummy plant in case of imbalance of supply and demand is intended to guarantee that the condition of balance must be attained at the optimal flow. It also guarantees that all plants are operated in its capacity or less, besides total demand satisfied at all retailer must be similar to the requested demand (in case of subsidized products) or less than/equal to the requested one (in case of commercial product).

Since the concept of Destination Spanning Tree of Gallo deals with single source network, we have to modify Gallo’s algorithm in order to cope with our ‘multisource’ problem. We propose the notion of clustering of retailers into some groups which depends on the number of plants. Such an idea is solved by introducing bi-level programming. Step-wise of bi-level programming is depicted in figure 3.

The first level is aimed to cluster \( R_i \)'s based on the associated production point \( P_i \) which is the best-suited to be assigned to. In order to solve multicommodity problem, in this level we develop one sub-NR for each product. Each sub-NR is named Product Sub Network Representation (P-SNR). All links and nodes of a P-SNR must be associated to a certain product. Furthermore, we consider our model as a linear model which takes form of Minimum Linear cost Flow problem. The optimal flows of each P-SNR is solved by Primal-dual Algorithm. The total optimal flow of NR is found by superimposing the optimal flow of all P-SNR’s. Clustering is made heuristically based on the composition of source-sink of such optimal flow. Finally, from such clustering we define Group Subnetwork Representation (G-SNR) which takes form of Single Source Multi destination network. In such case, nodes \( P_{im} \) and links between \( P_{im} - P_i \) are manipulated into node \( P_i \) without violating the function of such nodes and links. Hence, node \( P_i \) now becomes source of G-SNR.

Furthermore, at the second level we are dealing with MCMF problem of location model of G-SNR’s. Location decision follows the ADD algorithm (Daskin, 1995) and solution of the MCMF problem of location problem follows Gallo’s algorithm regarding Destination Spanning Tree approach.

5. ILLUSTRATIVE EXAMPLE

In an attempt to figure out the step-wise proposed in chapter 4, the ensuing contrived example is discussed. The distribution network of the example consists of two plants, one consolidation center and four retailers. It deals with two kinds of products. Unit cost posted in production and transportation link actually is a linear approximation of the real concave unit cost. Figure 4 denotes Network Representation of such distribution network. Such NR is composed into two Product Sub Network Representation (P-SNR), those are P-SNR 1 and P-SNR 2 (figure 5a and 5b). Through the Primal-dual algorithm, it is found the optimal flows of each P-SNR as shown in figure 6a and 6b. Figure 6c denotes the superimposed optimal flows of both P-SNR’s. This figure becomes the input of step 4b, in which the destination nodes (those are retailers) are grouped into either plant 1 or plant 2.
Figure 3. Step-wise of bilevel programming

**FIRST LEVEL**

1. **Step 1:** Determine Network Representation (NR) of the problem. Define Flow Requirements \(q_{im}\) of all nodes and cost function \(\phi_{imj}()\) of all links of NR.

2. **Step 2:** For \(m=1,...,M\), where \(M\) is number of types of products, define P-SNR of product-\(m\). Define Flow Requirements \(q_{im}\) of all nodes and cost functions \(\phi_{ijm}()\) of all links of P-SNR. Linear cost functions are assumed for P-SNR’s.

3. **Step 3:** Solving MCF problem of P-SNR’s by Primal-Dual Algorithm.

4. **Step 4:** Clustering of NR
   - 4.a. Superimpose all the optimal paths of MCF solutions of step 3.
   - 4.b. Clustering destination nodes of decomposed NW of step 4.a based on the source of each optimal path.

5. **Step 5:** For \(p = 1,...,P\), define Group – Subnetwork of NR (G-SNR) based on the clustering of step 4.b (\(P\): Number of plants). Retrieve Flow Requirements and link cost function as defined in step-1; Initial value of objective function = \(\infty\).

6. **Step 6:** Locate certain potential warehouse which may minimize the objective function.

7. **Step 7:** Solve the MCMF problem of G-SNR by Destination Spanning Tree.

8. **Step 8:** Fix the warehouse in the solution.

9. **Step 9:** Location decision of G-SNR.

10. **Step 10:** Superimpose all the optimal paths of all G-SNR and make final location decision.

**SECOND LEVEL**

End no

Objective Value reducing site found?

yes yes

End

End no

Objective Value reducing site found?

no

yes

p := p

p := P

End

Figure 3. Step-wise of bilevel programming
This step is followed by step 5, in which the NR is composed into two Group Sub Network Representation (G-SNR), those are G-SNR 1 and G-SNR 2. G-SNR 1 is originated at Plant 1 and G-SNR 2 is originated at plant 2. Both G-SNR’s are shown in figure 7a and 7b. Step 6 – 9 are parts of ADD algorithm to decide which combination of warehouses that gives the best value of objective function. The value of objective function is determined through Gallo’s algorithm of Destination Spanning Tree approach. In step 10, we conclude the location decision of all G-SNR. From the optimal paths of figure 8a and 8b it can be seen that the final location decision is to open Consolidation Center 1, eventhough G-SNR 2 does not need such warehouse. Figure 8c shows the superimposed optimal paths of G-SNR1 and G-SNR2 if the CC1 is opened.

![Network Representation of the distribution network under consideration](image1)

![Product Sub Network Representation 1 (P-SNR 1)](image2)

![Product Sub Network Representation 2 (P-SNR 2)](image3)
Figure 6a. The optimal paths of P-SNR 1

Figure 6b. The optimal paths of P-SNR 2

Figure 6c. The superimposed optimal flows of P-SNR 1 and P-SNR 2
Notes:

\[ C_1 = \frac{5}{0.7x + 2} \]
\[ C_2 = \frac{30}{0.1x + 3} \]
\[ C_3 = \frac{7}{0.1x + 1} \]

\( x \): link flow

Figure 7a. Group Sub Network Representation 1 (G-SNR 1)

Figure 7b. Group Sub Network Representation 2 (G-SNR 2)

Notes:

\( R_{i1} \): Demand at retailer \( i \) on product \( m \)

\( P_{it} \): Capacity at plant \( i \) on product \( m \)

Figure 8a. The optimal paths of G-SNR 1

Figure 8b. The optimal paths of G-SNR 2
6. CONCLUSION

We propose such location model which consider the characteristics of PSO-SOC. It takes form of Minimum Concave-cost Multicommodity Flow problem by making use of Network Representation to formulate and solve the problem. Bi-level programming is proposed to heuristically solve the problem. It is realized that the proposed bi-level programming is merely an attempt to come close to the global optimum solution. This research work is essentially intended to make contribution to research field of freight distribution as well as to the distribution system of PSO-SOC.

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