A Strategic Facility Location Model for an Integrated Logistics System in a Finite Planning Horizon with Probabilistic Customer/Supplier Participation

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ABSTRACT

This paper has developed a mathematical model that minimizes the total operating and capital cost of an integrated logistics system (reverse and forward logistic system) with facility sharing. The constraints included in the model are the supply and demand limitations, opening, expansion and closing constraints, and capacity constraints. The model has been translated using General Algebraic Modeling Systems (GAMS) modeling language and solved using CPLEX. Hypothetical data are used using two solution methodologies. These are the sequential method and integrated method. The integrated method results to a better solution than the sequential method for non-balance demand and supply parameters.

KEYWORDS: *Facility location model, Forward Distribution, Integrated Logistics, and Reverse Distribution*

I. INTRODUCTION

Strategic location of distribution centers helps in minimizing the cost of investment and operation costs of any facility location or distribution systems. Typical facility location models consider the location of warehouses and plants, warehouse and plant capacity load ratio, assignment of customer demands to warehouses, and assignment of open warehouses to open plants (Jayaraman, 1998). Facility location models have been applied not only to the distribution of goods (Zhang, 2001; Ho, 1995 and Sazaki et. al., 2001), but also in the collection of used materials (Jayaraman et.al., 2001; Ammons, et. al., 2004; Baetz, 1994).

I.1 Types of Distribution

Distribution systems can be classified as Forward or Reverse Distribution. Forward Distribution is defined as the distribution of products usually from the manufacturer to the customers, while Reverse Distribution or Reverse Logistics refers to the collection of materials, usually from the customers back to the suppliers.

There are two ways in which the used materials or products could be collected: Curbside and Bring (Jahre, 1995). "Curbside" is similar to door-to-door collection where recyclable materials are collected from each household. "Bring" is to have the consumers bring the recyclable materials to a transfer station. The manner of collection affects the total cost of the system. Curbside tends to encourage recycling and recovery of material by the consumer and transportation costs are typically shouldered by the company. Bring scheme would be less costly for the company, but would lessen the customer's desire to recycle or recover the material.

I.2 Application of Forward and Reverse Distributions

Forward distribution and reverse distribution are often applied separately in past studies. With the stronger need for Reverse Logistics in recent years, a synchronized logistical activity among supply chain members creates more value for the end customers by reducing costs associated with resource redundancy and duplication. By integrating the logistic resources of the Forward and Reverse distribution systems, the entire system can serve its customers better (Stank et al., 2001).

These resource redundancies and duplications may be in the form of pick-up and delivery operations, inventory stocking, and the operating cost and fixed costs of the facilities. Separate forward and reverse distribution systems results to a larger total investment. An integrated logistics not only achieves substantial cost minimization, but also helps in minimizing waste through product recovery, reprocessing and redistribution.

I.3 Integrated Logistics

Integrated logistics is where the activities of the forward and reverse logistics are considered simultaneously. In the study of Fleischmann (2001), there are two types of integrated logistics used: Closed Loop Logistics and Open Loop Logistics. Closed loop logistics is where the suppliers of the used materials are also the customers of the reprocessed products. As for the open loop logistics, the suppliers and the customers are different.

By linking the two types of distribution systems, effective control in the synchronization of flows between the two can be achieved. The need for reprocessed products would lead to a forward distribution to "pull" the supplies out of the reverse distribution. Conversely, the reverse distribution would also "push" these suppliers to the forward distribution side of the system.

One of the major links between the reverse and forward distribution are the products used for recovery and distribution. Some products consider the recycled materials as part of its raw material input. Integration of the forward and reverse logistics would help achieve the best solution that would balance the penalty costs from both sides. Thus, results in considerable savings in the operating of the company.

II. THE INTEGRATED LOGISTICS SYSTEM

II.1 Customer-Supplier Zones and Material flow of the system

Customers and suppliers are grouped in pre-defined zones where customers and suppliers can co-exist. The material flow starts with the collection (reverse distribution) of the used products from suppliers. After which these used materials or products would be reprocessed, and redistributed to the customer (forward distribution). There would be times occurring of oversupply of used products, and there would also be times that over demand happen for a certain reprocessed product. This means that penalty costs may occur due to inability to provide service to the suppliers (no collection of excess supply), or to the customers (not providing the demand). This situation is dealt with by allowing the system to collect, and to store used and reprocessed materials for future demand requirements.

II.2 Collection Points

The Integrated logistic system considers 3 types of collection points. These are Transfer Points (short term storage facilities), Warehouses (long term storage facilities), and Reprocessing Plants. The set of available collection locations are known.

Transfer Points – A transfer point acts as collector/distributor located within a zone. These transfer points comes in two forms: dedicated transfer stations and combined transfer stations. The dedicated transfer stations are established for one type of flow only. These types of transfer stations are solely used for reverse distribution only (reverse transfer point) or for forward distribution only (forward transfer point). Reverse transfer points collect the used materials from the suppliers of the zone where it is situated. Combined transfer stations can perform the two tasks: collection and distribution. Transfer Points are not allowed to keep materials or products.

Warehouses - Warehouses act as an intermediary between the reprocessing plants and the transfer stations. Warehouses can also be in the dedicated or combined form.

Reprocessing Plants - Reprocessing plant is the destination of the reverse distribution process and the source of the forward distribution process. The collected goods would be brought to the reprocessing plants for refurbishment. After refurbishing, the reprocessed products would be delivered back to the customers. All collected materials pass through a reprocessing plant before it can be delivered to the customers.

II.3 System Constraints

- Demand constraints - This states that the demand of the customers should be satisfied by the system.
- Supply constraints - These constraints state that the total supply that is collected should be less then or equal to the supply available in the system
- Capacity constraints - This set of constraints states that the amount of products that is in the facilities at a certain point in time should be less than or equal to its capacity.

II.4 System Costs

- Capital costs - These are costs incurred on the first year that the facility has been established.
- Operating costs – Operating costs are classified as variable and fixed operating costs. The variable operating costs depend on the amount of products that is

flowed through a certain facility. The fixed operating costs are incurred when the facility is operational.

- Transportation costs – This cost depends on the distance that a material or product is being transported. The total transportation cost incurred by the system would be the total products transported between facilities and the unit transportation cost per product. There are two types of transportation costs considered: collection of the used materials from the suppliers and the delivery of the reprocessed products to the customer.

- Closing costs - Closing costs will be incurred when the company decides to close a facility. Closing costs would be incurred on an end-of-year basis. Facilities would be open on the start of the year and closes at the end of the year that it decides to close.

- Expansion Costs - Expansion costs are incurred if the previous facility can no longer manage the existing demand. This would be dependent on the increase in the range of size of the facility.

- Holding costs – This represents the cost of keeping inventories of used and processed materials or products.

- Reprocessing costs –This is the cost incurred when used materials are being processed in the reprocessing plants and converted to reprocessed products.

- Penalty costs – This represents the costs of not collecting the used products from the customers and the penalty costs of not satisfying the demand of the customers.

- Cost of Products Collection and Distribution

  For Reverse Distribution, suppliers may bring the used materials to the facilities or have the facilities collect the used materials from the suppliers.

  For Forward Distribution, customers may opt to have the reprocessed materials deliver directly from the facilities to them or buy the reprocessed products from the facilities.

II.5 Probabilistic Customer/Supplier Participation

The distribution model considers the probabilistic interaction of customer/supplier to the number of facilities its locations. This probability interaction represents the probability of suppliers or customers to engage in “bring” and “buy” activities when there are more facilities located near to the supplier and customer, respectively.

II.6 Customer service costs

Ho and Perl (1995) suggested the importance of customer service level in their study. Because of this, “customer service costs” would be included in the study. These are the costs that would be incurred by the company when the supplier brings the used products to the facilities assigned, or when the customer approaches the facilities to buy reprocessed products. This can be the payment that the company would give to the customers that brought the goods to designated depots.

II.7 Capacitated Facilities

Facilities have the ability to select the appropriate size based from a set of available facility size category. Each facility size category would have a corresponding capital and operating costs.

II.8 Pre-segregation of Used Materials

In this system, it would be assumed that the materials to be collected are already segregated at the source. These fractions would be delivered to the reprocessing plants for reprocessing.

II.9 Probability of Collection and Delivery

The system of bringing and collection as part of the suppliers, or the buying and delivery for the customers is shown as Figure 1.

Zones A and B are supplier and customer zones. In each zones there are a number of possible transfer points to create. In Figure 1, three transfer points are made available for each of the zones denoted by the three smaller circles inside the zones. The shaded transfer points represent the selected facilities to operate inside the zone. The arrow pointing towards the transfer points would be the chance that the suppliers (customers) will bring (buy) the used (reprocessed) material to the facility. The probability that the transfer point would have to collect (deliver) the used (reprocess) materials or products from the suppliers (customer) is represented by the dotted arrows pointing away from the facilities.

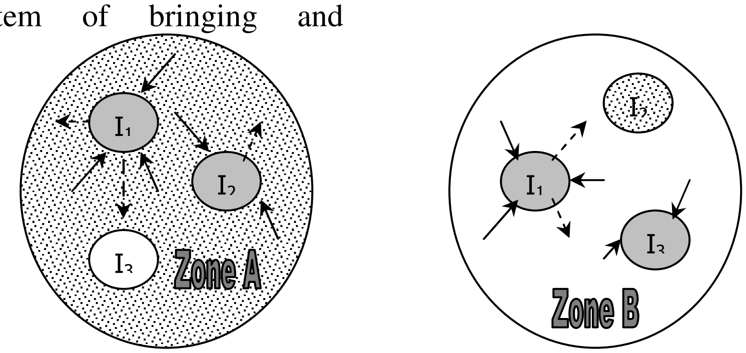

Figure 1: System Definition with Probability (Scenario 1)

In Figure 2 below, no transfer points open in zone A while two transfer points opened in zone B. The transfer points that are operational in zone B should collect not only the used materials from zone B, but also from zone A.

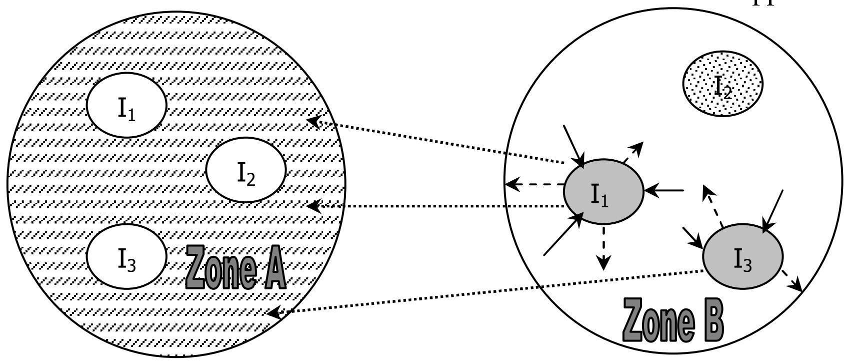

Figure 2: System Definition with Probability (Scenario 2)

The more transfer points available in the zone, the higher the probability that the suppliers (customers) will bring (buy) the used (reprocessed) goods in the same zone. This probability is expressed as,

$$P_Z(x=K,y)=1-x^y \qquad \textbf{eqn. 1},$$

where x is the probability parameter and y is the number of transfer points to be opened.

The more facilities put up within a zone, the less the probability that a collection or delivery have to be performed since suppliers and customers would have more accessibility to the facilities. The probability to collect would then be express as,

$$P(collect) = PROBCOLL^y \qquad \textbf{eqn. 2},$$

where PROBCOLL represents the probability that the facilities would have to collect the used materials from the suppliers and Y the number of operating facilities that are made to collect.

The same probability principles are applied in the delivery and buying of customers from the facilities. If there is no transfer facility in the zone, then all of the used (reprocessed) materials would have to be collected (deliverd) by the facility.

In summary, Figure 3 shows the flow of the materials in the integrated logistics system with corresponding costs associated to each activity.

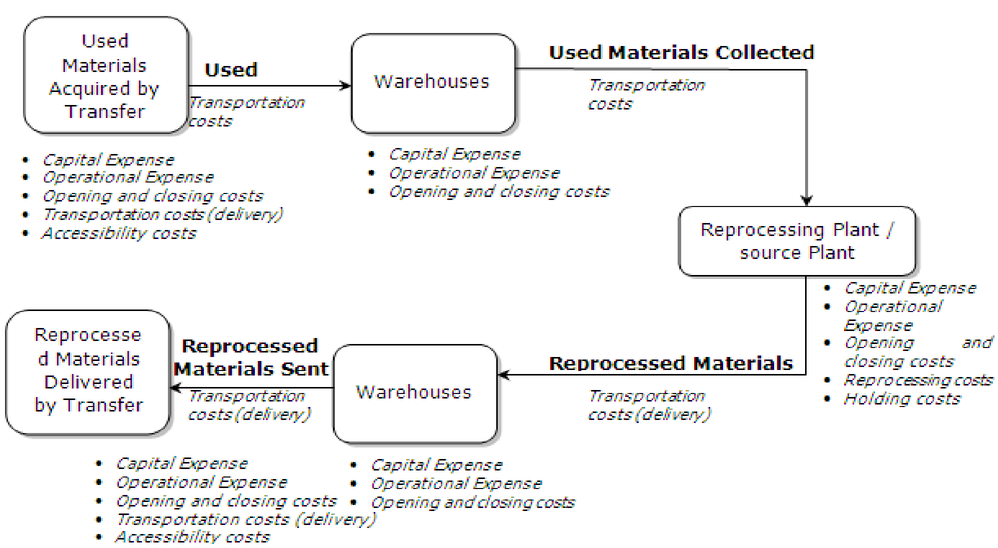

Figure 3: Material Flow of the Integrated Logistics System with Costs

III. THE MATHEMATICAL MODEL

This mathematical model aims to minimize total expected costs of the Integrated Logistics System over a given planning horizon. The objective function consists of the net present value of capital, operational and transportation costs over the planning horizon.

III.1 Objective Function

The NPV factor per period will be multiplied to the different components of the objective function given as follows:

MIN Costs

$$\sum_{t} NPV_t \; (\text{facility}_t + \text{Intra-zone}_t + \text{reverse}_t + \text{penalty}_t + \text{others}_t)$$

Facility location

$$+ \sum_{r} RCAPEX_{rt} * RFOPN_{rt}$$
Reprocessing plants: capital costs

$$+ \sum_{r} ROPEX_{rt} * ROPN_{rt}$$
Reprocessing plants: annual operating costs

$$+ \sum_{r} RCLOS_{rt} * RCLOSE_{rt}$$
Reprocessing plants: Closing costs

$$+ \sum_{w}\sum_{n} WCAPEX_{wnt} * WFSIZE_{swnt}$$
Warehouses : Capital costs

$$+ \sum_{w}\sum_{n} WOPEX_{wnt} * WCAP_{wbt}$$
Warehouses: variable operating costs

$$+ \sum_{s}\sum_{w}\sum_{n} WMAINT_{swnt} * WOPN_{wnt}$$
Warehouses: fixed operating costs

$$+ \sum_{w}\sum_{n} WCLOS_{wnt} * WCLOSE_{wnt}$$
Warehouses: Closing costs

$$+ \sum_{s}\sum_{w}\sum_{n} WEXP_{wt} * WUP_{swnt}$$
Warehouses: expansion costs

$$+ \sum_{g}\sum_{i}\sum_{m} GCAPEX_{gimt} * GFCAP_{gimt}$$
Transfer points : Capital costs

$$+ \sum_{g}\sum_{i}\sum_{m} GOPEX_{gimt} * GCAP_{gimt}$$
Transfer points: variable operating costs

$$+ \sum_{s}\sum_{g}\sum_{i}\sum_{m} GMAINT_{sgimt} * GOPN_{gimt}$$
Transfer points: fixed operating costs

$$+ \sum_{g}\sum_{i}\sum_{m} GCLOS_{gimt} * GCLOSE_{gimt}$$
Transfer points: Closing costs

$$+ \sum_{s}\sum_{g}\sum_{i}\sum_{m} GEXP_{gimt} * GUP_{sgimt}$$
Transfer points: expansions costs

Intra- zone

$$+ \sum_{g}\sum_{i}\sum_{m}\sum_{f} CBRING_{gift} * ABRING_{gimft} + CCOLL_{gift} * ACOLL_{gimft}$$
Transfer point in zone: reverse distribution costs

$$+ \sum_{g}\sum_{i}\sum_{m}\sum_{p} CDELIV_{gipt} * ADELIV_{gimpt} + CBUY_{gipt} * ABUY_{gimpt}$$
Transfer point in zone: forward distribution costs

Reverse distribution	$+ \sum_g \sum_i \sum_m \sum_f TGGPREVERSE_{ggpft} * AGCOL_{gg'imft}$	Transportation cost (reverse): zone g' to zone g
	$+ \sum_g \sum_w \sum_i \sum_f TGWREVERSE_{wgift} * AGW_{wgift}$	Transportation cost (reverse): Zone g to warehouse w
	$+ \sum_g \sum_r \sum_i \sum_f TGRREVERSE_{rgift} * AGR_{rgift}$	Transportation cost (reverse): Zone g to reprocessing plant r
	$+ \sum_g \sum_w \sum_f TWRREVERSE_{wrft} * AWR_{wrft}$	Transportation cost (reverse): Warehouse w to reprocessing plant r
Penalty	$+ \sum_g \sum_f \sum_p \left(PENREV_f * NOCOLL_{gft} + PENFOR_p * NODELIV_{gpt}\right)$	Penalty costs
Other costs	$+ \sum_g \sum_i \sum_f \sum_k REPCOST_f * \left(AVSUPPLY_{giftk} + AGCOL_{gg'ift}\right)$	Reprocessing costs / unit
	$+ \sum_p HOLDCOST_{pt} * \left(stock_{pt} / 2 \right)$	Holding costs

III.2 System Constraints

The constraints are supply constraints, demand constraints, conservation of flow, opening and closing constraints, and the probabilities of the bringing and buying of the products. All of the equations are linear, but for the delivery and collect constraints which makes use of eqn. 1 and eqn.2. The non-linear constraints of the of deliver and collect are as follows:

$$AVSUPPLY_{gft} * PROBCOL^{\sum_i GOPN_{gimt}} = \sum_i ACOLL_{gimft} \qquad \forall g, m, t \qquad \text{eqn. 3}$$

$$AVSUPPLY_{gft} * \left(1 - PROBCOLL^{\sum_i GOPN_{gimt}}\right) = \sum_i ABRING_{gimft} \qquad \forall g, m, t \qquad \text{eqn. 4}$$

$$AVDEMAND_{gpt} * PROBDEL^{\sum_i GOPN_{gimt}} = \sum_i ADELIV_{gimpt} \qquad \forall g, m, t \qquad \text{eqn. 5}$$

$$AVDEMAND_{gpt} * \left(1 - PROBDEL^{\sum_i GOPN_{gimt}}\right) = \sum_i ABUY_{gimpt} \qquad \forall g, m, t \qquad \text{eqn.6}$$

The exponent is a sum of binary variables, these constraints resulted into a non-linear form. The probability of collection or delivery is a parameter that is triggered by the number of transfer points that opens.

III.3 Linearizing the Non Linear Constraints

To make the delivery and collection constraints linear, a new index, a variable and few constraints were added to the model. The index k is the sum of total facilities that opened inside a zone. This is applied to the equation shown below:

$$\sum_k \left(k * GROPEN_{gmtk}\right) = \sum_i GOPN_{gimt}$$

$$\forall g, mrev.mcom, t \qquad \text{eqn. 7}$$

The constraint converts the sum of the open variables in the zone to the number of zones open k. The variable k runs from 1 to the total number of collection points available. GROPEN is the binary variable that would be equal to one so that k would be equal to the sum of GOPN. Therefore, when the sum of GOPN is equal to three, then GROPEN should be equal to one when k is three. The type of transfer point that is considered here are the transfer points for the reverse distribution of the fractions.

As for the forward distribution, the equation would be:

$$\sum_k \left(k * GFOPEN_{gmtk}\right) = \sum_i GOPN_{gimt}$$

$$\forall g, mfor, mcom, t \qquad \text{eqn. 8}$$

In this case, GFOPREN is the binary variable that would balance k and the sum of the open forward distribution transfer points. It is possible that binary variable GROPEN or GFOPEN would be equal to one more than once. For example, if the sum of the open transfer points is equal to three, then GFOPEN would activate when k is equal to three or when k is equal to one and two. The illustrative example is shown below:

$$1*GFOPEN_{gmtk}+2*GFOPEN_{gmtk}+3*GFOPEN_{gmtk}=3$$

$$1*(1)+2*(1)+3*(0)=3$$
$$1*(0)+2*(0)+3*(1)=3$$

Since GROPEN and GFOPEN counts the number of open transfer points, then *k* should only appear once. Therefore, it is constrained that the sum of *k* should be less than or equal to one. This is applicable to all zones of all transfer station types through time.

$$\sum_k GROPEN_{gmtk} \leq 1$$
$$\forall g, mrev, mcom, t$$
$$\sum_k GFOPEN_{gmtk} \leq 1$$
$$\forall g, mfor, mcom, t$$

It would be difficult to linearize the model wherein a direct relationship between the probability parameter and the open facilities is equated. If this happens, then the probability parameter would also become a variable. Multiplying this to the available supply/demand (*AVSUPPLY/AVDEMAND)* may lead to another non-linear constraint.

Therefore, to maintain the parameter as it is, the result from the *GROPEN/GFOPEN* would have to manipulate the variable *AVSUPPLY* and *AVDEMAND*. The *AVSUPPLY* and *AVDEMAND* variables both have the subscript *k* as part of their indices.

Constraints were formulated such that *AVSUPPLY* and *AVDEMAND* would only assume value if the variable *k* in its subscript is equal to the index *k* of *GROPEN* and *GFOPEN*. Therefore, the constraints below show that all fractions or products would be equal to zero unless *GROPEN* or *GFOPEN* is equal to one. The left hand side is the amount of supply while the right hand is the binary variable multiplied by a very large number *M*. Therefore, if *GROPEN* is not available, then *AVSUPPLY* from the zone will be equal to zero. On the other hand, when *GROPEN* is available, then *AVSUPPLY* would be able to obtain any value less than *M*.

$$\sum_f AVSUPPLY_{gftk} \le M * \sum_i GROPEN_{gmtk} \qquad \forall g,t,k \qquad \text{eqn. 9}$$

$$\sum_p AVDEMAND_{gptk} \le M * \sum_i GFOPEN_{gmtk} \qquad \forall g,t,k \qquad \text{eqn. 10}$$

With these additional constraints, the constraints for the probabilities can now be formulated. The probabilities are maintained as parameters by setting probabilities into tables. The table consists of probabilities of collection of fractions when there is *k* number of transfer points operational at time t. This is also the same with the probabilities of delivery of products.

For the reverse distribution, the collection constraint would be:

$$AVSUPPLY_{gftk} * PROBCOL_{fk} \le \sum_i ACOLL_{gimft} + M * \left(1 - GROPEN_{gmtk}\right)$$

$$\forall g,f,t,k \qquad \text{eqn.11}$$

$$AVSUPPLY_{gftk} * PROBCOL_{fk} \ge \sum_i ACOLL_{gimft} - M * \left(1 - GROPEN_{gmtk}\right)$$

$$\forall g,f,t,k \qquad \text{eqn. 12}$$

This shows that *AVSUPPLY* at *k* would be multiplied by the parameter *PROBCOL* at *k*. This would be the amount of used materials that would collected by the facilities. Moreover, a pair of constraint was used to avoid integer infeasibility.

$$AVSUPPLY_{gftk} * (1 - PROBCOL_{fk}) \le \sum_i ABRING_{gimft} + M * \left(1 - GROPEN_{gmtk}\right)$$

$$\forall g,f,t,k \qquad \text{eqn. 13}$$

$$AVSUPPLY_{gftk} * (1 - PROBCOL_{fk}) \ge \sum_i ABRING_{gimft} - M * \left(1 - GROPEN_{gmtk}\right)$$

$$\forall g,f,t,k \qquad \text{eqn. 14}$$

The above constraint is the amount of used materials that the customers would bring to the facilities. This is just the complement of the previous constraint. This means that *ABRING* and *ACOLL* is equal to *AVSUPPLY*.

$$AVDEMAND_{gptk} * PROBDEL_{pk} \leq \sum_i ADELIV_{gimpt} + M * \left(1 - GFOPEN_{gmtk}\right)$$

$$\forall g, p, t, k \qquad \text{eqn. 15}$$

$$AVDEMAND_{gptk} * PROBDEL_{pk} \geq \sum_i ADELIV_{gimpt} - M * \left(1 - GFOPEN_{gmtk}\right)$$

$$\forall g, p, t, k \qquad \text{eqn. 16}$$

The above constraint is the amount of reprocessed products that would be delivered by the company. This is derived when the demand of that were delivered to zone is multiplied by the probability of delivery of the facilities to the customer zones.

$$AVDEMAND_{gptk} * (1 - PROBDEL_{pk}) \leq \sum_i ABUY_{gimpt} + M * \left(1 - GFOPEN_{gmtk}\right)$$

$$\forall g, p, t, k \qquad \text{eqn. 17}$$

$$AVDEMAND_{gptk} * (1 - PROBDEL_{pk}) \geq \sum_i ABUY_{gimpt} - M * \left(1 - GFOPEN_{gmtk}\right)$$

$$\forall g, p, t, k \qquad \text{eqn. 18}$$

This constraint is the complement of the previous constraint. The products bought by the customers would be the difference between the available demand and the total products delivered to the customers. Moreover, fractions cannot flow through a dedicated forward distribution transfer point. Conversely, products cannot flow through a reverse distribution only transfer point. Therefore, another set of constraints was formulated.

$$\sum_f \sum_i ACOLL_{gimft} = 0 \qquad \forall g, f, t, k, mfor$$

$$\sum_f \sum_i ABRING_{gimft} = 0 \qquad \forall g, f, t, k, mfor$$

$$\sum_p \sum_i ADELIV_{gimpt} = 0 \qquad \forall g, p, t, k, mrev$$

$$\sum_p \sum_i ABUY_{gimpt} = 0 \qquad \forall g, p, t, k, mrev$$

The above constraints show that *ACOLL* and *ABRING*, both part of the reverse distribution process, should not use the forward distribution only transfer point. Moreover, *ADELIV* and *ABUY*, both are part of the forward distribution and will not be allowed to use the dedicated reverse distribution transfer point. With these constraints, the mathematical model is transformed to a linear model.

III.4 Comparison of Sequential And Integrated Method

Two methods of solving an Integrated Logistics System were done by Fleischmann's (2001). The two methodologies used to solve for the optimal solution are called sequential method and integrated methods.

Fleischmann compared the two approaches to find out if there would be any significant impact to an existing logistics system. For his sequential method, the forward distribution model was solved and the result was then inputted to the reverse distribution model. The results was to a forward and reverse distribution model was used simultaneously. His study did not show any significant difference in the optimum solutions of the two methodologies.

For the first half of the whole system, reverse distribution is considered. The demand is directly equated to the supply just so to place an endpoint for the system. The cost for the combined facilities should be separated for reverse and forward distribution depending on its weight. For example, if the percentage of the supply over the total materials to flow (supply and demand) is 87% then 87% of the combined facility operating costs would be allocated to the reverse distribution.

For the second half, the result for the reverse distribution would be inputted into the forward distribution. The operational facilities would be forced open into the forward distribution. The operating cost used in this stage is back to the original setup. The costs for the integrated method would remain as is.

The system used here would comprise on two grids with three transfer points each, five warehouses and two reprocessing plants.

After a series of runs, it was found that there are instances that there is no difference between the sequential and integrated method as demonstrated by Fleischmann's (2001). The sequential method and integrated method is the same when the whole system is balanced. Balanced system means that the both grids have the same demand and same supply, there is the same weight placed on the facilities.

Changing the reverse distribution costs and the forward distribution costs would not affect the decision of the model. This is also evident in the previous section where changing the reverse and forward distribution costs during the sensitivity. Table 3.1 compares the result for the sequential and integrated method.

Table 3.1: Comparison of Sequential and Integrated method in a balanced system

Method used	**Open facilities**	**Total costs**
Sequential method	Grid 2, transfer point 2 Reprocessing plant 2	1936475.41
Integrated method	Grid 2, transfer point 2 Reprocessing plant 2	1936475.41

On the other hand, the sequential and integrated methods differ where the system is imbalanced. This means that the supply of one grid is significantly greater than the other grid, or one demand of the grid is significantly greater than the other grid. It may be due to the different "pull of weights" of the two grids.

Table 3.2 shows the result when the demand of one grid is greater than the other grids for two consecutive years. The sequential method shows that both grids had each established one transfer point. The cost turns out to be almost 200,000 monetary units. As for the integrated method, only one grid was open. The percentage difference of the costs between the two methods is about 47%.

Table 3.2: Comparison of Sequential and Integrated method when demand of one grid is greater

Method used	**Open facilities**	**Total costs**
Sequential method	Grid 1; transfer point 3 Grid 2; transfer point 1 Reprocessing plant 1	198551.68
Integrated method	Grid 1; transfer point 3 Reprocessing plant 1	122458.67
		Percent difference: **47.4084%**

Table 3.3 shows the result of the model when the demand of one grid is greater than the other grid is one year and less on than the other grid on the second year. It shows that the sequential method decided to operate two transfer points, one on each grid. The integrated method however, decides to operate only one grid. The cost difference between the two is around 41%.

Table 3.3: Comparison of Sequential and Integrated method when demand of one grid is greater on one year

Method used	**Open facilities**	**Total costs**
Sequential method	Grid 1; transfer point 3 Grid 2; transfer point 1 Reprocessing plant 1	187607.35
Integrated method	Grid 1; transfer point 3 Reprocessing plant 1	123957.02
		Percent difference: **40.8585%**

When the supply of one grid is less than the supply for the other grid, it shows that there is also a difference in the decision of which facility to open. This may be because while running the reverse distribution part of the model, the weight was towards the grid that has the higher supply (which is grid 1). This is because for the reverse distribution, placing the facilities nearer to the supply would lessen the overall costs due to smaller transportation costs. This operational transfer point is forced to the forward distribution to use. This would result to higher transportation costs since grid 1 is not the best allocation for the forward distribution. However, for the integrated method, the heuristic was able to consider the best location for both the reverse and forward distribution. Therefore, it had considered the smaller total costs. Table 3.4 shows the comparison between the two methods.

Table 3.4: Comparison of Sequential and Integrated method when supply of one grid is greater

Method used	Open facilities	Total costs
Sequential method	Grid 1; transfer point 2 Reprocessing plant 1	187390.57
Integrated method	Grid 2; transfer point 1 Reprocessing plant 2	139262.85
		Percent difference: **29.47%**

It can be concluded that the integrated heuristic is better than the sequential heuristic because it considers the forward and reverse distribution system simultaneously. Thus, would be able to assign the best location for both the reverse and forward logistics.

IV. CONCLUSIONS

The following conclusions can be derived based on the relationship of location decisions and the following pairs of cost parameters.

1. Transportation costs between grids and operating expense transfer points

   It was found that the system would always opt to establish a larger transfer point for the whole system where all the grids would depend on. This is true unless transportation costs in greater than operating expense, capital expense and all the transportation costs that could have been incurred when each grid established when each grid established its own transfer point.

2. Transportation costs of reverse and forward distribution

   Even if transportation costs increases, the decision of the facility location remains the same. This is because of the grids having the same number of supply and demand, thus it has equal influence to the facilities. Since both grids have the same supply and demand, simultaneously changing the costs would not affect the placement of the facility.

3. Operating expense of combined distribution system and the dedicated distribution system

   It can be concluded that the combined transfer station is still preferred by the system since it is comparably cheaper than operating two different dedicated distribution systems.

V. RECOMMENDATIONS FOR FURTHER STUDIES

1. Routes to collect and deliver

   The detailed routes for collect and delivery can be considered, that is which customers/suppliers be serviced first so that all of them would be accommodated. The shortest, most economical route would be expected as a result.

2. Function of reprocessing costs

   Using material science, the introduction of new materials and the acquisition of these new materials can be considered for future study.

3. Consider the costs of acquiring new materials

The option of acquiring new materials when there is shortage of supply can be considered. The acquisition cost of the new materials and the cost of the new materials itself is included.

4. Depreciation and Salvage value be considered

Consideration of depreciation and salvage value can be used for further study. Facilities would have its expected life and corresponding salvage value.

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