

Sensitivity Analysis of Partial Joint Ordering Policy in Multi-Location Distribution Systems

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Abstract

This research performs a sensitivity analysis on inventory replenishment for multiple demand locations using a partial joint ordering policy. Specifically, the study examines inventory replenishment for dispersed systems comprising five and ten locations. A performance index compares the partial joint ordering policy against a full joint ordering policy by calculating the ratio of their total inventory costs. The problem is formulated as a binary linear programming optimization model and solved using the Excel Solver to minimize total inventory cost. Sensitivity analysis is conducted to evaluate the impact of variable setup costs and demand levels on the total inventory cost of partial joint ordering. Variable setup costs are analyzed across a range from 2,000 to 40,000. The study considers dispersed location systems with both equal and unequal variable setup costs. Furthermore, demand is classified into two cases: equal value of 10,000 and unequal values between 8,000 to 22,000. The results show that for the distribution system having different demands, when variable setup cost increases, the performance index decreases. For five locations problem and ten locations with the unequal demands and high variable setup cost, the partial joint ordering gives the total inventory cost in average lower than the full joint ordering by 1.69% and 2.75%, respectively. The distribution system with high different dispersed demands, the partial joint ordering has an advantage in term of total inventory cost. On the other hand, the partial joint ordering is not advantageous when the dispersed demands are equal or not much difference.

Keywords: Inventory cost, Multiple locations, Partial joint ordering, Performance index, Variable setup cost

INTRODUCTION

The inventory decisions of multiple items or multiple locations in the distribution system involve solving for replenishment quantities and replenishment periods from the same supplier to reduce the ordering cost. Joint ordering policy is known as the replenishment method for multiple items or multiple locations' demands by applying the same replenishment period for delivery. The distribution system with multiple demands' locations involves replenishing decisions of when and how much to order items or how many locations' demands including to the same delivery schedule that minimizes the total costs of the inventory holding cost and the procurement cost. The joint ordering is developed based on the economic order quantity principle which considers the total replenish cost to serve all demands of multiple items or locations. The Economic Order Quantity or EOQ firstly presented by Harris F. in 1913 is the principle of economic replenishment quantity of an item. The EOQ model considers replenishment quantity that minimizes the total cost of the inventory setup cost or procurement cost and the inventory holding cost according to the item's demand. Therefore, each item has its own reorder point and replenishment period. On the other hand, the other replenishment policy by applying the economic order interval is based on replenishment period which has an advantageous in practicality. Each item with different demand will occupy different replenishment period, thus the joint ordering policy can be applied to get the same replenishment period. Several research have studied the variance problems of multiple items in logistics and supply chain. The systematic literature review of the full joint replenishment inventory control are studied by [1]. The research of [2] firstly proposed a "Power-of-Two" policy and demonstrated that by rounding the ordering intervals to powers of two guarantees a cost within 2% of the optimal solution. In the supply chain management, the replenishment problem of the multiple items and multiple locations has been studied widely. The research of [3] extended the power of two policy to solve inventory and routing problem of one warehouse and multiple retailers' distribution system. The replenishment decisions have been studied extensively in the variance problems of the logistics and supply chain management. The research of [4] proposes the power of two policy applied to determine the inventory replenishment policy for the problem of vehicle routing of multiple warehouses and multiple retailers' distribution system. From the full joint replenishment presented by [5], all items or locations are replenished at the same time. When all locations' demands are replaced at the same period which means that the replenishment quantities are adjusted to respond to the demand rate and replenishment period. The full joint replenishment is simplest to manage but it is inefficient if the demand rates vary and the inventory will be a mix of items with shortages and excess inventory. The full joint replenishment considered inventory costs which compose of inventory holding cost, the procurement cost consisting of fixed setup cost, and the variable setup cost varying on the individual item. [6] applied genetic algorithm to solve the can-order policies in the joint replenishment problem. This research aims to determine the can-order level of each item that minimize the number of items in storage, the number of stockout items, and the number of placed orders. The cost structure of joint ordering is studied by [7] introducing the jointly incurred fixed procurement costs based on the interrelationship of items. This research introduces the nonlinear (mixed integer) programming formulation for the problem of determining an optimal power-of-two policy. The joint ordering policy for multi-item inventory control under stochastic demand and step-wise structure of purchasing cost is presented by [8]. This research has introduced a new policy called the (s, Q) policy, which places an order of a fixed quantity Q every time the



inventory position of any given item drops to the reorder point s . Each replenishment order is distributed among multiple items to equalize the inventory levels of all items as much as possible.

The inventory management using spreadsheet based or Excel Solver is extensively studied by researchers. Simulation optimization is more interesting than the heuristics method in solving the real problem, since demand and lead time are not constant and deterministic values. Thus, the traditional model like EOQ which solve constant and deterministic demand and lead time is not practical. The research of [9], [10], [11] apply spreadsheet or Excel to simulate and apply the optimization model in inventory management problems. [9] proposes a practical application by developing the spreadsheet to manage inventory problem in National Pharmacy Chain. The research of [10] applies simulation approach with spreadsheet to solve stochastic inventory model of perishable product. [11] focuses on developing model by applying function and formulars in spreadsheet and performing the factor analysis. The research of [12] focuses on simulating the join ordering policy on Excel and comparing the difference inventory policies by varying the values inventory parameters which are replenishment quantity, replenishment period, and safety stock.

From the literature survey, the research of partial joint ordering simulated on spreadsheet is rarely studied. The partial joint replenishment policy in the multi-item or muti-location distribution system is the inventory management strategy between individual ordering and full joint ordering. Since, the solution from the full joint ordering does not always give the minimum total cost and are not practical for the capacitated vehicle, the partial joint replenishment will be more advantage when the multi-item inventory model has unequal demands. The partial joint replenishment tends to have benefit on lower inventory cost when demands are varied as well. The improvement of the full joint ordering policy by implementing the partial joint ordering is presented by [13]. The research of [13] proposed heuristic clusters multiple items by considering the replenishment intervals those are close values. The annual cost of the partial ordering and individual ordering are compared. The extension study to improve full joint ordering of multiple items inventory problem with partial joint ordering is interesting. In addition, the inventory simulation on spreadsheet This research also focuses on improving the solution by varying the inventory holding cost fractions.

Therefore, this research focuses on setting the simulation model of the partial joint ordering on spreadsheet to solve for the optimal solution, performing sensitivity analysis on the related parameters and comparing the scenarios of equal and unequal demands. The solutions to the partial joint ordering are the set of clusters of demands' locations those minimize the total inventory cost. Each cluster represents the same delivery route. The solutions from applying the partial joint ordering are the clusters of demands which each cluster contains the locations those have the same replenishment period. Thus, the decision variable value (x_{ij}) is either 1 or 0. x_{ij} value is 1, if location i is assigned to cluster j , otherwise the value is 0. The variable setup cost represents the cost of adding each item to the delivery cluster. The examples of the variable setup cost are the cost of delivery, the cost of setting up order when adding more items or locations, administrative costs, or other costs relating to adding more items or locations to the order. This research considers the constant values of inventory holding cost, inventory setup cost, and demand. This research aims to develop the partial joint ordering model using spreadsheet focusing on optimizing delivery schedules and minimizing total costs. Then the sensitivity analysis is performed to evaluate how changes in inventory setup cost and demand impact the total cost, facilitating

improved inventory control. The locations' demands are varied from equal demand for all locations to unequal demands which divided into two groups: the locations with low level demand and the locations with high-level demand. For the setup cost, the variable setup cost is added to the total inventory cost, if the items are included to the same cluster. The variable inventory setup cost represents extra delivery cost, or extra procurement cost when adding that locations to the considering delivery cluster. The research question addresses whether a joint ordering policy yields greater cost advantages than a full joint ordering approach when inventory setup costs vary across locations. Therefore, the research objective is to study the sensitivity analysis of demand and variable inventory setup cost on the partial joint ordering. The total inventory cost from the solution of partial joint ordering is compared to the full joint ordering. Thus, this research aims to develop the model on Excel spreadsheet and perform the sensitivity analysis by varying the demands and variable setup cost of each location to study the performance of partial joint ordering. The total cost of partial joint and full joint is compared.

METHODS

1. Research Methodology

This research aims to study sensitivity of variable setup cost to the partial joint replenishment policy with the capacitated vehicle in the distribution system of multiple locations' demands. The solution by applying the partial joint ordering is the clusters of locations which demands belonging to each cluster has the same replenishment interval. To compare the performance of partial joint to the full joint ordering, the total cost of both models is compared. The demands and setup cost are varied to study the behavior of partial joint ordering.

The related assumptions are as follows:

- 1) The annual demand of each location is deterministic and constant.
- 2) The total inventory cost consists of holding cost and procurement cost or setup cost.
- 3) The holding inventory cost is known and constant.
- 4) The inventory setup cost consists of fixed cost and variable cost which is deterministic and constant.
- 5) There are multiple identical capacitated vehicles

The related notations are as follow:

D_i is the item demand of location i

x_{ij} is the decision variable of which the value is either 1 or 0, if $x_{ij} = 1$ location i is assigned to cluster j , otherwise $x_{ij} = 0$

C_i is the item cost of location i

Q_i is the replenishment quantity of location i

T_i is the replenishment interval of location i

H_i is the inventory holding cost of items of location i

SF_i is the fixed setup cost of the inventory replenishment of location i

SV_i is the variable cost of the inventory replenishment of location i

T_{joint} is the replenish period of the joint ordering policy

T_{ij} is the replenishment period of location i belonging to cluster j for partial joint ordering policy

VC is the vehicle capacity

TC_{joint} is the total inventory costs of all locations with joint ordering

$TC_{partial_joint}$ is the total inventory costs of partial joint ordering cost of cluster 1 to cluster m

The economic order quantity considers the replenishment policy with the minimization of total inventory cost composing of the inventory setup cost and the carrying cost according to the equation (1) and (2). On the other hand, the replenishment period is calculated as equation (3). The replenishment quantity (Q_i) is solved by the differentiation of the total cost function according to equation (4). The replenishment period is solved for the optimal point of equation (5). The joint ordering policy considers all items' replenishing cost and the replenishment interval with minimum total cost with equation (6). The formula for the joint ordering replenishment period is shown in equation (6).

$$TC(Q_i) = \frac{(SF_i)Q_i}{D_i} + \frac{H_i Q_i}{2} \quad (1)$$

$$Q_i = \sqrt{\frac{2SF_i D_i}{H_i}} \quad (2)$$

$$T_i = \sqrt{\frac{2SF_i}{D_i H_i}} \quad (3)$$

$$TC(Q_i)_{joint} = \sum_{i=1}^n \left\{ \frac{(SF_i + SV_i)Q_i}{D_i} + \frac{H_i Q_i}{2} \right\} \quad (4)$$

$$TC(T_i)_{joint} = \sum_{i=1}^n \left\{ \frac{(SF_i + SV_i)}{T_i} + \frac{H_i D_i T_i}{2} \right\} \quad (5)$$

$$T_i = \sqrt{\frac{2 \sum_{i=1}^n (SF_i + SV_i)}{\sum_{i=1}^n H_i D_i}} \quad (6)$$

For partial joint ordering replenishment policy, the solutions are the set of clusters which each cluster contains locations having the same replenishment period. The objective function is to minimize the total cost of all clusters for all demands' location. Each cluster contains locations are grouped to deliver at the same replenishment period. The total cost of the partial joint ordering as shown in equation (7) is the function of T_{ij} . The total inventory cost consists of the inventory holding cost, $\frac{H_i D_i T_{ij}}{2}$, and the ordering setup cost, $\frac{(SF_i + SV_i)}{T_{ij}}$, which composes of the fixed setup cost and the variable setup cost.

$$TC(T_{ij})_{partial_joint} = \sum_{j=1}^m \sum_{i=1}^n \left\{ \frac{(SF_i + SV_i)}{T_{ij}} + \frac{H_i D_i T_{ij}}{2} \right\} \quad (7)$$

The replenishment quantities of all locations are calculated as the following equation.

$$Q_i = D_i \times T_{ij_partial_joint} \quad (8)$$

The vehicle capacity of the partial joint ordering is the additional considered constraint. The replenishment quantities are calculated according to equation (8). The replenishment quantities of all locations in the same cluster must not exceed the vehicle capacity as shown in equation (9).

$$\sum_{i=1}^n Q_i \leq VC \quad (9)$$

2. The Mathematic Model

The problem is formulated as binary linear optimization. The problem model is set and solved by using Excel Solver. The research model is solved under the following objective function and constraint functions.

The objective is to minimize,

$$TC_{partial_joint} = \sum_{j=1}^m \sum_{i=1}^n \left[\left\{ \frac{(SF_i + SV_i)}{T_{ij}} + \frac{H_i D_i T_{ij}}{2} \right\} \times X_{ij} \right] \quad (10)$$

Subject to

$$\sum_{i=1}^n X_{ij} = n \quad (11)$$

$$\sum_{j=1}^m X_{ij} = n \quad (12)$$

$$\sum_{i=1}^a Q_i \leq VC, a \leq n \quad (13)$$

$$X_{ij} = \{0,1\} \quad (14)$$

The objective function, equation (10), considers the inventory holding cost and the ordering setup cost. The first constraint is all n locations must be assigned to the deliver cluster. The second constraint is the total locations in all clusters are equal to m . Equation (13) represents the replenishment quantities of all assigned locations in each cluster must not exceed the vehicle capacity. The last equation (14) is the problem solution is binary value. The solution to the problem is to assign location i to the cluster j . All locations are clustered by considering the total inventory cost according to equation (10).

3. The Setting Up Model Using Excel Solver

The problem is formulated as binary linear optimization. The problem model is set and solved by using Excel Solver. The inventory problem of 5 locations (R1 to R5) and 10 locations (R1 to R10) are set up. The sensitivity analysis of the variable setup cost and demands are studied to observe the behavior of the model. From figure 1, R1 to R5 represent location 1 to location 5, respectively. Cluster 1 to Cluster 5 represent the solution alternatives. The problem solutions are shown in yellow area which the solution (X_{ij}) is either 1 or 0. If $X_{ij} = 1$, the location i is assigned to cluster j , otherwise, $X_{ij} = 0$. Row 9 is the variable setup cost which represent the cost of ordering

individual item. The examples of variable setup cost are costs of delivery, material handling, extra services, or other extra costs beside common fixed setup cost when order for multiple locations. Row 10 is the value of Fixed ordering cost which will cost only once when the order of any number of locations is placed. Row 11 is the inventory holding cost. Row 12 is the demand values of each location. Row 13 and row 14 is the time between order (TBO) in year and day of each location when the location places order independently. Row 15 is the fixed ordering cost same as row 10 and row 18 is the vehicle capacity.

1	B	C	D	E	F	G	H	I	J	K	L
2		R1	R2	R3	R4	R5	sum	T*joint(Partial)	Tday	TotalCost	Q
3	Cluster1	1	0	0	0	0	1	0.469	169	46904.1576	4691
4	Cluster2	0	1	0	0	0	1	0.469	169	46904.1576	4691
5	Cluster3	0	0	1	0	0	1	0.787	283	78740.0787	7875
6	Cluster4	0	0	0	1	0	1	0.787	283	78,740.08	7875
7	Cluster5	0	0	0	0	1	1	0.787	283	78,740.08	7875
8	sum	1	1	1	1	1	5			330,028.55	33007
9	VariableOC(SVi)	10000	10000	30000	30000	30000					
10	FixedOC (SFi)	1000	1000	1000	1000	1000					
11	Holdingcost (Hi)	10	10	10	10	10					
12	Demand (Di)	10000	10000	10000	10000	10000					
13	TBO (year) (Ti)	0.141	0.141	0.141	0.141	0.141					
14	TBO (Day)	51	51	51	51	51					
15	FixedOC	1000									
16	VehicleCap	100,000									

Figure 1: The five locations problem setting on Excel

For 10 locations problem, the cells setup is the same except there are five more rows and 5 more columns for the 5 more locations as details shown in figure 2.

1	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
2		R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	sum	T*joint (Partial)	Tday	TotalCost	Q
3	Cluster1	0	0	0	0	0	0	0	0	0	0	0	0.000	0	0	0
4	Cluster2	0	0	0	0	0	0	0	0	0	0	0	0.000	0	0	0
5	Cluster3	0	0	0	0	0	0	0	0	0	0	0	0.000	0	0	0
6	Cluster4	1	0	0	0	1	1	0	0	0	1	4	0.897	323	358887.1689	35889
7	Cluster5	0	0	0	0	0	0	0	0	0	0	0	0.000	0	0	0
8	Cluster6	0	0	0	0	0	0	0	0	0	0	0	0.000	0	0	0
9	Cluster7	0	0	0	0	0	0	0	0	0	0	0	0.000	0	0	0
10	Cluster8	0	1	0	1	0	0	1	0	1	0	4	0.897	323	358887.1689	35889
11	Cluster9	0	0	0	0	0	0	0	1	0	0	1	0.906	326	90553.85138	9056
12	Cluster10	0	0	1	0	0	0	0	0	0	0	1	0.906	326	90553.85138	9056
13	SUM	1	1	1	1	1	1	1	1	1	1	10			898,882.04	89890
14	VariableOC(SVi)	40000	40000	40000	40000	40000	40000	40000	40000	40000	40000					
15	FixedOC (SFi)	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000					
16	Holdingcost (Hi)	10	10	10	10	10	10	10	10	10	10					
17	Demand (Di)	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000					
18	TBO (year) (Ti)	0.141	0.141	0.141	0.141	0.141	0.141	0.141	0.141	0.141	0.141					
19	TBO Day	51	51	51	51	51	51	51	51	51	51					
20	FixedOC	1000														
21	VehicleCap	100,000														

Figure 2: The ten locations problem setting on Excel

The Solver analysis is set as shown in figure 3 and figure 4 for five locations' problem and ten locations' problem. The Evolutionary method is applied. The objective function is to minimize total inventory cost which is cell K8 and cell P8 for five locations and ten locations, respectively.

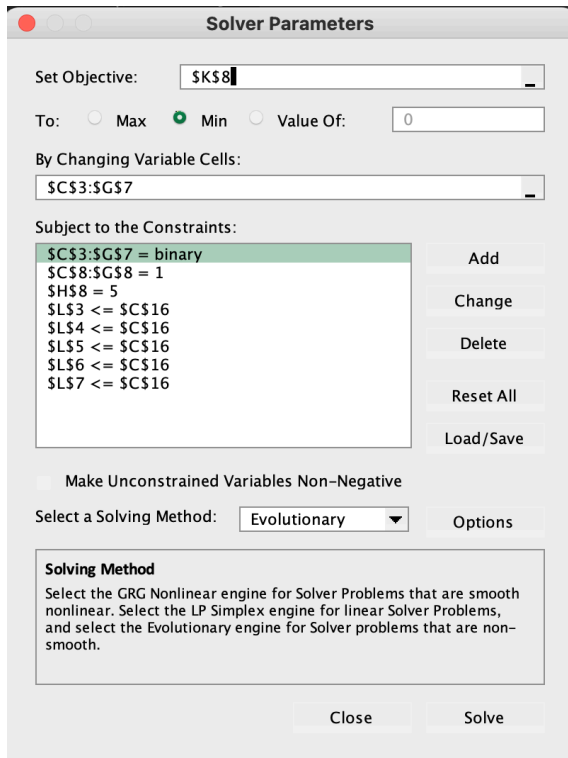


Figure 3: Setting five locations problem on Excel Solver

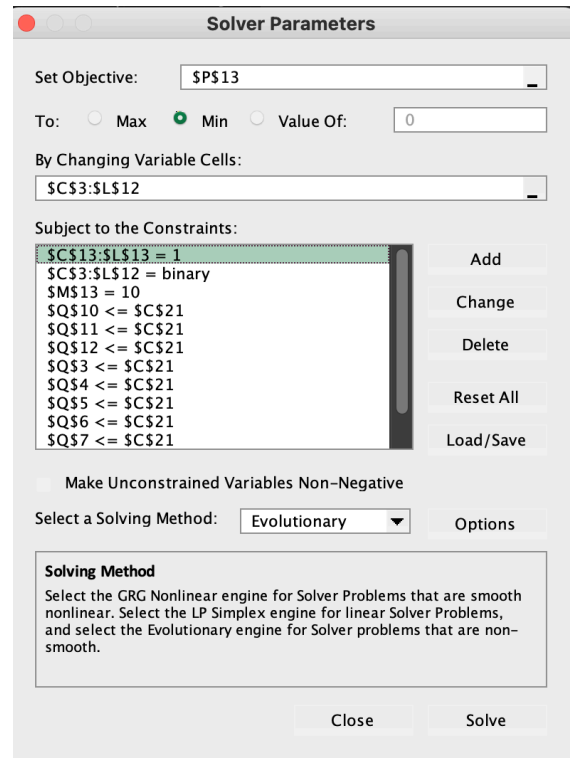


Figure 4: Setting ten locations problem on Excel Solver

4. Experimental Design

The research objective is to study the sensitivity of related parameters of the partial joint ordering model. The replenishment of 5 locations and 10 locations are solved by using Excel solver. The demand and ordering setup cost are the interested factors. The demand is classified as equally and constant demands' problem and the different demands at each location problem. The different demands are grouped as low and high demands. In addition, the variable setup cost of ordering is varied from low to high values.

The sensitivity analysis of parameters is studied on small problem of five locations and large problem of ten locations. The values of demands, inventory holding cost per unit, the inventory setup cost, are as follow:

For 5 locations problem

$$D_i = 10,000 \text{ units/year of all locations for the case of constant demands, and}$$

$$= 20,000, 25,000, 10,000, 12,000, \text{ and } 8,000 \text{ for different demand of location 1 to 5, respectively.}$$

$$H_i = 10 \text{ Baht per unit}$$

$$SF_i = 1,000 \text{ Baht per order}$$

$$SV_i = 2,000, 5,000, 10,000, 20,000, 30,000, 40,000 \text{ Baht per order}$$

RESULTS AND DISCUSSION

The sensitivity analysis of the partial joint ordering model is studied by varying demand of equal demand and different demands. The variable setup cost is varied from low to high. The demand values are classified to low and high demand for each location to study the behaviors of partial joint ordering. The performance index represents how the solution is better than all joint ordering. If the value of performance index is lower than 1, the partial joint

gives lower cost or better solution. The performance index of partial joint ordering is shown as equation (15). For the individual ordering, each location will place order independently. Each location has its own replenishment period and will order independently. The performance of individual ordering is measured as shown in equation (16).

$$\text{Performance Index}_{\text{partial}} = \frac{\text{Cost of Partial Joint Order}}{\text{Cost of All Joint Order}} \quad (15)$$

$$\text{Performance Index}_{\text{individual}} = \frac{\text{Cost of Individual Order}}{\text{Cost of All Joint Order}} \quad (16)$$

Table 1: The scenarios of small problem of 5 locations with the difference values of demands and variable setup cost

Location	Equal Demand	Unequal Demand	Scenarios of Different Ordering Setup Cost (Variable Cost)									
			1	2	3	4	5	6	7	8	9	10
1	10,000	20,000	2,000	5,000	10,000	20,000	30,000	40,000	2,000	5,000	10,000	30,000
2	10,000	25,000	2,000	5,000	10,000	20,000	30,000	40,000	2,000	5,000	10,000	30,000
3	10,000	10,000	2,000	5,000	10,000	20,000	30,000	40,000	5,000	2,000	30,000	10,000
4	10,000	12,000	2,000	5,000	10,000	20,000	30,000	40,000	5,000	2,000	30,000	10,000
5	10,000	8,000	2,000	5,000	10,000	20,000	30,000	40,000	5,000	2,000	30,000	10,000

Table 2: The scenarios of large problem of 10 locations with the difference values of demands and variable setup cost

Location	Equal Demand	Unequal Demand	Scenarios of Different Ordering Setup Cost (Variable Cost)									
			1	2	3	4	5	6	7	8	9	10
1	10,000	20,000	2,000	5,000	10,000	20,000	30,000	40,000	2,000	5,000	10,000	30,000
2	10,000	25,000	2,000	5,000	10,000	20,000	30,000	40,000	2,000	5,000	10,000	30,000
3	10,000	22,000	2,000	5,000	10,000	20,000	30,000	40,000	2,000	5,000	10,000	30,000
4	10,000	20,000	2,000	5,000	10,000	20,000	30,000	40,000	2,000	5,000	10,000	30,000
5	10,000	25,000	2,000	5,000	10,000	20,000	30,000	40,000	2,000	5,000	10,000	30,000
6	10,000	10,000	2,000	5,000	10,000	20,000	30,000	40,000	5,000	2,000	30,000	10,000
7	10,000	8,000	2,000	5,000	10,000	20,000	30,000	40,000	5,000	2,000	30,000	10,000
8	10,000	12,000	2,000	5,000	10,000	20,000	30,000	40,000	5,000	2,000	30,000	10,000
9	10,000	10,000	2,000	5,000	10,000	20,000	30,000	40,000	5,000	2,000	30,000	10,000
10	10,000	8,000	2,000	5,000	10,000	20,000	30,000	40,000	5,000	2,000	30,000	10,000

By varying the demand values and the setup cost values according to table 1 and table 2, the performance index values are shown in table 3 and table 4 for 5 locations problem. When the demand is constant and equal with the higher value of setup cost, the better the performance index of partial joint ordering comparing to all joint ordering. However, for equal demand, all joint ordering gives better solution than the partial joint ordering. On the other hand, for the unequal demand (table 4), two locations with high demand and three locations with low demand, the partial joint ordering gives lower cost than the solution of all joint ordering, since performance index values are lower than 1. In conclusion, when the distribution system with constant and unequal demands, the replenishment solution from partial joint ordering is better than all joint solution since the performance index of partial joint ($PI_{\text{partial joint}}$) is less than 1.0, especially when the variable setup cost increase. When the system has

different variable setup cost values, the locations with high demands and low setup cost will be grouped into the same clusters and the locations with low demands will be grouped into another cluster.

Table 3: The results of performance index values of partial joint ordering and independent ordering
(5 locations with constant and equal demand of 10,000)

Location	Equal Demand	Scenarios of Different Ordering Setup Cost (Variable Cost)									
		1	2	3	4	5	6	7	8	9	10
1	10,000	2,000	5,000	10,000	20,000	30,000	40,000	2,000	5,000	10,000	30,000
2	10,000	2,000	5,000	10,000	20,000	30,000	40,000	2,000	5,000	10,000	30,000
3	10,000	2,000	5,000	10,000	20,000	30,000	40,000	5,000	2,000	30,000	10,000
4	10,000	2,000	5,000	10,000	20,000	30,000	40,000	5,000	2,000	30,000	10,000
5	10,000	2,000	5,000	10,000	20,000	30,000	40,000	5,000	2,000	30,000	10,000
Performance Index _{partial_joint}		1.000	1.000	1.010	1.000	1.003	1.002	1.017	1.028	0.976	0.970
Performance Index _{individual}		1.168	1.074	1.038	1.020	1.013	1.010	1.081	1.095	0.991	0.988

Table 4: The results of performance index values of partial joint ordering and independent ordering
(5 locations with difference demand of 20,000, 25,000, 10,000, 12,000, 8,000)

Location	Unequal Demand	Scenarios of Different Ordering Setup Cost (Variable Cost)									
		1	2	3	4	5	6	7	8	9	10
1	20,000	2,000	5,000	10,000	20,000	30,000	40,000	2,000	5,000	10,000	30,000
2	25,000	2,000	5,000	10,000	20,000	30,000	40,000	2,000	5,000	10,000	30,000
3	10,000	2,000	5,000	10,000	20,000	30,000	40,000	5,000	2,000	30,000	10,000
4	12,000	2,000	5,000	10,000	20,000	30,000	40,000	5,000	2,000	30,000	10,000
5	8,000	2,000	5,000	10,000	20,000	30,000	40,000	5,000	2,000	30,000	10,000
Performance Index _{partial_joint}		1.025	0.9997	0.997	0.985	0.988	0.983	0.953	1.000	0.976	1.000
Performance Index _{individual}		1.141	1.050	1.015	0.9965	0.990	0.987	1.022	1.108	0.991	1.018

Table 5: The results of performance index values of partial joint ordering and independent ordering
(10 locations with constant and equal demand of 10,000)

Location	Equal Demand	Scenarios of Different Ordering Setup Cost (Variable Cost)									
		1	2	3	4	5	6	7	8	9	10
1	10,000	2,000	5,000	10,000	20,000	30,000	40,000	2,000	5,000	10,000	30,000
2	10,000	2,000	5,000	10,000	20,000	30,000	40,000	2,000	5,000	10,000	30,000
3	10,000	2,000	5,000	10,000	20,000	30,000	40,000	2,000	5,000	10,000	30,000
4	10,000	2,000	5,000	10,000	20,000	30,000	40,000	2,000	5,000	10,000	30,000
5	10,000	2,000	5,000	10,000	20,000	30,000	40,000	2,000	5,000	10,000	30,000
6	10,000	2,000	5,000	10,000	20,000	30,000	40,000	5,000	2,000	30,000	10,000
7	10,000	2,000	5,000	10,000	20,000	30,000	40,000	5,000	2,000	30,000	10,000
8	10,000	2,000	5,000	10,000	20,000	30,000	40,000	5,000	2,000	30,000	10,000
9	10,000	2,000	5,000	10,000	20,000	30,000	40,000	5,000	2,000	30,000	10,000
10	10,000	2,000	5,000	10,000	20,000	30,000	40,000	5,000	2,000	30,000	10,000
Performance Index _{partial_joint}		1.067	1.057	1.015	1.01	1.005	1.004	1.046	1.056	0.987	0.994
Performance Index _{independent}		1.168	1.077	1.044	1.022	1.015	1.011	1.091	1.091	0.991	0.99

For the bigger problem, the 10 locations scenarios are studied. There are two scenarios which are constant and equal demands as shown in table 5 and constant unequal demands as shown in table 6. The average demand is 22,400 for the group of high demand and the average of 9,600 for the group of low demand. The variable setup cost of ordering is varied from low to high between 2,000 to 40,000.

From table 3 and table 5, the distribution system with the equal or not much difference demand of all locations, the full joint ordering gives lower total cost than the partial joint ordering, since the performance index is greater than one. However, if the distribution system has difference inventory ordering cost, the partial joint ordering gives the lower total cost than the full joint ordering. The individual ordering gives the same results as the partial joint ordering.

By considering the solutions of unequal demands distribution system (table 4 and table 6), the scenarios of the partial joint ordering with high variable setup cost gives lower total inventory cost than the full joint ordering, since the performance index values are less than 1. The average values of performance index from the scenarios are shown in table 7. The solution from the partial joint ordering with high variable setup cost gives lower cost than the solution from full joint ordering about 1.69% and 2.75% in average for 5 locations and 10 locations, respectively.

Table 6: The results of performance index values of partial joint ordering and independent ordering
(10 locations with difference demand of 20,000, 25,000, 22,000, 20,000, 25,000, 10,000, 8,000, 12,000, 10,000, 8,000)

Location	Unequal Demand	Scenarios of Different Ordering Setup Cost (Variable Cost)									
		1	2	3	4	5	6	7	8	9	10
1	20,000	2,000	5,000	10,000	20,000	30,000	40,000	2,000	5,000	10,000	30,000
2	25,000	2,000	5,000	10,000	20,000	30,000	40,000	2,000	5,000	10,000	30,000
3	22,000	2,000	5,000	10,000	20,000	30,000	40,000	2,000	5,000	10,000	30,000
4	20,000	2,000	5,000	10,000	20,000	30,000	40,000	2,000	5,000	10,000	30,000
5	25,000	2,000	5,000	10,000	20,000	30,000	40,000	2,000	5,000	10,000	30,000
6	10,000	2,000	5,000	10,000	20,000	30,000	40,000	5,000	2,000	30,000	10,000
7	8,000	2,000	5,000	10,000	20,000	30,000	40,000	5,000	2,000	30,000	10,000
8	12,000	2,000	5,000	10,000	20,000	30,000	40,000	5,000	2,000	30,000	10,000
9	10,000	2,000	5,000	10,000	20,000	30,000	40,000	5,000	2,000	30,000	10,000
10	8,000	2,000	5,000	10,000	20,000	30,000	40,000	5,000	2,000	30,000	10,000
Performance Index _{partial_joint}		1.065	1.030	1.012	0.998	0.988	0.987	1.019	1.026	0.917	1.010
Performance Index _{independent}		1.168	1.060	1.020	0.999	0.992	0.988	1.040	1.115	0.917	1.020

Table 7: The average values of performance Index_{partial_joint} which less than one from unequal demands cases

Problems of unequal demands	Average Performance Index _{partial_joint}	Average Performance Index _{partial_joint} (%)	Percentage of Total Cost from Solutions of Partial Less than Full (%)
5 locations (table 4)	0.9831	98.31	1.69
10 locations (table 6)	0.9725	97.25	2.75

CONCLUSION

This research develops a spreadsheet-based inventory model for partial joint ordering across multiple demand locations, focusing on optimizing delivery schedules and lowering total costs. By applying sensitivity analysis, the model evaluates how changes in inventory ordering cost and demand impact the total cost, facilitating improved inventory control. The study applied a binary linear programming optimization model solved by using Excel Solver to minimize total inventory costs under varying the value of demand and variable setup costs. The performance of the partial joint ordering policy was evaluated against the full joint ordering policy using the performance index. The results indicate that the effectiveness of the partial joint ordering policy is highly dependent on the demand structure and variable inventory setup costs. The results indicate that, firstly, for distribution systems with equal or consistent demands across locations, the partial joint ordering policy offers no significant advantage over the full joint ordering policy. However, in scenarios characterized by unequal dispersed demands, the partial joint ordering policy demonstrates a clear cost advantage. Secondly, as the variable setup cost increases, the performance index decreases and less than one, indicating greater savings than the full joint ordering. Thirdly, for system with five and ten locations featuring unequal demands and high variable setup costs, the partial joint ordering policy reduced the total inventory cost by an average of 1.69% and 2.75%, respectively, comparing to the full joint ordering. Lastly, partial joint ordering trends to gives lower total cost, when the number of demand locations of the distribution system increases, especially the complex distribution system with variation values of demand and ordering cost. In conclusion, the partial joint ordering policy is the superior strategy for distribution system with high demand variance and significant varying of inventory setup costs, while full joint ordering remains sufficient for systems with uniform demand patterns.

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