# Retraction Notice

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Expression of Concern:
**X** yes, date: 2020-6-19
☐ no

Correction:
☐ yes, date: yyyy-mm-dd
**X** no

**Comment:**

This article has been retracted to straighten the academic record. In making this decision the Editorial Board follows COPE's Retraction Guidelines. Aim is to promote the circulation of scientific research by offering an ideal research publication platform with due consideration of internationally accepted standards on publication ethics. The Editorial Board would like to extend its sincere apologies for any inconvenience this retraction may have caused.

Editor guiding this retraction: Prof. Moran Wang (EiC of OJOp)

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# Optimization of Supply Chain Networks Using MINLP Model with Deterministic Demand

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## Abstract

This paper aims at investigating the optimization of supply chain networks (SCN) for industrial plants under vendor managed inventory (VMI) policy. The vendor uses Long Range Wide Area Network (LoRaWAN) to minimize the total cost of networks. The problem was developed as a mixed-integer non-linear program (MINLP) model, which helped in reducing the total cost of a VMI, to formulate the coordinated decision issue that incorporates the location inventory issue with the allocation task of LoRaWAN technology and its level of investment. We performed different strategies of investment of LoRaWAN technology of having objective function with three different scenarios: 1) Investment of LoRaWAN technology only in ordering operations; 2) Investment of LoRaWAN technology only in holding operations; 3) Investment of LoRaWAN technology in both holding and ordering operations. The simulation results indicated that the cost-saving obtained by the third scenario is significant due to the least total cost of the objective function as compared with the total cost of the objective function obtained by the first and second scenarios.

## Keywords

Supply Chain Networks, Vendor Managed Inventory, Mixed-Integer Non-Linear Programming Model, Long Range Wide Area Network Technology

## 1. Introduction

Manufacturing settings have been confronted by rising costs, strong competition, and refined requirements and rules. These factors have increased the importance of supply chains in the manufacturing arena [1]. Managing supply chain inventory is a considerable undertaking for many firms that have tried at the same time to decrease their expenses as well as improve customer service in this current competitive business environment [2]. To prevail over the rift in managing inventory in the manufacturing sector, a few supply-chain management systems, including VMI have been applied to support supply-chain software [3].

Vendor Managed Inventory is defined as a replenishment and collaborative delivery strategy in which replenishment choices and related costs are covered by the vendors rather than buyers in the traditional system. As a concerted strategy, VMI seeks to optimize the availability of products and services at a reduced cost. Generally, VMI is considered a demand-driven supply chain network [4].

Long Range Wide Area Network technology plays a vital role in reduction of inventory by handling the expired date items as well as the defective items. The use of LoRaWAN leads to cost reduction of both expired and defective items reaching the end customers and has the ability to reduce the rate of inventory waste. Based on that, vendors decided to adopt this technology with the aim of reducing the total network cost. Additionally, the vendor must implement a more effective inter-firm information technology system that uses advanced technology for the purpose of enhancing supply chain traceability and integrity like LoRaWAN technology, which enhances information sharing and collaboration between the involved supply network parties.

**Figure 1** illustrates the assignment of LoRaWAN technology chart and VMI based on the location-inventory assignment problem in a network of industrial plants with or without allocated warehouses [5].

This study is relatively engaged in investigating inventory problems through the implementation of LoRaWAN technology to enhance the efficiency of holding and ordering operations. LoRaWAN technology can minimize the total cost of the supply chain networks by enhancing of holding and ordering operations efficiency. The discussion section explains the cost of savings generated through the implementation of LoRaWAN technology and its effect on the location assignment of storage facilities at assigned industrial plants. The study identifies two supply chain LoRaWAN investment factors of holding and ordering efficiencies and developed quantitative methods that have optimal LoRaWAN investment levels for such factors.

In our research, we develop mathematical modeling and apply a newly modified firefly algorithm for the integrated location inventory supply chain network. Moreover, we identified the effects of LoRaWAN on cost savings on-location assignments of storage facilities in each industrial plant.

Vendors used Radio Frequency Identification (RFID) as a perfect technology to minimize the total cost of supply chain networks in healthcare systems [6]. Beyond the research done by [6], there has still been little research done on optimization of supply chain networks in manufacturing systems using LoRaWAN technology to minimize the total cost of supply chain networks. Based on that, in this research, the problem was developed as a mixed-integer non-linear program (MINLP) model, which helped in reducing the total cost of a VMI, to formulate

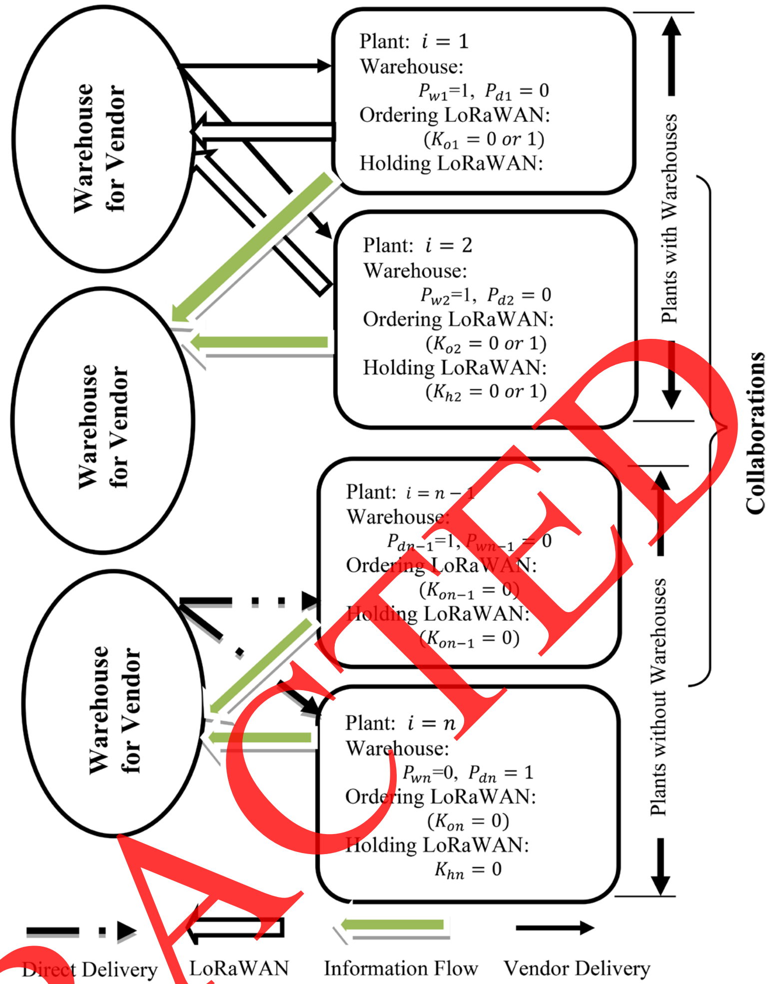


Figure 1. Assignment of LoRaWAN technology chart and VMI [5].

the coordinated decision issue that incorporates the location inventory issue with the allocation task of LoRaWAN technology and its level of investment.

## 2. Related Works

Research focusing on the integrated location inventory network dilemma is somewhat new. Jayaraman [7] developed a mathematical model to study the effect of the combination of facility location on inventory decisions and transportation modes. Erlebacher [8] offered a location-inventory model to improve the service level with limited associated inventory and transportation costs. Recently, Liao [9] further investigated the aspect of integrated location-inventory distribution network problems by incorporating the effect of distribution, facility location, and inventory issues in VMI contracts on the inventory decisions. The researchers presented a Multi-Objective Location-Inventory Problem (MOLIP) model then tested the Multi-Objective evolutionary algorithm used to solve MOLIP. The multi-objective approach was used to display inventory management assignments as operational decisions and the location assignment as strategic decisions with VMI policy as a single replenishment policy. The summary of the most related works for VMI contract and our contribution to this research are presented in **Table 1**.

The model in [10] [11] [12] addressed only VMI policy regardless of other effective policies like Direct Delivery Problem (DDP). The model in [13] addressed DDP and developed the problem as a non-linear programming (NLP) regardless of MINLP. Additionally, [14] developed the problem as NLP model and addressed only DDP policy while the model in [15] [16] [17] addressed only VMI policy. In our model, we developed the problem as MINLP model which is very effective model and addressed DDP and VMI policies.

Nozick [18] offered a location-inventory model based on an exchange between cost and service responses level. Miranda [19] combined facility location problems with inventory decisions and came up with a Mixed Integer Non-Linear Programming (MINLP) model by introducing inventory decisions in facility location models.

In this research, a Single Objective Optimization (SOO) is used to incorporate the inventory location assignment problem as a Mixed-Integer Non-Linear Problem (MINLP) with the aim of presenting operational and strategic decisions rather than using a Multi-Objective Optimization (MOO) as it has been in most past studies. Additionally, our study's model is developed upon the assignment of replenishment policy for each industrial plant based on each plant's storage facility location assignment where a direct delivery policy was used for plants with no assigned warehouses and the VMI policy was used for each industrial plant with assigned warehouses.

As stated in recent research, LoRaWAN technology is statistically believed to be the best Information Technology (IT) investment tool for the expansion of companies. This technology extends business value by enabling supply chains to easily and inexpensively gather and share information, thus taking a significant

**Table 1.** The summary of vendor managed inventory policy in the literature.

| References | Direct delivery problem | Non-linear programming | Vendor managed inventory | Mixed integer non-linear programming |
|---|---|---|---|---|
| [10] | | | ✓ | |
| [11] | | | ✓ | |
| [4] | | | ✓ | |
| [12] | | | ✓ | |
| [8] | ✓ | | | |
| [13] | | ✓ | ✓ | |
| [14] | ✓ | ✓ | | |
| [15] | | | ✓ | |
| [16] | | | ✓ | |
| [17] | | | ✓ | |
| **Model** | ✓ | | ✓ | ✓ |

role in enhancing supply chain visibility, which in turn leads to reduced stock-out and lead time. Inventory waste is eliminated, labor costs are decreased, transaction costs are reduced, and both customer satisfaction and inventory and logistics management are improved [20].

The current study incorporates the LoRaWAN investment evaluation model together with its investment level and its relative warehouse location assignment. The LoRaWAN investment evaluation model was integrated through the examination of the relationship between variables, model parameters and the level of LoRaWAN investment contained in the inventory-location assignment problem. In general, Inaccuracy in the inventory management system is due to inaccurate accounts in the warehouses, which lead to lost and expired items.

In this research, enhancement in the efficiency of holding and ordering operations can deal with inventory waste problem by implementing LoRaWAN technology as a promising solution. The implementation of LoRaWAN was found to have reduced the overall costs of supply in many industries and improved the quality of administration. The cost of implementing and maintaining this technology was found to be higher as compared to the traditional model of tracking. However, researchers like Tung and Nguyen [21] argued that the use of this technology leads to overall cost savings with reduced inventory and labor costs, as well as improved efficiency in terms of shortened administrative work where purchase and material orders are done on time which leads to minimized waste and rejected items. The benefits of LoRaWAN technology for holding and ordering operations are shown in Table 2. The assumptions of MINLP model is as follows:

- The demand of all industrial plants for products is deterministic.
- We used a continuous review policy for VMI policy
- We assumed that the delivery of products to the industrial plants with no allocated warehouse made by courier and the direct delivery with the same day should be charged.
- The efficiency of ordering and holding operations is considered an exponential function where the efficiency of ordering and holding operations is improved by LoRaWAN investment costs [22].
- Ignorance of the shipment of quantity per order, the cost of ordering is expected to have the fixed cost. Additionally, all other costs associated with setting up the order examination, creating a local purchase order and order inspection is the same ignorance of the weight.

Table 2. The benefits of LoRaWAN technology for ordering and holding operations.

| LoRaWAN benefits for ordering operations | LoRaWAN benefits for holding operations |
|---|---|
| • Enhancement of inventory data through the automated advantages of LoRaWAN<br>• Improvement of the process of verifications through the advantages of LoRaWAN<br>• Improving the time of process for delivering orders using GPS through LoRaWAN | • Improving the time of reduction in inventory<br>• Elimination of mistakes in labeling of units by the automated tagging<br>• LoRaWAN technology enhances the process of tracking of the records of inventory |

- Ignorance of the location of industrial plant and the demand size, the demand must be satisfied.

## 3. Problem Statement and Mathematical Formulation

In this research, the objective function is to reduce the total cost of the vendor. The operational decision problem is related to replenishment inventory decisions. The expectation of vendors is to make decisions on the size of orders which should be delivered to the industrial plant. The level of safety stock must be maintained at each plant with a warehouse. Indexes, notations, and decision variables are presented in Table 3 and Table 4.

### Mathematical Modeling

$$\begin{aligned}\min \sum_{i=1}^{n}\sum_{j=1}^{m}\left(OC_i+T_{ij}\right)R_{ij}P_{di}+\sum_{i=1}^{n}U_iOE_iNS_i \\ +\sum_{i=1}^{n}\sum_{j=1}^{m}HE_iHC_{ij}\left(\left(Z_{ij}/2\right)+L_{ij}\right) \\ +\sum_{i=1}^{n}\left(SC_i+SS_iRe_i\right)P_{wi}+\sum_{i=1}^{n}L_{hi}+\sum_{i=1}^{n}L_{oi}\end{aligned} \tag{1}$$

$$\sum_{j=1}^{m}\left(Z_{ij}+L_{ij}\right)V_i\le P_{wi}\quad \text{for}\quad \forall i=1,2,\cdots,n\quad \text{and}\quad j=1,2,\cdots,m. \tag{2}$$

$$NS_i\le P_{wi}*bigM\quad \text{for}\quad \forall i=1,2,\cdots,n. \tag{3}$$

Table 3. Indexes and parameters used in this paper.

| **Parameters, indexes** | |
|---|---|
| $T_{ij}$ The cost of transportation per order for product *j* delivered to plant *i*. | $U_i$ Truck shipment per unit and ordering cost for plant *i*. |
| $V_i$ The volume of item per product *i* | $CA_{Tr}$ The capacity of Truck to deliver items to plant i. |
| *bigM* Very large number. | $SS_i$ The total size space of the allocated warehouse per unit of time at the plant *i*. |
| $A_h$ The minimum level of LoRaWAN investment to improve the efficiency of holding at the allocated warehouse. | $R_{ij}$ The rate of demand of plant *i* of product *j* per unit of time. |
| $A_o$ The minimum level of LoRaWAN investment to improve the efficiency of ordering at the allocated warehouse. | $SC_i$ Total setup cost to have a warehouse at the plant i. |
| $\mu$ Exponential for the efficiency of holding. | $Re_i$ Cost of rental space per unit of time. |
| $\beta$ Exponential for the efficiency of ordering. | $HC_{ij}$ Holding cost of product *j* for plant *i*. |
| *C* There is no investment in LoRaWAN technology if the lowest level of efficiency of holding is achieved. | $OC_i$ Ordering cost for plant *i*. |
| *F* There is no investment in LoRaWAN technology if the lowest level of efficiency of ordering is achieved. | |
| *G* The highest level of efficiency of ordering which is achieved by $L_{oi}$ investment in LoRaWAN technology. | **Indexes** |
| *M* The highest level of efficiency of holding which is achieved by $L_{hi}$ investment in LoRaWAN technology. | $i, j$ indices for plants and products respectively |
| $S_{ij}$ The minimum level of safety stock for product *j* at the plant *i* | |

**Table 4.** The decision variables used in this paper.

| Decision variables | |
|---|---|
| $Z_{ij}$ | The number of order quantity of product *j* delivered to plant *i* with allocated warehouse. |
| $(NS)_i$ | The number of shipments to plant *i* with allocated warehouse. |
| $L_{ij}$ | Safety stock level at the plant *i* with allocated warehouse for j product. |
| $P_{di}$ | 1 if the delivery of shipment is delivered directly to plant *i*, otherwise 0. |
| $P_{wi}$ | 1 if there is a warehouse facility for plant i, otherwise 0. |
| $L_{oi}$ | Level of LoRaWAN investment for efficiency of ordering for plant *i* with the allocated warehouse. |
| $(OE)_i$ | The degree of the ordering cost is reduced by LoRaWAN investment $L_{oi}$ at the plant *i* based on the efficiency of ordering [8]. |
| $(HE)_i$ | The degree of the holding cost is reduced by LoRaWAN investment $L_{hi}$ at the plant *i* based on the efficiency of holding [8]. |
| $K_{oi}$ | 1 if LoRaWAN technology is installed for the efficiency of ordering at the assigned warehouse. |
| $K_{hi}$ | 1 if LoRaWAN technology is installed for the efficiency of holding at the assigned warehouse. |
| $L_{hi}$ | Level of LoRaWAN investment for efficiency of holding for plant *i* with the allocated warehouse |

$$OE_i = \left(G + \left(F - G\right)e^{-\beta L_{oi}}\right)P_{wi} \quad \text{for} \quad \forall i = 1, 2, \cdots, n. \tag{4}$$

$$L_{oi} \geq K_{oi} A_o \quad \text{for} \quad \forall i = 1, 2, \cdots, n. \tag{5}$$

Equation (1) represents the total cost related to the vendor managed inventory problem. It shows the sum of making orders and courier transportation delivery costs per item for all demanded products and each plant with no designated warehouse. It also shows the cost, if coalesced ordering and trucking transportation cost for all orders delivered at each industrial plant with designated warehouses. Holding cost per item of the added average order quality and the safety stock level for all the products at each industrial plant with designated warehouses is also shown in Equation (1). The fourth term stands for the sum of total costs of the fixed cost of setting up the warehouses at each industrial plant as well as the rental cost for the assigned space by each plant for the vendor's warehousing purposes. The fifth and sixth terms stand for LoRaWAN holding and ordering investment costs for each plant with designated warehouses. Equation (2) indicates the space of warehouse while Equation (3) represents the maximum number of safety stock level constraint. Equation (4) represents that the level of efficiency of ordering operations can be a function of investment level in LoRaWAN technology for ordering operations ($L_{oi}$) [23]. Equation (5) states that the minimum level of investment in LoRaWAN technology to improve the efficiency of ordering operations is greater than or equal to a minimum level of investment in LoRaWAN for $A_o$.

The level of efficiency of holding operations can be an exponential function of investment level in LoRaWAN for holding operations ($L_{hi}$) as shown in (6). A lower value of the efficiency of holding operations represents a higher value of efficiency [23]. Equation (7) indicates that each order of quantity for products should be less than or equal to the value of *bigM* for the plant *i* with the allocated warehouse while Equation (8) shows that each plant *i* could have a warehouse with vendor managed inventory (VMI) delivery or could have a direct delivery with no allocated warehouse. Equation (9) states that the lower bound level of safety stock is limited and equal to the minimum value represented by $S_{ij}$ for plants *i* with the allocated warehouse. The constraint of the space of the truck is shown in Equation (10). It states that the total size of order quantities for all products that delivered to plant *i* with allocated warehouses is less than or equal to the truck's capacity. Equation (11) is the constraint of demand satisfaction. It states that the total number of order quantity of product *j* delivered to the plant *i* with allocated warehouse is greater than or equal to the demand of product *j* of plant *i* with the allocated warehouse.

$$HE_i = \left(M + \left(C - M\right)\mathrm{e}^{-\mu L_{hi}}\right)P_{wi} \quad \text{for} \quad \forall i = 1, 2, \cdots, n \tag{6}$$

$$Z_{ij} \le P_{wi} * bigM . \tag{7}$$

$$P_{di} + P_{wi} = 1 \quad \text{for} \quad \forall i = 1, 2, \cdots, n . \tag{8}$$

$$L_{ij} = P_{wi} S_{ij} \quad \text{for} \quad \forall i = 1, 2, \cdots, n \quad \text{and} \quad j = 1, 2, \cdots, m \tag{9}$$

$$\sum\nolimits_{j=1}^{m} Z_{ij} \le CA_{Tr} \quad \text{for} \quad \forall i = 1, 2, \cdots, n . \tag{10}$$

$$Z_{ij} NS_i \ge R_{ij} P_{wi} \quad \text{for} \quad \forall i = 1, 2, \cdots, n \quad \text{and} \quad j = 1, 2, \cdots, m . \tag{11}$$

Equation (12) shows that the maximum value of investment level in LoRaWAN technology for holding operations at the plant *i* with allocated warehouse is less than or equal to the value of *bigM*. The investment level in LoRaWAN in the efficiency of holding is equal to or less than *bigM* value as shown in Equation (13). Equation (14) represents the investment level in LoRaWAN in the efficiency of ordering operations should be less than or equal to *bigM* value. The maximum value of investment level in LoRaWAN for ordering at the plant *i* with allocated warehouse should be less than or equal to the value of *bigM* as presented in Equation (15). Equation (16) indicates that minimum investment level in LoRaWAN for improving the efficiency of holding is applied at the allocated warehouse at the plant *i*.

$$L_{hi} \le P_{wi} * bigM \quad \text{for} \quad \forall i = 1, 2, \cdots, n . \tag{12}$$

$$L_{hi} \le K_{hi} * bigM \quad \text{for} \quad \forall i = 1, 2, \cdots, n . \tag{13}$$

$$L_{oi} \le K_{oi} * bigM \quad \text{for} \quad \forall i = 1, 2, \cdots, n . \tag{14}$$

$$L_{oi} \le P_{wi} * bigM \quad \text{for} \quad \forall i = 1, 2, \cdots, n . \tag{15}$$

$$K_{hi} \le P_{wi} \quad \text{for} \quad \forall i = 1, 2, \cdots, n . \tag{16}$$

Equation (17) represents the constraint of the minimum level investment in LoRaWAN technology in holding operations. The minimum investment level in LoRaWAN technology to improve the efficiency of holding is equal to or higher than minimum level investment in LoRaWAN of $A_h$, see Equation (17). The minimum investment level in LoRaWAN for improving the efficiency of ordering operations is applied at the assigned warehouse at the plant *i* as shown in Equation (18). Equation (19) represents the binary constraint. All decision variables in the model should be non-negative values for validation, as shown in Equation (20).

$$L_{hi} \ge K_{hi} A_h \quad \text{for} \quad \forall i = 1, 2, \cdots, n. \tag{17}$$

$$K_{oi} \le P_{wi} \quad \text{for} \quad \forall i = 1, 2, \cdots, n. \tag{18}$$

$$P_{di}, P_{wi}, K_{oi}, K_{hi} \in [0,1]. \tag{19}$$

$$Z_{ij}, NS_i, L_{hi}, L_{oi}, L_{ij} \ge 0 \quad \text{for} \quad \forall i = 1, 2, \cdots, n \quad \text{and} \quad j = 1, 2, \cdots, m. \tag{20}$$

## 4. Results and Discussions

The problem is developed as a mixed-integer non-linear programming (MINLP) model to reduce the total cost of a VMI supply chain networks. We estimated values of the parameter to make the model behaviors of investment decisions of LoRaWAN technology more understandable. The values of the parameter are shown in Table 5. We used the values of parameter shown in Table 5 as the input data for this problem. Note that the reason for choosing $A_o$ & $A_h = \$1000$ is to make an implementation of LoRaWAN decision applicable and efficient. If the investment of LoRaWAN value is less than \$1000, it will be undependable, and GAMS will not accept the investment of LoRaWAN in either ordering or holding operation.

Figure 2 presents the cost-saving obtained by the third scenario (investment in LoRaWAN technology in both holding and ordering operations) is significant due to the least total cost of the objective function as compared with the total cost of the objective function obtained by the first and second scenarios. Figure 2 also shows the enhancement in the total cost obtained by the third scenario compared to the first and second scenarios.

We used GAMS optimizer software to solve the problem using KNITRO solver; CPU time is 0.016.

We performed different strategies of investment of LoRaWAN technology of having objective function with three different scenarios: 1) Investment of LoRaWAN technology in only in ordering operations; 2) Investment of LoRaWAN technology

Table 5. Parameter setting.

| Parameter | Value |
|---|---|
| $F$ | 1 |
| $A_o$ | \$1000 |
| $OC_i$ | \$100 |
| $M$ | 0.3 |
| $G$ | 0.2 |
| $A_h$ | \$1000 |
| $C$ | 1 |
| $\beta$ | 0.004 |
| $\mu$ | 0.0038 |

only in holding operations; 3) Investment of LoRaWAN technology in both holding and ordering operations. Figure 3 shows GAMS output for the total cost made by LoRaWAN investment in only ordering operation (scenario 1). Figure 4 shows GAMS output for the total cost made by LoRaWAN investment in only holding operation (scenario 2) while Figure 5 represents GAMS output for the


Figure 2. Total cost (objective function) of each scenario.

```
                S O L V E       S U M M A R Y

     MODEL   OrderingOperations   OBJECTIVE  OB
     TYPE    MINLP                DIRECTION  MINIMIZE
     SOLVER  KNITRO               FROM LINE  179

**** SOLVER STATUS     1 Normal Completion
**** MODEL STATUS      8 Integer Solution
**** OBJECTIVE VALUE          3156930.0000

 RESOURCE USAGE, LIMIT          0.046      1000.000
 ITERATION COUNT, LIMIT         0    2000000000
 EVALUATION ERRORS              0             0

KNITRO           30.1.0 re01a340 Released Jan 10, 2020 WEI x86 64bit/MS Window
```

Figure 3. GAMS output (Using KNITRO solver) forthe total cost made by LoRaWAN investment in only ordering operations (Scenario 1).

```
                S O L V E       S U M M A R Y

     MODEL   HoldingOperations   OBJECTIVE  OB
     TYPE    MINLP               DIRECTION  MINIMIZE
     SOLVER  KNITRO              FROM LINE  177

**** SOLVER STATUS     1 Normal Completion
**** MODEL STATUS      8 Integer Solution
**** OBJECTIVE VALUE          3098160.0000

 RESOURCE USAGE, LIMIT          0.047      1000.000
 ITERATION COUNT, LIMIT         0    2000000000
 EVALUATION ERRORS              0             0

KNITRO           30.1.0 re01a340 Released Jan 10, 2020 WEI x86 64bit/MS Window
```

Figure 4. GAMS output (Using KNITRO solver) for total cost made by LoRaWAN investment in only holding operations (Scenario 2).

total cost made by LoRaWAN investment in both ordering and holding operations (scenario 3).

Figure 6 shows the result of $OE_i$ and $HE_i$, which indicates the efficiency of ordering and the efficiency of holding operation, respectively. It shows if the value of $OE_i$ and $HE_i$ decreases continuously, the demand level increases rapidly. Also, Figure 6 shows that the efficiency rate still in improving cases if the demand level increases.

Figure 7 represents the impact of level of demand on the cost-saving. It shows that if the level of demand increases, the cost-saving of the third scenario (investment of LoRaWAN in ordering and holding operations) is the highest compared with the first and second scenarios.

The results show that the level of demand plays a significant role in the application of investment of LoRaWAN technology and affects the level of investment in the efficiencies of ordering and holding operations. The results also show that the vendor with a vendor managed inventory (VMI) policy can acquire higher cost-saving by applying LoRaWAN technology in the field of manufacturing for the industrial plants.



```
               S O L V E      S U M M A R Y

     MODEL   MyProject2            OBJECTIVE  OB
     TYPE    MINLP                 DIRECTION  MINIMIZE
     SOLVER  KNITRO                FROM LINE  223

**** SOLVER STATUS     1 Normal Completion
**** MODEL STATUS      8 Integer Solution
**** OBJECTIVE VALUE          3063330.0000

 RESOURCE USAGE, LIMIT          0.047      1000.000
 ITERATION COUNT, LIMIT         0     2000000000
 EVALUATION ERRORS              0              0

KNITRO          30.1.0 re01a340 Released Jan 10, 2020 WEI x86 64bit/MS Window
```

Figure 5. GAMS output (Using KNITRO solver) for total cost made by LoRaWAN investment in both ordering & holding operations (Scenario 3).

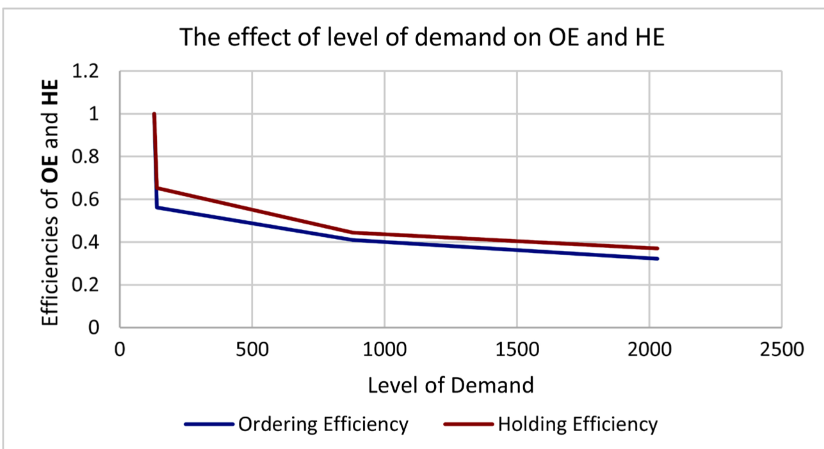


Figure 6. The effect of level of demand on $OE_i$ and $HE_i$.


Figure 7. The effect of level of demand on cost-saving.

## 5. Conclusion

A mixed-integer non-linear programming (MINLP) model is developed to reduce the total supply network cost of a Vendor Managed Inventory (VMI). This research showed that the vendor improves his holding and ordering operations and has the ability to eliminate inventory waste of the products, which considered defective by implementing LoRaWAN technology. Based on this research, the location inventory supply chain network problem is solved easily by using a mixed-integer non-linear programming (MINLP) model with an investment level in LoRaWAN technology. The MINLP model was initially developed as a deterministic approach by assuming the demand is deterministic. Moreover, our research can be extended in developing a stochastic mixed-integer non-linear programming (SMINLP) model as a stochastic approach by assuming the demand is stochastic.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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