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Regular Research Article

Application of the Vendor Managed Inventory (VMI) Model Based on Total Distribution Cost Optimization

Giovano Alberto* **and Alexander Jimmy**

Pusat Studi Rantai Pasok, Universitas Katolik Parahyangan, Indonesia

*giovano@unpar.ac.id; Tel.: +6281384464718

Abstract: This study develops an optimization-based Vendor-Managed Inventory (VMI) model to improve coordination between inventory and transportation decisions in an upstream automotive distribution network in West Java. The problem is formulated as a multi-period Inventory Routing Problem (IRP) and solved using AMPL with CPLEX. The model minimizes total logistics cost, including transportation and inventory holding costs. A benchmark comparison with the company's existing decentralized replenishment policy is conducted. Results show that the proposed VMI model reduces total monthly logistics cost by 10.66%, from IDR 2.74 billion to IDR 2.44 billion. In addition, service performance improves significantly, with demand fulfilment increasing from 91.3% to 99.2% and stock-out occurrences eliminated. The findings highlight the importance of integrated decision-making in freight distribution systems and provide practical insights for transport capacity planning and inventory positioning.

Keywords: Vendor-Managed Inventory; Industrial Logistics; Automotive Distribution; Inventory Routing Problem; Optimization

1. Introduction

Freight transportation systems play a fundamental role in supporting industrial activity, international trade, and regional economic development. As global supply chains become increasingly interconnected, the efficiency and reliability of freight distribution have emerged as critical challenges for both transport operators and society. Supply chain management aims to coordinate material, information, and financial flows to minimize total system-wide costs while maintaining service performance [1], [2]. In many emerging economies, inventory and transportation decisions are still managed independently, resulting in suboptimal logistics performance.

In transport-intensive industries such as automotive manufacturing, upstream logistics coordination between manufacturers and main dealers face similar challenges. Existing replenishment policies are commonly based on historical demand averages and periodic shipment rules. While practical, such approaches often lead to inventory imbalance across regional warehouses, manifested as excess inventory in certain locations and stock-outs in others. These inefficiencies increase total distribution costs and reduce service reliability, especially under demand uncertainty and operational disruption risks [3].

Vendor-Managed Inventory (VMI) has been widely recognized as a collaborative logistics strategy that enhances coordination between supply chain partners by transferring inventory decision authority to the upstream vendor [4],[5]. Previous studies show that VMI improves inventory efficiency, reduces the bullwhip effect, and enhances service levels through better information sharing and coordinated decision-making [6], [7]. From a broader transport systems perspective, integrated inventory–transportation planning contributes to improved resource utilization, reduced transport inefficiencies, and more stable freight

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movements. Although this study focuses on land-based distribution, the insights are relevant to intermodal logistics systems where coordination between nodes is essential.

This study aims to develop and evaluate an optimization-based VMI model for an automotive distribution network in West Java. The model is assessed against the company's existing replenishment policy to quantify improvements in both cost efficiency and service performance.

2. Methodology

2. Methodology

2.1 Model Formulation

The study considers an upstream distribution system consisting of one manufacturing plant and three regional warehouses. The objective is to determine optimal shipment quantities and routing decisions over a multi-period planning horizon. VMI problems are frequently formulated as Inventory Routing Problems (IRPs), which integrate inventory control and vehicle routing decisions within a unified optimization framework [8]. These problems are classified as NP-hard and require advanced optimization techniques [9], [10]. The notation used in the proposed IRP model is defined as follows.

Sets

n	:	Number of customers
T	:	Number of periods
m	:	Number of vehicles

Parameters

d_{it}	:	Demand of customer i in period t
c_{ij}	:	Transportation cost from location i to location j
a_k	:	Vehicle capacity k
h_i	:	Inventory cost at location i
I_i^{max}	:	Maximum inventory quantity at location i
I_{i0}	:	Beginning inventory at location i
SS_i	:	Safety stock at location i

Decision Variables

x_{ijkt}	:	A binary variable takes the value 1 if vehicle k moves from location i to location j in period t.
z_{ikt}	:	A binary variable takes the value 1 if vehicle k serves customer i in period t.
u_{ikt}	:	A "dummy" variable related to vehicle k in period t to ensure no sub routing occurs.
I_{it}	:	Amount of inventory at location i in period t.
q_{ikt}	:	Amount of goods delivered to location i by vehicle k in period t.
Q_t	:	Amount of goods received by the depot in period t.

The IRP is formulated as a mixed-integer optimization model that minimizes total logistics cost, consisting of transportation and inventory holding costs, as follows [4]:

$$Min \sum_{\forall i}\sum_{\forall j}\sum_{\forall k}\sum_{\forall t} c_{ij}x_{ijkt} + \sum_{\forall i}\sum_{\forall t} h_i I_{it} \qquad (1)$$

subject to:

$$\sum_{\forall i} x_{ijkt} - z_{jkt} = 0, \forall j,k,t \qquad (2)$$

$$\sum_{\forall j} x_{ijkt} - z_{ikt} = 0, \forall i,k,t \qquad (3)$$

$$\sum_{\forall j} x_{0jkt} - z_{0kt} = 0, \forall i,k,t \qquad (4)$$

$$\sum_{\forall i} q_{ikt} \leq a_k z_{0kt} m, \forall k,t \qquad (5)$$

$$q_{ikt} \leq M z_{ikt} \ \forall i,k,t \qquad (6)$$

$$u_{0kt} = 1, \forall k,t \qquad (7)$$

$$u_{ikt} \leq n, \forall i,k,t \qquad (8)$$

$$u_{0kt} \geq 2, \forall k,t \qquad (9)$$

$$u_{ikt} - u_{jkt} + 1 \leq (n-1)\big(1 - x_{ijkt}\big), \forall i,j,k,t \qquad (10)$$

$$I_{it} = I_{it-1} + \sum_{\forall k} q_{ikt} - d_{it}, \forall i,t \qquad (11)$$

$$I_{0t} = I_{0t-1} + Q_t - \sum_{\forall i}\sum_{\forall k} q_{ikt}, \forall t \qquad (12)$$

$$I_{it} \geq SS_i, \forall i,t \qquad (13)$$

$$I_{it} \leq I_i^{max}, \forall i,t \qquad (14)$$

$$x_{ijkt}, z_{ikt} \in \{0,1\}, u_{ikt}, q_{ikt}, I_{it}, Q_t \geq 0$$

Although extensive research has examined VMI and IRP applications, empirical studies employing exact optimization methods and benchmarking results against real industrial baseline policies remain limited, particularly in emerging automotive markets. Recent literature emphasizes the importance of integrated

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logistics optimization and collaborative distribution mechanisms to improve supply chain performance [11], [12]. This study addresses the minimization of total logistics cost associated with product distribution from a manufacturing facility to multiple regional warehouses by integrating inventory replenishment and transportation decisions within a unified optimization framework. The empirical setting represents an automotive distribution network in West Java, Indonesia, consisting of a single production plant and three downstream warehouse nodes.

2.2 Data, Assumptions, and Solutions Approach

The model is parameterized using empirical data, including historical demand realizations, warehouse storage capacities, and transportation cost coefficients derived from operational records. Inventory holding cost parameters are estimated based on established logistics cost benchmarks reported in the literature and incorporated as linear cost coefficients in the objective function. The analysis is conducted at the tactical planning level over a discrete, finite multi-period horizon of 21 working days, representing one operational cycle.

Demand at each warehouse node is constructed from historical time-series data and modelled as deterministic parameters over the planning horizon. This assumption enables the formulation of the problem as a deterministic mixed-integer linear program (MILP), allowing the application of exact optimization techniques while maintaining computational tractability.

Under the Vendor-Managed Inventory (VMI) coordination mechanism, replenishment and inventory control decisions are centralized at the manufacturer level. The model captures two primary cost components inherent in VMI systems: transportation cost and inventory holding cost. Transportation cost is modelled as a linear function of inter-facility distance and fuel consumption per kilometer, while inventory holding cost is assumed to be proportional to inventory levels at each warehouse. This formulation explicitly captures the fundamental trade-off between shipment frequency and inventory accumulation in coordinated logistics systems.

The resulting optimization problem is formulated as a MILP, belonging to the NP-hard class of integrated inventory–distribution problems. To ensure operational feasibility, the model incorporates key constraints, including vehicle capacity limits, warehouse storage capacity bounds, inventory balance equations, and minimum inventory requirements to prevent stock-out. A fixed fleet size of 100 vehicles, each with a capacity of 40 units per trip, is assumed. Preliminary computational experiments indicate that a smaller fleet size leads to infeasible solutions due to insufficient delivery capacity, thereby justifying the selected fleet configuration as a feasibility-driven modelling assumption.

Model parameters are primarily obtained from empirical company data and supplemented by literature-based estimates, particularly for inventory holding cost. The use of such estimates ensures consistency with established logistics cost structures and provides a practical reference for coordination between upstream and downstream supply chain entities.

The mathematical model is implemented using AMPL (A Mathematical Programming Language), enabling an exact and structured representation of the optimization problem. The model is solved using the CPLEX solver, selected for its robustness in handling large-scale MILP problems. Given the computational complexity, a time limit of 21,600 seconds (6 hours) is imposed to obtain high-quality solutions within reasonable computational effort. Solution optimality is evaluated using the relative mixed-integer programming (MIP) gap, ensuring that the obtained solution is sufficiently close to the global optimum for practical application.

The model outputs include optimal shipment quantities to each warehouse per period, inventory trajectories over the planning horizon, and the decomposition of total logistics cost into transportation and inventory components. These outputs provide the analytical basis for evaluating cost efficiency, service performance, and operational feasibility under the proposed VMI coordination scheme.

3. Results and Discussion

The Vendor-Managed Inventory (VMI) model was developed and implemented using AMPL (A Mathematical Programming Language) to minimize the total logistics cost associated with upstream distribution from the manufacturing plant to regional warehouses. The objective

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function integrates two primary cost components: transportation cost and inventory holding cost, which represent the dominant trade-offs in coordinated logistics systems.

Transportation cost is modelled as a function of total delivery distance and fuel cost per kilometer, reflecting routing efficiency and vehicle utilization. Inventory holding cost is formulated as a linear function of inventory levels at each warehouse over the planning horizon. This integrated structure explicitly captures the trade-off between shipment frequency and inventory accumulation, which is fundamental to VMI-based coordination.

Given the NP-hard nature of the problem, the optimization was performed with a computational time limit of 21,600 seconds (6 hours) to ensure practical solvability. The solver achieved a final relative MIP gap of 0.00122615, indicating that the solution is very close to the global optimum. The computational process involved 25,143,400 simplex iterations and 2,597,310 branch-and-bound nodes, reflecting the complexity of the integrated inventory–routing problem.

The optimal allocation of products to each warehouse over the 21-period planning horizon is presented in Table 1. The results exhibit relatively stable allocation patterns across periods, indicating balanced inventory positioning and consistent demand fulfilment at each warehouse. Minor variations in allocation quantities reflect adaptive adjustments to demand fluctuations while maintaining inventory levels within capacity and safety stock constraints.

Table 1. Optimal Product Allocation for Each Warehouse per Period

Period	Warehouse A	Warehouse B	Warehouse C
1	4.015	6.266	1.255
2	4.022	5.910	1.258
3	4.015	5.910	1.255
4	4.015	5.910	1.258
5	4.015	5.910	1.275
6	4.027	5.910	1.259
7	4.015	5.915	1.255
8	4.015	5.910	1.257
9	4.030	5.910	1.255
10	4.015	5.910	1.255
11	4.015	5.911	1.255
12	4.015	5.910	1.255
13	4.015	5.910	1.255
14	4.015	5.914	1.255
15	4.015	5.910	1.255
16	4.017	5.910	1.255
17	4.015	5.914	1.255
18	4.015	5.910	1.262
19	4.025	5.910	1.255
20	4.015	5.910	1.263
21	4.015	5.910	1.255

From a cost perspective, the model yields a minimum total logistics cost of IDR 2,443,958,775 per month. The decomposition of this cost shows that inventory holding cost accounts for IDR 2,278,328,455, indicating that inventory-related expenses dominate the overall logistics cost structure. This finding highlights the critical role of inventory positioning in determining system-wide efficiency. Transportation cost is estimated at IDR 165,630,320, which, although smaller in proportion, remains sensitive to routing decisions and fuel consumption parameters.

To evaluate the effectiveness of the proposed approach, a benchmark comparison is conducted against the existing replenishment policy, which operates under a decentralized and reactive framework. Under this policy, each warehouse independently determines replenishment quantities based on historical demand without integrated coordination of transportation decisions. The baseline total logistics cost is estimated at IDR 2,735,420,000, reflecting inefficiencies associated with overstock conditions and fragmented shipment planning. The proposed VMI model achieves a cost reduction of approximately 10.66%, primarily driven by improved synchronization between inventory control and transportation decisions. This result demonstrates that centralized coordination can significantly enhance cost efficiency in distribution systems.

In addition to cost performance, service level improvements are observed. Under the existing policy, the average demand fulfilment rate is approximately 91.3%, with stock-out occurrences observed across multiple periods. In contrast, the VMI model achieves a demand fulfilment rate of 99.2%, effectively eliminating stock-out conditions within the planning horizon. These results indicate that cost reduction is achieved alongside substantial improvements in service reliability. The dominance of inventory holding cost suggests that reducing excess inventory and improving allocation accuracy are key drivers of

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performance improvement. At the same time, the relatively stable allocation patterns produced by the model indicate that coordinated planning reduces variability in shipment schedules, leading to more predictable transport operations.

The analysis also highlights the importance of fleet capacity in ensuring system feasibility. Preliminary experiments showed that a smaller fleet size resulted in infeasible solutions, emphasizing that sufficient transport capacity is a prerequisite for effective coordination. This finding provides practical insight for logistics planners, as under-capacity can lead to disrupted delivery schedules and increased operational cost. From a computational standpoint, the model demonstrates that integrated inventory–routing problems can be effectively addressed using exact optimization methods within a bounded computational time. However, scalability remains a consideration for larger networks, suggesting that heuristic or decomposition approaches may be required in future applications.

Finally, while the empirical analysis focuses on road-based automotive distribution, the results provide conceptual insights relevant to broader freight transport systems. Integrated planning approaches such as VMI can support more stable freight flows and improved resource utilization. These insights may be extended to intermodal and port–hinterland logistics systems, although such applications require further empirical validation.

4. Limitations and Future Research

Despite the contributions of this study, several limitations should be acknowledged. First, the model assumes deterministic demand over the planning horizon. While this assumption improves tractability and enables the use of exact optimization methods, it does not fully capture the inherent uncertainty and variability in real-world demand patterns. As a result, the robustness of the solution under stochastic demand conditions is not explicitly evaluated. Second, the model adopts a fixed fleet size configuration. Although the selected fleet size ensures feasibility, it does not explicitly consider fleet sizing as a decision variable. Consequently, the trade-off between transportation cost and fleet investment is not explored, which may limit the model's applicability for strategic-level transport planning.

Third, inventory holding cost parameters are estimated based on literature benchmarks rather than detailed cost accounting data. While this approach provides methodological consistency and practical approximations, it may not fully reflect firm-specific cost structures, potentially affecting the precision of cost-related results. Fourth, the study focuses on a single-echelon upstream distribution system, considering only the flow from the manufacturing plant to regional warehouses. Downstream distribution to retailers and multi-echelon interactions are not explicitly modeled, which may overlook additional coordination complexities present in broader supply chain networks.

Future research can address these limitations by extending the model in several directions. Incorporating stochastic or robust optimization approaches would allow the model to account for demand uncertainty and improve solution resilience. Integrating fleet sizing and vehicle utilization decisions into the optimization framework would provide a more comprehensive analysis of transport capacity planning. In addition, future studies may incorporate environmental performance indicators, such as fuel consumption, emissions, or carbon costs, to align logistics optimization with sustainability objectives.

Further extensions could include multi-echelon supply chain structures, dynamic demand patterns, and real-time decision-making frameworks. From a broader perspective, applying the proposed model to intermodal and maritime logistics contexts such as port hinterland coordination would provide valuable insights into its applicability across different freight transport systems.

5. Conclusions

This study addresses the challenge of coordinating inventory and transportation decisions in an upstream automotive distribution system by developing an integrated Vendor-Managed Inventory (VMI) model formulated as a mixed-integer linear programming (MILP) problem. The motivation for this research stems from the operational inefficiencies observed in decentralized replenishment systems, where fragmented decision-making often leads to excess inventory, stock-out risk, and suboptimal

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transport utilization.

The results demonstrate that centralized coordination through the proposed VMI framework provides a structured and effective mechanism for aligning shipment planning with inventory control. The model achieves a near-optimal solution within a practical computational time and generates a minimum total logistics cost of IDR 2,443,958,775 per month. Compared to the existing replenishment policy, the proposed approach yields a significant cost reduction and substantially improves service performance, as reflected in higher demand fulfilment rates and the elimination of stock-out occurrences.

A key finding is that inventory holding cost constitutes the dominant portion of total logistics cost, indicating that improvements in inventory positioning and replenishment timing are critical drivers of overall system efficiency. At the same time, the results highlight the importance of adequate transport capacity in ensuring feasibility and maintaining service continuity, emphasizing the interdependence between inventory decisions and transportation resources.

From a managerial perspective, the study provides practical insights into how integrated optimization can support tactical decision-making in logistics systems. The proposed framework enables more stable allocation patterns, reduces variability in shipment schedules, and enhances coordination across supply chain entities. These improvements contribute not only to cost efficiency but also to more reliable and predictable freight operations. Overall, this study demonstrates that the integration of inventory and transportation decisions within a VMI framework offers a robust analytical foundation for improving supply chain coordination. The findings reinforce the value of optimization-based approaches in addressing complex logistics problems and provide a basis for extending such models to broader and more dynamic distribution environments

Conflict of Interest declaration: This research has no affiliations with or involvement in any organization or entity with any financial interest in the subject matter or materials discussed in this manuscript.

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