A BILEVEL PROGRAMMING APPROACH IN A SUPPLY HUB IN INDUSTRIAL PARK (SHIP)

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ABSTRACT
A Supply Hub in Industrial Park (SHIP) gains revenue from leasing space. Important questions faced by the SHIP and each manufacturer within the same industrial park are: how to price space considering manufacturers’ responses, and how to replenish raw materials from the SHIP and deliver finished products to the SHIP in response to SHIP’s storage pricing strategy. This paper discusses how SHIP and manufacturers interact to optimize their decisions on storage pricing, replenishment and delivery. A dynamic storage pricing strategy depending on the length of storage is adopted. A bi-level program is proposed to model this problem. A numerical study is conducted to examine the influences of major parameters.
1 INTRODUCTION

A Supply hub in Industrial park (SHIP) is defined as a public provider of warehousing and logistics services for manufacturing enterprises within an industrial park [1]. With the application of SHIP, all enterprises share the storage space at SHIP for storing both raw materials and finished products without their own warehouses for holding inventories at. This paper considers a supply chain consisting of one SHIP and multiple manufacturers within an industrial park. The SHIP, via charging a storage price, leases space to all manufacturers. Alternatively, manufacturers could rent space from a public warehouse (PW) outside the industrial park. To facilitate the problem description, one manufacturer is taken for instance. The manufacturer first orders raw materials from outside suppliers based on the “lot-for-lot” policy. The raw materials are stored either solely at SHIP or both at SHIP and PW, and are then replenished to the manufacturer in equal quantity and equal intervals of time. The manufacturer converts raw materials into a single type of finished products, and delivers the fixed quantities to SHIP or PW at a fixed-time interval. Finally, finished products are dispatched to the outside buyer for satisfying the demands. After one shipment to the buyer, the manufacturer plans for the next production, and the working process described above repeats in the next production run. The distribution of finished products to the buyer is periodic at a fixed-time interval. The whole operation process is the same for other manufacturers.

According to SHIP’s operation mode [1], its revenue comes mostly from leasing storage space. It is natural that the SHIP attempts to establish a storage pricing strategy to attain the maximum possible profit. Setting an exorbitant storage price may discourage manufacturers from renting space from SHIP, and thus result in large amount of wasted storage capacities. Hence, which storage pricing strategy to adopt is an important question faced by the SHIP. In response to the storage price, manufacturers within the same industrial park enjoy the rights to determine what replenishment policy of raw materials to apply, and which storage site finished products are delivered to. Therefore, it is practical for each of them to give optimal decisions on both replenishment and delivery in order to minimize the individual cost.

The literature dealing with the pricing strategies of storage space is scarce. Castilho and Daganzo [2] pioneer the study on storage pricing through addressing a pricing problem for temporary storage facilities at ports. Later works [3]-[5] are all conducted on pricing strategies for storing inbound containers in a container yard for the purpose of gaining efficient utilization of the storage space in a container terminal. To authors’ best knowledge, to authors’ best knowledge, there has been hardly any research done on the storage pricing strategy of SHIP.

The problems confronted by the SHIP and manufacturers, and the shortfall of literature on storage pricing strategy motivate the study in this paper. This paper aims at exploring how the SHIP and manufacturers in the same industrial park interact with each other to optimize SHIP’s profit and manufacturer’s individual cost by adjusting the storage pricing strategy, replenishment schedules of raw materials, and delivery schedules of finished products. In this supply chain, individual manufacturers are independent enterprises and the SHIP is operated by a third-party logistics provider [1]. Hence, they have their own objectives and make decisions based on their own interests. However, the decisions of SHIP and manufacturers would impact each other’s interests in the sense that they share parameters in making optimal decisions. Therefore, the SHIP and manufacturers optimize their own objectives whilst still considering the choice of the other. Such characteristics motivate the application of bilevel programming [6]-[7] for modelling the supply chain. As SHIP serves as the only public service provider in an industrial park, it is treated as the leader, and each manufacturer as a follower. The SHIP first announces the storage pricing strategy. In response to the pricing strategy of storage space, each manufacturer decides the number of
replenishments from the SHIP and that of deliveries to the SHIP, while minimizing its overall cost.

Following the strategy on pricing space in container terminals proposed in the literature, this paper adopts a dynamic storage pricing strategy where the price is charged based on the length of storage. This is due to two reasons. First, in practice, the adoption of such dynamic storage pricing strategy is win-win for the SHIP and manufacturers. Via charging a higher price for longer storage time, the strategy induces manufacturers to store products at SHIP in short-term, namely, the turnover frequency at SHIP is increased. Hence, SHIP could gain external profits from providing logistics services. As for manufacturers, such strategy could indirectly improve their inventory turnover rates, resulting in less working capital [8]. Second, as SHIP’s capacity is limited, long-term storage of items from some manufacturers may hamper the use of space by others. Such dynamic storage pricing is able to guarantee that SHIP has enough space to provide public services to all manufacturers.

The paper is organized as follows. Section 2 develops the bilevel programming model. Section 3 provides a numerical study for examining the impacts of major parameters. Finally, Section 4 concludes the paper.

2 THE BILEVEL PROGRAMMING MODEL

In this section, the above described storage pricing - replenishment / delivery problem is formulated as a bilevel programming model. The proposed bilevel model is based on the following assumptions. (1) The supply chain system operates for a finite horizon \([0, T]\). (2) The capacity of SHIP is limited, but sufficient enough to satisfy all manufacturers’ space requirements. (3) The capacity of PW is unlimited. (4) One unit of goods occupies one unit of storage space at both SHIP and PW. (5) There is an ample stock of raw materials at outside suppliers, and the replenishments of raw materials are instantaneous. (6) The production rate of each manufacturer is finite and constant, and greater than any demand in the planning horizon. (7) Shortages are not allowed. (8) Delivery time is negligible. (9) No stock is held at the beginning and the end of the planning horizon. The demands of finished products from buyers are generated by \(\mu + a \sin(2\pi \cdot t/T)\), where \(\mu\) is the mean demand; \(a\) stands for the amplitude of the seasonal component; and \(T\) is the length of the seasonal cycle. (9) Homogeneous vehicles with limited capacity are used for transporting raw materials and finished products, and the number of available vehicles is infinite. (10) The capacity of each common vehicle is no less than the replenishment or delivery quantity.

The notations to be used are listed as follows:

- \(t\) index of time period, \(t=0,1,...,T\)
- \(i\) index of finished product and manufacturer \((i=1,...,I);\) manufacturer \(i\) produces finished product \(i\)
- \(r\) index of raw material \((r=1,...,R)\)
- \(CSF\) storage capacity of SHIP for finished products (units)
- \(CSR\) storage capacity of SHIP for raw materials (units)
- \(MP\) storage price charged by PW ($/unit/time)
- \(HS\) holding cost rate of products at SHIP ($/unit/time)
- \(KS\) delivery cost charged by the SHIP per delivery ($/delivery)
- \(KP\) delivery cost charged by the PW per delivery ($/delivery) \((KP>KS)\)
- \(f_{ir}\) quantity of raw material \(r\)'s replenishment at manufacturer \(i\) in \(j\)th production cycle
- \(P_i\) Production rate for manufacturer \(i\) (units/time)
- \(NR_{ijr}\) number of raw material \(r\)’s replenishment at manufacturer \(i\) in \(j\)th production cycle
- \(ND_{ir}\) number of finished product’s deliveries in \(j\)th production cycle of manufacturer \(i\)
- \(L_i\) shipment interval of finished product \(i\) to the buyers over the planning horizon
2.1 SHIP’s Model

The objective of SHIP is to decide the appropriate storage pricing strategy so that its total profit is maximized. The SHIP’s profit is equivalent to the total revenue minus the total cost. Under the dynamic storage pricing strategy, the storage charge depends on the length of storage time. A basic storage price \( B \) per unit per period is charged for storing within a fixed time period \( F \), and the storage price increases at the rate of \( S \) only when the length of storage time exceeds \( F \). \( B \), \( F \) and \( S \) are SHIP’s decision variables. The dynamic storage price function at SHIP is thus formulated as:

\[
SP(t) = \begin{cases} 
B & 0 < t \leq F \\
B + S \cdot (t - F) & t > F 
\end{cases} \tag{1}
\]

As aforementioned, a public warehouse (PW) outside the industrial park, in which a constant storage price \( MP \) is charged, is an alternative storage site for manufacturers to store finished products. Therefore, in order to improve the utilization of storage space at SHIP, the basic storage price \( B \) should be set smaller than \( MP \).

With the above notations and definitions, the objective function of SHIP is formulated as:

\[
\text{Maximize } PF(B, F, S) = \sum_{i=1}^{I} \left( \sum_{r=1}^{R} \sum_{j=1}^{J} \left( \frac{OB_{ij}}{NR_{ij}} \right) \cdot \left( \prod_{c=1}^{NRS_{ij}-1} \left( \int_{0}^{TP_{ij}} \left( \int_{0}^{SP(t)} dt \right) dt \right) \right) 
+ \sum_{i=1}^{I} \left( \sum_{j=1}^{J} \left( \frac{OB_{ij}}{ND_{ij}} \right) \cdot \left( \prod_{c=1}^{NDS_{ij}-1} \left( \int_{0}^{TP_{ij}} \left( \int_{0}^{SP(t)} dt \right) dt \right) \right) \right) \right)
\] \tag{2}

(3)
\[ + \sum_{i=1}^{I} \sum_{r=1}^{R} \sum_{j=1}^{J} (NRS_{ijr} \cdot KS) \]  
\[ + \sum_{i=1}^{I} \sum_{j=1}^{J} (NDS_{ij} \cdot KS) \]  
\[ - \sum_{i=1}^{I} \sum_{r=1}^{R} \sum_{j=1}^{J} HS \cdot \left( \frac{OB_{ij} f_{ijr}}{PNR_{ijr}} \right) \cdot \left( \frac{NRS_{ijr} - 1}{2} \right) \cdot NRS_{ijr} \]  
\[ - \sum_{i=1}^{I} \sum_{j=1}^{J} HS \cdot \left( \frac{OB_{ij}^2}{PND_{ij}} \right) \cdot \left( \frac{NDS_{ij} - 1}{2} \right) \cdot NDS_{ij} \]  

Subject to:
\[ 0 < F < T ; \]  
\[ 0 < B < MP ; \]  
\[ S > 0 \]  

The objective function is comprised of six components: the total storage charge of raw materials \(2\) and finished products \(3\) at SHIP, the total delivery charge for replenishing raw materials \(4\) and delivering finished products \(5\), and the total inventory holding cost of raw materials \(6\) and finished products \(7\) at SHIP. Constraints \(8\), \(9\) and \(10\) show the domain of \(F\), \(B\) and \(S\).

2.2 Manufacturers’ Model

The objective of each manufacturer is to minimize its total cost. Each manufacturer decides on the replenishment and delivery decisions, which are represented by two decision variables: \(NRS_{ijr} (j = 1, ..., J, r = 1, ..., R)\) and \(NDS_{ij} (j = 1, ..., J)\). \(NRS_{ijr}\) denotes the number of raw material \(r\)'s replenishment from SHIP in production cycle \(j\) of manufacturer \(i\), and \(NDS_{ij}\) represents the number of finished product's deliveries to SHIP in production cycle \(j\) of manufacturer \(i\).

With the above notations and definitions, the objective function of manufacturer \(i\) is formulated as:

Minimize \(TCM_i(NRS_{ijr}, NDS_{ij}) = \sum_{r=1}^{R} \sum_{j=1}^{J} \left( OB_{ijr} \cdot NRS_{ijr} \right) \cdot \left( \sum_{c=1}^{NRS_{ijr} - 1} \left( \frac{TP_i}{NRS_{ijr}} \right)SP(t)dt \right)\)  
\[ + \sum_{j=1}^{J} \left( OB_{ij} \cdot NDS_{ij} \right) \cdot \left( \sum_{c=1}^{NDS_{ij} - 1} \left( \frac{TP_i}{NDS_{ij}} \right)SP(t)dt \right)\]  
\[ + \sum_{r=1}^{R} \sum_{j=1}^{J} NRS_{ijr} \cdot KS\]  
\[ + \sum_{j=1}^{J} NDS_{ij} \cdot KS \]  

31-5
\[ \text{(15)} \]
\[
+ \sum_{j=1}^{S} \sum_{i=1}^{J} MP \cdot \left( \frac{OB_{ij} \cdot TP_{ij}^2}{NR_{ij}^2} \right) \left( NRS_{ij} - 1 \right) \left( NR_{ij} - NRS_{ij} \right) \]
\[
+ \sum_{j=1}^{S} MP \cdot \left( \frac{OB_{ij} \cdot TP_{ij}^2}{ND_{ij}^2} \right) \left( NDS_{ij} - 1 \right) \left( ND_{ij} - NDS_{ij} \right) \]  
\[(16)\]
\[
+ \sum_{j=1}^{S} \sum_{i=1}^{J} (NR_{ij} - NRS_{ij}) \cdot KP \]  
\[(17)\]
\[
+ \sum_{j=1}^{S} (ND_{ij} - NDS_{ij}) \cdot KP \]  
\[(18)\]

Subject to:
\[
1 \leq NDS_{ij} \leq ND_{ij} \]  
\[(19)\]
\[
1 \leq NRS_{ij} \leq NR_{ij} \]  
\[(20)\]
\[NRS_{ij} \text{ and } NDS_{ij} \in \text{integers.} \]  
\[(21)\]

The objective function is comprised of eight components: the rent of storage space for storing raw materials (11) and finished products (12) at SHIP, the delivery cost of replenishing raw materials from SHIP (13) and delivering finished products to the SHIP (14), the rent of storage space for storing raw materials (15) and finished products (16) at PW, and the delivery cost of replenishing raw materials from PW (17) and delivering finished products to the PW (18). Constraints (19) and (20) show the domain of the number of replenishments and deliveries between manufacturers and the SHIP. Constraint (21) imposes the integer restrictions on the two decision variables.

3 NUMERICAL STUDY

This section presents a numerical example for the proposed bilevel programming model, and analyzes the impact of major cost parameters (KS, KP, and HS).

Here, two manufacturers and two kinds of raw materials are discussed over a season of 365 days. The input parameters for the base example are given as follows: \( MP = 0.5 \) unit/day, \( NR_{i,j} = (90, 109, 117, 109, 90, 67, 47, 40, 47, 67) \), \( HS = 0.2 \) unit/day, \( f_{ir} = 4 \), \( L_i = 36.5 \) days, \( ND_{i,j} = (54, 66, 70, 66, 54, 40, 29, 24, 29, 40) \), \( J_i = 10 \), \( KS = 10 \) delivery, \( KP = 550 \) delivery, \( P_i = 150 \) units/day, \( D_{ij} = 80 + 40 \sin(2\pi \cdot t/365) \), \( CSF = 8588 \) units, \( CSR = 69102 \) units. The initial inventory is assumed to be zero.

3.1 Solution Procedure

In this section, an enumerative algorithm is developed to solve the proposed bilevel model. With regard to the three decision variables of SHIP, this paper assumes that they are chosen from a finite and discrete value set respectively. The sets of \( B \) and \( F \) are indicated by \( \{ B_1, ..., B_N \} \) and \( \{ F_1, ..., F_M \} \) respectively, and the set of \( S \) given the value of \( B \) and \( F \) is denoted by \( \{ S(B, F), ..., S(B, F) \} \). Plenty of research made assumptions on prices as being chosen from a finite and discrete set \([9]-[10]\). In the following experiments, each value set is comprised of three values representing low, medium, and high level of the variable respectively. \( \text{Table 1} \) presents the value sets designed for enumeration in the solution algorithm. The detailed steps of the solution algorithm are summarized as follows:

\[31-6\]
Step 1: Set \( n = 1 \);
Step 2: Set \( B = B_n \);
Step 3: Set \( n = 1 \);
Step 4: Set \( F = F_m \);
Step 5: Set \( l = 1 \);
Step 6: Set \( S = S_i(B, F) \);
Step 7: For each manufacturer \( i \), calculate \( NDS_{i,j}^* \), \( NRS_{i,j}^* \) with given \( B \), \( F \) and \( S \) by enumerating from 1 to \( NR_{i,j} \) and from 1 to \( ND_{i,j} \) respectively;
Step 8: Calculate \( PF(B, F, S) \) with \( NRS_{i,j}^* \) and \( NDS_{i,j}^* \) obtained from Step 7;
Step 9: If \( l < L \), set \( l = l + 1 \) and go to Step 6; otherwise, go to Step 10;
Step 10: If \( m < M \), set \( m = m + 1 \) and go to Step 4; otherwise, go to Step 11;
Step 11: If \( n < N \), set \( n = n + 1 \) and go to Step 2; otherwise, go to Step 12;
Step 12: Get the minimum value of \( PF \) for all \( n \), \( m \), and \( l \), and obtain \( PF^* \), and the corresponding \( B^*, F^*, S^*, NRS_{i,j}^* \), and \( NDS_{i,j}^* \).

### Table 1: The Value Sets Of SHIP's Decision Variables

<table>
<thead>
<tr>
<th>( B ) ($/unit/day)</th>
<th>( F ) (days)</th>
<th>{( S_1, S_2, S_3 )} ($/unit/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.15</td>
<td>1</td>
<td>[0.031, 0.028, 0.025]</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>[0.032, 0.029, 0.026]</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>[0.033, 0.030, 0.027]</td>
</tr>
<tr>
<td>0.25</td>
<td>1</td>
<td>[0.028, 0.023, 0.018]</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>[0.029, 0.025, 0.021]</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>[0.030, 0.027, 0.024]</td>
</tr>
<tr>
<td>0.35</td>
<td>1</td>
<td>[0.025, 0.021, 0.017]</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>[0.026, 0.022, 0.018]</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>[0.027, 0.024, 0.019]</td>
</tr>
</tbody>
</table>

\( \{S_1, S_2, S_3\} \) is the value set of the storage price per unit per unit time after the time-limit (S).

The enumeration method ensures the acquirement of the global optimum of the whole problem. For the illustrative example, the computation is efficient. The CPU running time for all cases is less than 12 seconds on a computer with Intel (R) Core (TM) i5 2.40GHZ processor and 2.00GB RAM.

### 3.2 Sensitivity Analysis

The optimal decisions and performance of the SHIP and each manufacturer along with the sensitivity analysis for \( KS \), \( KP \), and \( HS \) are presented in Table 2. The findings from Table 2 are summarized below.

1. With the increase of \( KS \), \( PF \) decreases slightly, while \( TCM \) first increases slightly and then decreases remarkably. As \( KS \) increases, the SHIP keeps the storage pricing decision stable so as to obtain the maximum possible profit. For instance, \( B \), \( F \), and \( S \) remain at 0.35, 3, and 0.019 respectively as \( KS \) ranges from 5 to 20. Under this condition, less benefit could be obtained by each manufacturer through renting space from SHIP. Hence, the numbers of replenishments and deliveries decrease. This accounts for the moderate decrease and increase of \( PF \) and \( TCM \) respectively. When \( KS \) is high, in order to encourage more space requirements from manufacturers, the SHIP reduces the base price, leading to the dramatic decrease of \( TCM \). Nevertheless, \( PF \) still decreases slightly due to the dominant role played by the reduction of storage price. This finding implies that \( KS \) has little influence on SHIP’s profit. When \( KS \) is significantly high, manufacturers could enjoy remarkable performance improvement.
(2) Both PF and TCM go up with the increase of KP. The increasing rate of TCM is remarkable when KP is low. With the increase of KP, increasingly large expenses have to be spent on hiring PW. In this situation, SHIP is enabled to raise its storage price while ensuring sufficiently large space requirements from manufacturers. Therefore, PF increases with KP. When KP is low, the increase of KP enables the SHIP to raise the base price. The change of storage pricing decision discourages manufacturers from renting space from SHIP. This is the reason for the dramatic increase of TCM. When the value of KP is significantly large, SHIP makes minor changes to its storage pricing decision by reducing F and S while keeping B remain at origin. As a consequence, TCM increases moderately with KP. This observation implies that the higher KP, the greater profit could be gained by the SHIP. Manufacturers’ cost performance would be considerably improved when KP is significantly low.

(3) With the increase of HS, PF decreases drastically, and TCM first increases significantly and then keeps approximately unchanged. For the sake of dealing with the higher inventory holding cost rate, the SHIP raises its storage price to obtain the maximum possible profit. However, PF still decrease with the increase of HS because of the dominant role played by the increase of total inventory holding cost in SHIP’s total profit. When HS is low, the increase of base price with the increase of HS discourages manufacturers from leasing SHIP’s storage space. Consequently, the space requirements to the SHIP decrease sharply, resulting in the considerable increase of TCM. When the value of HS is significant large, the SHIP makes minor changes to the storage pricing decision by reducing both the F and S, which accounts for the decrease of the storage space rented from SHIP and hence the slight increase of TCM. This finding implies that SHIP would make more profit when HS is low. The higher HS, the higher storage price would manufacturers suffer from. Manufacturers would achieve substantial cost savings under significantly low HS.

Table 2: Impact Of Major Cost Parameters On The Decisions And Performance Of SHIP And Each Manufacturer

<table>
<thead>
<tr>
<th>Parameters</th>
<th>B</th>
<th>F</th>
<th>S*</th>
<th>NDSi</th>
<th>NRSi,r</th>
<th>PF</th>
<th>TCM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base case</td>
<td>0.35</td>
<td>3</td>
<td>0.019</td>
<td>(90,91,92,91,90,67,47,40,47,67)</td>
<td>(54,59,59,59,54,40,29,24,29,40)</td>
<td>3357383.29</td>
<td>1280961.38</td>
</tr>
<tr>
<td>5</td>
<td>0.35</td>
<td>3</td>
<td>0.019</td>
<td>(90,92,92,92,90,67,47,40,47,67)</td>
<td>(54,60,60,60,54,40,29,24,29,40)</td>
<td>3395319.88</td>
<td>1271490.03</td>
</tr>
<tr>
<td>KS 15</td>
<td>0.35</td>
<td>3</td>
<td>0.019</td>
<td>(90,91,92,91,90,67,47,40,47,67)</td>
<td>(54,59,59,59,54,40,29,24,29,40)</td>
<td>3324856.56</td>
<td>1290407.01</td>
</tr>
<tr>
<td>20</td>
<td>0.35</td>
<td>3</td>
<td>0.019</td>
<td>(90,90,90,90,90,67,47,40,47,67)</td>
<td>(54,58,57,58,54,40,29,24,29,40)</td>
<td>3315579.85</td>
<td>1299817.40</td>
</tr>
<tr>
<td>25</td>
<td>0.25</td>
<td>3</td>
<td>0.019</td>
<td>(90,109,114,109,90,67,47,40,47,67)</td>
<td>(54,66,70,66,54,40,29,24,29,40)</td>
<td>3311613.75</td>
<td>1117566.71</td>
</tr>
<tr>
<td>25</td>
<td>0.35</td>
<td>3</td>
<td>0.019</td>
<td>(90,109,117,109,90,67,47,40,47,67)</td>
<td>(54,66,70,66,54,40,29,24,29,40)</td>
<td>3238260.35</td>
<td>1080063.98</td>
</tr>
<tr>
<td>KP 75</td>
<td>0.35</td>
<td>2</td>
<td>0.018</td>
<td>(90,91,92,91,90,67,47,40,47,67)</td>
<td>(54,61,62,61,54,40,29,24,29,40)</td>
<td>3582563.97</td>
<td>1306556.65</td>
</tr>
<tr>
<td>100</td>
<td>0.35</td>
<td>2</td>
<td>0.018</td>
<td>(90,94,95,94,90,67,47,40,47,67)</td>
<td>(54,65,65,65,54,40,29,24,29,40)</td>
<td>3801452.41</td>
<td>1309702.74</td>
</tr>
<tr>
<td>125</td>
<td>0.35</td>
<td>1</td>
<td>0.017</td>
<td>(90,95,94,95,90,67,47,40,47,67)</td>
<td>(54,66,67,66,54,40,29,24,29,40)</td>
<td>3973562.63</td>
<td>1335048.51</td>
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<tr>
<td>0.05</td>
<td>0.25</td>
<td>2</td>
<td>0.019</td>
<td>(90,109,116,109,90,67,47,40,47,67)</td>
<td>(54,66,70,66,54,40,29,24,29,40)</td>
<td>4108251.38</td>
<td>1087060.38</td>
</tr>
<tr>
<td>HS 0.125</td>
<td>0.35</td>
<td>3</td>
<td>0.019</td>
<td>(90,91,92,91,90,67,47,40,47,67)</td>
<td>(54,59,59,59,54,40,29,24,29,40)</td>
<td>3707150.88</td>
<td>1280961.38</td>
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<tr>
<td>0.275</td>
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<td>3</td>
<td>0.019</td>
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<td>(54,59,59,59,54,40,29,24,29,40)</td>
<td>3007615.70</td>
<td>1280961.38</td>
</tr>
</tbody>
</table>
4 CONCLUSION

In this paper, a storage pricing - replenishment / delivery problem is investigated in a supply chain where a SHIP and multiple manufacturers interact with each other to determine the optimal storage pricing strategy, replenishment policies of raw materials, and delivery decisions of finished products. A dynamic storage pricing strategy is applied at SHIP where the storage charge is proportional to the length of storage time beyond a fixed time period. This problem is modelled by using the bilevel programming approach with the SHIP as the leader and manufacturers as followers. A numerical study is conducted to examine the influence of the ordering cost of raw materials from external suppliers and the holding cost rate of products at SHIP on the optimal decisions and performance of the SHIP and manufacturers. From the sensitivity analyses, the major findings and managerial implications are observed as follows. First, SHIP’s profit is significantly affected by the variation of the delivery charge of PW and the holding cost rate at SHIP, while little influenced by the change of the delivery charge of SHIP. The higher delivery charge of PW or the lower holding cost rate at SHIP, the more profit could be gained by the SHIP. Second, manufacturers could achieve substantial cost reductions when the delivery charge of SHIP is significantly high, or the delivery charge of PW or the holding cost rate at SHIP is significantly low.

This paper has some limitations which may be extended in future research. Firstly, this paper assumes the same demand and parameters for all manufacturers. Future work could consider heterogeneous manufacturers and examine how the scale of manufacturers influences the relationship between the SHIP and manufacturers. Another interesting extension is to study the situation with dominating manufacturers, which may be formulated by a different game model. Secondly, this paper studies both the proposed dynamic storage pricing strategy and the constant one. It would be of interest to apply the constant or other forms of dynamic storage pricing strategies, and make comparisons between them. Finally, in this paper, manufacturers pay space rents depending on the storage time and units of space rented. It would be of interest to apply another space leasing schema.

5 REFERENCES


