Performance Evaluation of Pallet Rental Companies: A Non-Oriented Super-Efficiency Integer-Valued DEA Model

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ABSTRACT
Pallets play an important role in logistics. It is well known that pallet rental is beneficial to both pallet users and society, and the pallet rental industry is very large nowadays. A non-oriented super-efficiency integer-valued DEA (data envelopment analysis) model for the performance evaluation of pallet rental companies is presented. The method differs from traditional models in that (1) it can be used to accurately estimate the performance of efficient pallet rental companies with integer-valued and real-valued variables; (2) it is an alternative approach to providing numerical super-efficiency scores for efficient pallet rental companies when input-oriented or output-oriented VRS (variable returns to scale) super-efficiency models are infeasible for them. A case study of nine pallet rental companies proves the advantages of the proposed model, and it shows that the efficiency gap among pallet rental companies is very large. Based on the results, some suggestions on the development of the pallet rental industry are proposed. The methodology and results would provide valuable contributions to the decision-making processes of both pallet rental companies and their customers.

INDEX TERMS
DEA, logistics, pallet, integer, efficiency.

I. INTRODUCTION
A pallet is a tool used as a base for the unitization of cargos in logistics. Pallets play an important role in logistics. The global pallet market has been growing steadily since World War II. In 2018, there are about 6.87 billion pallets in the whole world [1]. The total number of pallets in use is about 2.6 billion in the United States, 500 million in Europe Unit, and 1.7 billion in China [2]. The global pallet market is expected to grow at a CAGR (compound annual growth rate) of around 5% and reach a volume of 9.18 billion by 2024 [1], [3].

Pallet rental (also named as pallet pooling) is proposed based on the idea of “sharing and reuse”. It is beneficial to both pallet users and society. Generally speaking, pallet rental is a cost-effective choice for many businesses [4], [5].

By using rental pallets, pallet users (such as manufacturers, distributors, retailers, etc.) can reduce logistics costs and improve logistics efficiency [6]–[9]. Pallet rental also is helpful in reducing carbon dioxide emissions that can adversely affect the environment. Therefore, pallet rental is an environmentally friendly pallet management mode [10]–[13].

Most of pallet rental systems work as follows:
Step 1: Customers order the number of pallets they need from a pallet rental service provider.
Step 2: The pallet rental service provider delivers pallets to its customers.
Step 3: Customers load the pallets with their products and send them to their partners. Their partners use these pallets to transport goods to their partners’ partners. The last user should inform the pallet rental service provider to collect empty pallets. Each user is only responsible for the pallets while they are in its hands.
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II. LITERATURE REVIEW AND PROBLEM DESCRIPTION

Although there is no literature on the performance evaluation of pallet rental companies, it is necessary to review the previous works on DEA and find out what we should do.

DEA models evaluate the distance from a DMU to its projection on the production frontier as its relative efficiency. DMUs should be selected as follows: (1) The numerical data of each input and output of all DMUs should be available and positive; (2) Chosen items (inputs, outputs, and choice of DMUs) should reflect decision-makers’ will; (3) Smaller input amounts and larger output amounts are more preferable; (4) The measurement units of inputs and outputs may be different [25]. A great number of DEA models have been developed as follows:

1. CRS V.S. VRS. CRS (constant returns to scale) models assume that outputs would change by the same proportion as inputs are changed. VRS (variable returns to scale) models suppose that the production technology may be decreasing, constant or increasing returns to scale. In 1978, Charnes, Cooper, and Rhodes developed the first CRS model [26]. This CRS model was extended by Banker, Charnes, and Cooper to a VRS model in 1984, and the VRS model was named as the BCC model [27].

2. Input-oriented V.S. output-oriented. Input-oriented DEA models are developed to determine how to achieve the optimum inputs to increase the efficiency of an inefficient DMU without changing the level of outputs. In contrast, output-oriented DEA models are configured to determine inefficient DMU’s potential outputs given its inputs if the inefficient DMU operates efficiently as those efficient DMUs. The efficiency scores of DMUs calculated by input-oriented and output-oriented approaches might be different. Hence, the accuracy of ranking obtained from the two approaches is doubtful. Fortunately, the non-oriented approach can overcome this problem. Non-oriented DEA models are developed to figure out how a DMU can move onto the efficient frontier by improving inputs and outputs simultaneously [28], [29].

3. Real-valued V.S. integer-valued. Standard DEA models assume that all input and output variables are real-valued. However, input or output variables may be integer-valued in some cases. Integer-valued DEA models are used to accurately calculate efficiency scores for DMUs with integer-valued input or output variables. Lozano and Villa firstly proposed a mixed integer DEA model [30], [31].

4. Efficiency V.S. super-efficiency. According to conventional DEA models, the efficiency scores of efficient DMUs are equal to 1, while inefficient DMUs are lower than 1. Thus, these conventional DEA models can be used to figure out which DMUs are efficient and rank the inefficient DMUs. But these models cannot be used to rank efficient DMUs if there are more than one efficient DMUs. Andersen and Petersen proposed a super-efficiency DEA model to measure the super-efficiency scores of efficient DMUs [32].
The basic idea of this approach is that the DMU under evaluation should be removed from the reference set [33]. By applying the super-efficiency DEA model, each efficient DMU is given a score that is greater than 1, so the DMU with the greater super-efficiency score can be located at a higher ranking. However, the super-efficiency model may be infeasible for some efficient DMUs under the assumption of VRS [34]. Tone proposed a super-efficiency slack-based measure model to overcome this issue [35]. Based on the two studies, many super-efficiency DEA models have been presented [36], [37].

The performance of pallet rental companies can be expressed as the ratio of useful outputs to total inputs. The inputs include pallets, employees, expenses, warehouses, and so on. And the outputs include revenue, customer satisfaction, and other things. The input variables may be real-valued or integer-valued. For example, the number of pallets and employees should be integer-valued. The reason is that, from the view of efficiency improvement, it is hard to reduce half a pallet or one-fifth of employees. The production technology of pallet rental companies may be decreasing, constant or increasing returns to scale. In order to improve their performance, inefficient pallet rental companies can not only reduce inputs but also increase outputs. Although we can modify existing DEA models to measure the efficiency of pallet rental companies, there may be several efficient companies and it is hard to rank them. Therefore, we have to develop a non-oriented super-efficiency integer-valued DEA model to evaluate the super-efficiency of efficient pallet rental companies.

The performance evaluation framework of pallet rental companies is shown in Fig. 1. The efficiency of pallet rental companies should be measured by applying a standard integer-valued DEA model, and then the super-efficiency of efficient rental companies should be measured by using a super-efficiency integer-valued DEA model. Super-efficiency integer-valued DEA models for pallet rental companies are proposed in Section 3. Standard integer-valued DEA models for pallet rental companies can be transformed from super-efficiency integer-valued DEA models, and the transformation process is shown in Section 4.

III. METHODOLOGY

Suppose each pallet rental company $DMU_i (i = 1, 2, \ldots, q)$ has $p$ inputs $x_{ij} (j = 1, 2, \ldots, p)$ and $m$ outputs $y_{lk} (l = 1, 2, \ldots, m)$. Following Wu and Zhou, Huang et al., and Yan et al., the set of input variables can be represented by $J = J^{NI} \cup J^I$, where the subset $J^{NI}$ is real-valued and $J^I$ is restricted to integer values [38]–[40]. $J^{NI}$ and $J^I$ are disjoint. The input variables can be partitioned in which $x_{ij} \in J^{NI} (j = 1, 2, \ldots, n)$ are real-valued inputs, while $x_{ij} \in J^I (j = n + 1, n + 2, \ldots, p)$ are integer-valued inputs.

Although our goal is to propose a non-oriented super-efficiency integer-valued DEA model, input-oriented and output-oriented integer-valued DEA models also are proposed. The reason is that some companies may only want to increase outputs because they cannot contract inputs (for example, a new company does not want to decrease pallets because they are brand-new), while some companies may only want to decrease inputs because they have no idea how to increase outputs (for instance, a company has to decrease inputs because the market is full and there is no clue how to increase revenue).

A. INPUT-ORIENTED AND OUTPUT-ORIENTED SUPER-EFFICIENCY INTEGER-VALUED DEA MODELS

Following previous researches on super-efficiency and integer-valued DEA models, the input-oriented super-efficiency integer-valued DEA model (IS-DEA) for the performance evaluation of $DMU_k$ can be represented by model (1).

In the model (1), $\varepsilon$ is a non-Archimedean infinitesimal. $\lambda_i$ is the weight of $DMU_i$; $\bar{x}_{jk}$ ($j = n + 1, n + 2, \ldots, p$) are targets for integer-valued inputs; and $s_{-i}, s_{-i}^+, s_{+i}^-$ respectively are slacks of real-valued inputs, integer-valued inputs, and outputs.

From the perspective of input-orientation, the super-efficiency score of $DMU_k$ is the optimal objective function value $\delta_k^*$ of model (1). The greater the super-efficiency value $\delta_k^*$, the greater the performance of the DMU. It is similar to the standard input-oriented BCC model (I-BCC) [27].

Different from conventional integer-valued DEA models, the $DMU_k$ under evaluation is removed from the reference set when the IS-DEA model is employed.

Infeasibility of the IS-DEA model occurs when

\[
\sum_{j=1, i
\neq k} y_{lj} \lambda_i \geq y_{lk} \quad \text{does not hold for any } \lambda_i \text{ with } \sum_{j=1, i
\neq k} \lambda_i = 1 \text{ and } \lambda_i \geq 0\ [34].
\]

Thus, it is the obvious thing to get Proposition 1.

Proposition 1: IS-DEA model is infeasible while the DMU under evaluation has the greatest values of outputs in
all DMUs.

\[
\min \delta_k = \theta_k - \varepsilon \left( \sum_{i=1}^{m} s_i^+ + \sum_{j=1}^{p} s_j^- + \sum_{j=n+1}^{p} s_j^- \right)
\]

\[
st \sum_{i=1,i\neq k}^{q} y_{il} \lambda_i - s_i^+ = y_{lk}, \quad l = 1, 2, \ldots, m
\]

\[
\sum_{i=1,i\neq k}^{q} x_{ji} \lambda_i + s_j^- = \theta_k x_{jk}, \quad j = 1, 2, \ldots, n
\]

\[
\sum_{i=1,i\neq k}^{q} x_{ji} \lambda_i + s_j^- = \bar{x}_{jk}, \quad j = n + 1, n + 2, \ldots, p
\]

\[
\sum_{i=1,i\neq k}^{q} \lambda_i = 1
\]

\[
\lambda_i \geq 0, \quad i = 1, 2, \ldots, q
\]

\[
\eta_k \geq 0
\]

\[
s_j^- \geq 0, \quad j = 1, 2, \ldots, p
\]

\[
s_j^- \geq 0, \quad j = n + 1, n + 2, \ldots, p
\]

\[
s_j^+ \geq 0, \quad l = 1, 2, \ldots, m
\]

\[
\bar{x}_{jk} \in J^l, \quad j = n + 1, n + 2, \ldots, p
\]

**B. NON-ORIENTED SUPER-EFFICIENCY INTEGER-VALUED DEA MODEL**

Any data set must contain a DMU with the largest outputs and a DMU with the smallest outputs, so IS-IDEA and OS-IDEA models must be infeasible for these efficient DMUs [35]. In order to solve this problem, we have to propose a non-oriented super-efficiency integer-valued DEA model (NS-IDEA). The constraints of 0 \( \leq \beta_k \leq 1 \) and \( \alpha_k \geq 1 \) in model (3) are used to make sure that outputs can only be decreased and inputs can only be increased, because the efficient DMU under evaluation should increase inputs or decrease outputs to move onto the efficient frontier generalized by the other DMUs.

The super-efficiency score of \( DMU_k \) is the optimal objective function value \( \psi_k^* \) of model (3). It is obvious that the greater the super-efficiency value \( \psi_k^* \), the greater the performance of the DMU.

\[
\min \psi_k = \frac{\alpha_k}{\beta_k} - \varepsilon \left( \sum_{i=1}^{m} s_i^+ + \sum_{j=1}^{p} s_j^- + \sum_{j=n+1}^{p} s_j^- \right)
\]

\[
st \sum_{i=1,i\neq k}^{q} y_{il} \lambda_i - s_i^+ = \beta_k y_{lk}, \quad l = 1, 2, \ldots, m
\]

\[
\sum_{i=1,i\neq k}^{q} x_{ji} \lambda_i + s_j^- = \alpha_k x_{jk}, \quad j = 1, 2, \ldots, n
\]

\[
\sum_{i=1,i\neq k}^{q} x_{ji} \lambda_i + s_j^- = \bar{x}_{jk}, \quad j = n + 1, n + 2, \ldots, p
\]

\[
\sum_{i=1,i\neq k}^{q} \lambda_i = 1
\]

\[
\lambda_i \geq 0, \quad i = 1, 2, \ldots, q
\]

\[
0 \leq \beta_k \leq 1
\]

\[
\alpha_k \geq 1
\]

\[
s_j^- \geq 0, \quad j = 1, 2, \ldots, p
\]

\[
s_j^- \geq 0, \quad j = n + 1, n + 2, \ldots, p
\]

\[
s_j^+ \geq 0, \quad l = 1, 2, \ldots, m
\]

\[
\bar{x}_{jk} \in J^l, \quad j = n + 1, n + 2, \ldots, p
\]
Proposition 3: The NS-IDEA model is always feasible.

Proof: For an DMU_k = (x_{jk}, y_{ik}), \{\alpha_k = \max \{x_{ij}\}/\min \{y_{i1}\}, \beta_k = \min \{y_{i1}\}/\max \{y_{i1}\}\} is always a feasible solution to model (3).

Proposition 4: The super-efficiency score obtained from the NS-IDEA model is greater than 1 if and only if the DMU under evaluation is efficient.

Proposition 5: The super-efficiency score obtained from the NS-IDEA model is not greater than 1 if and only if the DMU under evaluation is inefficient.

Proof: Suppose \psi_k^* > 1 and DMU_k is inefficient. DMU_k is inefficient, so model (1) and model (2) respectively provide 0 < \theta_k^* \leq 1 and \eta_k^* \geq 1. And [\alpha_k = 1, \beta_k = 1] must be a feasible solution to model (3). Thus, the optimal solution to model (3) must satisfy \alpha_k^* = 1 and \beta_k^* = 1, which indicates that \psi_k^* \leq 1. It is worth noting that \epsilon also is a non-Archimedean infinitesimal in model (3). The assumption is not valid. This proves that the super-efficiency score obtained from model (3) is greater than 1 only if the DMU under evaluation is efficient.

Suppose DMU_k is efficient and \psi_k^* \leq 1. Because \psi_k^* \leq 1 and the constraints of 0 \leq \beta_k \leq 1 and \alpha_k \geq 1, there must be \alpha_k^* = 1, \alpha_k^* = 1, and \beta_k^* = 1. This indicates that \theta_k^* = 1 and \eta_k^* = 1 are feasible solutions to models (1) and model (2), respectively. DMU_k exhibits inefficient. The assumption is not valid.

Proposition 4 is proved.

Because we have Proposition 4, Proposition 5 is valid.

The objective function of model (3) is nonlinear, so it is hard to solve the model. Following Wu and Zhou [38], we let \gamma_k = \alpha_k^* \beta_k^* t_k = \frac{1}{\beta_k^*} and model (3) can be transformed into model (4).

\[
\begin{align*}
\min \psi_k &= \gamma_k - \epsilon \left( \sum_{i=1}^{m} s_i^+ + \sum_{j=1}^{p} s_j^+ + \sum_{j=n+1}^{Q} s_j^- \right) \\
st \sum_{i=1, i \neq k}^{q} y_{ij} h_i - s_i^+ &= y_{ik}, \ i = 1, 2, \ldots, m \\
\sum_{i=1, i \neq k}^{q} x_{ij} h_i + s_j^- &= \gamma_k x_{jk}, \ j = 1, 2, \ldots, n \\
\sum_{i=1, i \neq k}^{q} x_{ij} h_i + s_j^- &= \bar{x}_j t_k, \ j = n + 1, n + 2, \ldots, p \\
\gamma_k x_{jk} - s_j^- &= \bar{x}_j t_k, \ j = n + 1, n + 2, \ldots, p \\
\sum_{i=1, i \neq k}^{q} h_i &= t_k \\
h_i \geq 0, \ i = 1, 2, \ldots, q \\
\gamma_k \geq 1 \\
t_k \geq 1 \\
\gamma_k \geq t_k \\
s_j^- \geq 0, \ j = 1, 2, \ldots, p \\
s_j^- \geq 0, \ j = n + 1, n + 2, \ldots, p \\
s_j^- \geq 0, \ l = 1, 2, \ldots, m \\
\bar{x}_j \in J^l, \ j = n + 1, n + 2, \ldots, p 
\end{align*}
\]

We also name model (4) as a non-oriented super-efficiency integer-valued DEA model (NS-IDEA). When we mention the NS-IDEA model later, we refer to this model.

Note that it is needed the constraint of \gamma_k \geq t_k in model (4) because we have 0 \leq \beta_k \leq 1 and \alpha_k \geq 1 in model (3). If we don’t add this constraint in model (4), there may be \gamma_k < t_k in the case of \beta_k < \alpha_k < 1. If \beta_k < \alpha_k < 1, the constraints of t_k = \frac{1}{\beta_k} \geq 1 and \gamma_k = \frac{\alpha_k}{\beta_k} \geq 1 in model (4) are satisfied, but the constraint of \alpha_k \geq t_k in model (3) is not satisfied.

Model (4) also is a non-linear programming model. In order to solve the model, we have to let t_k = 1 + (\lambda - 1) t and \psi_k^* = \min \psi_k^*(t_k). \lambda is the number of iterations and \epsilon is a small positive number. Of course, the super-efficiency score of DMU_k is the optimal objective function value \psi_k^* of the model (4). The greater the efficiency value \psi_k^*, the greater the performance of the DMU. The Proposition 3, Proposition 4, and Proposition 5 are valid for model (4).

IV. CASE STUDY

The proposed model is applied to measure the performance of pallet rental companies in 2018.

Pallet rental industry data are generally not publicly available [4]. As shown in Table 1, we have studied several well-known pallet rental service providers in the United States, European Union, Japan, Korea, Philippines, Australia, and China.

We take four steps to estimate the performance of the pallet rental industry.

Step 1: Determine the input and output variables and collect data. The input and output variables must be vital for the operation of pallet rental companies.

Step 2: Apply a non-oriented integer-valued DEA model to evaluate the efficiency of pallet rental companies. Based on the results, we rank the inefficient pallet rental companies and

\begin{table}[h]
\centering
\caption{Pallet rental companies.}
\begin{tabular}{|l|l|l|}
\hline
Company & Founded & Website \\
\hline
PECO Pallet & 1997 & www.pecopallet.com \\
intelligent Global Pooling Systems (IGPS) & 2006 & www.igps.net \\
Kamps & 1973 & www.kamps.com \\
Loscam & 1942 & www.loscam.com \\
Commonwealth Handling Equipment Pool (CHEP) & 1945 & www.chep.com \\
H & H Pallet Leasing & 1985 & www.hhwood.com \\
Japan Pallet Rental (JPR) & 1971 & www.jpr.co.jp \\
Nippon Pallet Pool system (NIPPON) & 1972 & www.npp-web.co.jp \\
La Palette Rouge (LPR) & 1992 & www.lpr.eu \\
Demes & 1999 & www.demes-logistics.com \\
Contraload & 2004 & www.contraload.com \\
Pooling Partner & 1997 & www.planetpal.net \\
Korea Pallet Pool (KPP) & 1985 & www.kpp.logisail.co \\
PMR Pallet & 1987 & www.pmrpallet.com \\
\hline
\end{tabular}
\end{table}
TABLE 2. Input and output variables.

| DMU | Output | Input 1 | Input 2 |
|-----|--------|---------|---------|
|     | Annual revenue (million U. S. dollars) | The number of employees | The number of pallets |
| 1   | 85.34  | 239     | 1000000 |
| 2   | 248.60 | 310     | 9200000 |
| 3   | 370.72 | 875     | 4000000 |
| 4   | 226.63 | 284     | 9600000 |
| 5   | 45.21  | 130     | 3000000 |
| 6   | 58.07  | 101     | 3000000 |
| 7   | 75     | 175     | 1000000 |
| 8   | 49.90  | 144     | 8000000 |
| 9   | 313.80 | 109     | 7000000 |
| Average | 163.63 | 263 | 20288888.89 |
| Maximum | 370.72 | 875 | 92000000 |
| Minimum | 45.21 | 101 | 3000000 |
| Standard deviation | 126.81 | 241.69 | 29117024.42 |

Step 3: Apply the NS-IDEA model (model 4) to measure the super-efficiency scores of efficient pallet rental companies, and then we can rank these efficient pallet rental companies.

Step 4: Comment on the results and propose some suggestions on the development of the pallet rental industry.

Note that decision-makers can also do step 3 before step 2. There is no difference between the two approaches.

A. THE DATA

Pallet rental is a complex business. It not only needs pallets as inputs, but also involves other inputs such as capital, warehouses, vehicles, and employees. In our research, the number of employees and the number of pallets are selected as input variables. Employees are important for pallet rental companies. Rental companies with more high-quality talent can provide better services for their customers. To any pallet rental company, pallets are the most important resources. Therefore, the two selected input variables are the most important inputs for pallet rental companies. In this study, annual revenue is selected as the single output variable for pallet rental companies. Revenue (sales) is the amount of money earned by a pallet rental company. Pallet rental companies cannot stay viable in the long run without revenue.

We have obtained nine companies’ information including the number of employees (integer-valued input), the number of pallets (integer-valued input), and annual revenue (real-valued output). All data are collected from official websites of these pallet rental companies, www.reuters.com, www.owler.com, and so on. It is worth noting that decision-makers can use the full-time equivalent (FTE) instead of the number of employees. FTE is a real-valued input, and the proposed model can also be employed. As shown in Table 2, the differences among pallet rental companies are obvious.

B. EFFICIENCY EVALUATION

We can calculate the efficiency scores and target values of the nine pallet rental companies by using a non-oriented integer-valued DEA model (N-IDEA).

In order to propose the N-IDEA model, we should add DMU_k under evaluation into the reference set. For example, the first constraint of model (4) should be modified to

\[
\sum_{i=1}^{q} y_i h_i - s_i^+ = y_k, \quad l = 1, 2, \ldots, m
\]

There is no difference between the two approaches.

\[
\min \Phi_k = y_k - \varepsilon (\sum_{i=1}^{m} s_i^+ + \sum_{j=1}^{n} s_j^- + \sum_{j=n+1}^{p} s_j^-)
\]

\[
st \; \sum_{i=1}^{q} y_i h_i - s_i^+ = y_k, \quad l = 1, 2, \ldots, m
\]

\[
\sum_{i=1}^{q} x_{ij} h_i + s_j^- = y_k x_{jk}, \quad j = 1, 2, \ldots, n
\]

\[
\sum_{i=1}^{q} x_{ij} h_i + s_j^- = \bar{x}_{jk} t_k, \quad j = n+1, n+2, \ldots, p
\]

\[
\gamma_k x_{jk} - s_j^- = \bar{x}_{jk} t_k, \quad j = n+1, n+2, \ldots, p
\]

\[
\sum_{i=1}^{q} h_i = t_k
\]

\[
h_i \geq 0, \quad i = 1, 2, \ldots, q
\]

\[
0 \leq \gamma_k \leq 1
\]

\[
0 \leq t_k \leq 1
\]

\[
\gamma_k \leq t_k
\]

\[
s_j^- \geq 0, \quad j = 1, 2, \ldots, p
\]

\[
s_j^- \geq 0, \quad j = n+1, n+2, \ldots, p
\]

\[
s_j^+ \geq 0, \quad l = 1, 2, \ldots, m
\]

\[
\bar{x}_{jk} \in J^l, \quad j = n+1, n+2, \ldots, p
\]

In fact, we can also employ a modified non-oriented super-efficiency integer-valued DEA model (MNS-IDEA) to evaluate the efficiency of pallet rental companies. We just need respectively use the constraints of \(0 \leq \gamma_k \leq 1, 0 \leq t_k \leq 1, \) and \(\gamma_k \geq t_k\) instead of \(\gamma_k \geq 1, t_k \geq 1, \) and \(\gamma_k \geq t_k\) in model (4). But the MNS-IDEA model is infeasible for efficient DMUs.

The proposed N-IDEA model (model 5) is applied to measure the efficiency of the nine pallet rental companies.

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**Figure out how to improve the performance of these inefficient pallet rental companies.**

**Step 3:** Apply the NS-IDEA model (model 4) to measure the super-efficiency scores of efficient pallet rental companies, and then we can rank these efficient pallet rental companies.

**Step 4:** Comment on the results and propose some suggestions on the development of the pallet rental industry.

Note that decision-makers can also do step 3 before step 2. There is no difference between the two approaches.
And then, we compare the results of the N-IDEA model with MNS-IDEA, I-BCC, and O-BCC models. DEAP software is used to solve I-BCC and O-BCC models, so the efficiency scores of pallet rental companies are not greater than 1.

As can be seen in Table 3, the efficiency scores of these pallet rental companies obtained from the N-IDEA model are not greater than BCC models. The average efficiency score of the nine pallet rental companies is 0.564 (I-BCC 0.738, O-BCC 0.656). The maximum score is 1 (I-BCC 1, O-BCC 1), which is achieved by DMU 3, DMU 6, and DMU 9 (Note that DMU 5 is also regarded as an efficient DMU by the I-BCC model). The minimum score is 0.139 (I-BCC 0.345, O-BCC 0.158) which is achieved by DMU 8 (I-BCC DMU 2, O-BCC DMU 8). As discussed in Section 2, the N-IDEA model is more accurate than I-BCC and O-BCC models because it is non-oriented. Thus, according to the N-IDEA model, three pallet rental companies (DMU 3, DMU 6, and DMU 9) are DEA efficient and they form a production frontier that acts as a benchmarking frontier. DMU 8 is the most inefficient company in the nine companies, and it needs to drastically improve its performance.

The efficiency scores of inefficient pallet rental companies obtained from the MNS-IDEA model are the same as the N-IDEA model. But the MNS-IDEA model is infeasible for efficient DMUs. Therefore, it is better to employ the N-IDEA model to measure the efficiency of pallet rental companies. The ranking of the nine pallet rental companies is presented based on the results.

The inefficient pallet rental companies should catch up with efficient pallet rental companies. In Table 4, the efficiency improvement schemes for inefficient pallet rental companies resulted from the N-IDEA model are given. The results show that there is a huge scope for each inefficient pallet rental company to improve its performance.

As to DMU 1, it can become efficient by decreasing 175 employees and 2600000 pallets and simultaneously increasing 263.90 million dollars in revenue. DMU 4 can become efficient by decreasing 17 employees and 2600000 pallets and simultaneously increasing 87.77 million dollars in revenue. DMU 5 can become efficient by decreasing 29 employees and simultaneously increasing 12.86 million dollars in revenue. DMU 7 can become efficient by decreasing 66 employees and 3000000 pallets and simultaneously increasing 238.80 million dollars in revenue. DMU 8 can become efficient by decreasing 35 employees and 1000000 pallets and simultaneously increasing 263.90 million dollars in revenue.

C. SUPER-EFFICIENCY EVALUATION

Because three pallet rental companies are regarded as efficient companies, it is not possible to make a comparison among these efficient companies by using the N-IDEA model. In order to further measure the performance of the efficient pallet rental companies, the NS-IDEA model (model 4) is employed. We also apply IS-IDEA (model 1) and OS-IDEA (model 2) models to show when they would be infeasible. In this case study, we let $\epsilon = 0.0001$ and the value of $-\lambda$ is from 1 to 1000001. It means that the value of $t_k$ is from 1 to 101. It is enough for this case because the value of $\beta_k = \frac{1}{t_k}$ is not lower than 0.01 according to our analysis (The minimum efficiency score obtained from the OS-IDEA model is 0.158). The results are shown in Table 5. The value of $t_k$ is as follows $t_1 = t_2 = t_4 = t_5 = t_7 = t_8 = 1$, $t_3 = 1.1814$, $t_6 = 1$, $t_9 = 1.3733$.

According to the NS-IDEA model, the performance of DMU 9 is better than DMU 6 and DMU 6 is better than DMU 3. According to the IS-IDEA model, the performance of DMU 9 is better than DMU 6. According to the OS-IDEA model, the performance of DMU 9 is better than DMU 3.

DMU 3 has the largest value of the output variable, so the IS-IDEA model is infeasible for it. Because DMU 6 has the smallest values of input variables, the OS-IDEA model is infeasible for it.

Obviously, the super-efficiency score obtained from the NS-IDEA model is more accurate than IS-IDEA and OS-IDEA models. The NS-IDEA model is able to let the DMU under evaluation move in both directions needed onto the efficient frontier generated by the remaining DMUs. Therefore, the NS-IDEA model is always feasible.

### Table 3. The efficiency scores of pallet rental companies obtained from N-IDEA, MNS-IDEA, I-BCC, and O-BCC models.

| DMU | N-IDEA | Ranking | MNS-IDEA | I-BCC | O-BCC |
|-----|--------|---------|----------|-------|-------|
| 1   | 0.190  | 7       | 0.190    | 0.426 | 0.268 |
| 2   | 0.279  | 6       | 0.279    | 0.345 | 0.756 |
| 3   | 0.525  | infeasible | 0.525    | 0.586 | 0.710 |
| 4   | 0.779  | 4       | 0.779    | 1     | 0.799 |
| 5   | 0.167  | 8       | 0.167    | 0.580 | 0.235 |
| 6   | 0.139  | 9       | 0.139    | 0.701 | 0.158 |
| 7   | 0.139  | 9       | 0.139    | 0.345 | 0.158 |

### Table 4. The efficiency improvement schemes for DMUs resulted from the N-IDEA model.

| DMU | Output | Input 1 | Input 2 |
|-----|--------|---------|---------|
| 1   | 228.46 | -130    | -3000000 |
| 2   | 65.20  | -201    | -8500000 |
| 3   | 87.77  | -175    | -2600000 |
| 4   | 12.86  | -29     | 0        |
| 5   | 238.80 | -66     | -3000000 |
| 6   | 263.90 | -35     | -1000000 |
| 7   | 0      | 0       | 0        |
| 8   | 0      | 0       | 0        |
| 9   | 0      | 0       | 0        |
The super-efficiency score obtained from NS-IDEA, IS-IDEA, and OS-IDEA models.

| DMU | NS-IDEA | IS-IDEA | OS-IDEA |
|-----|---------|---------|---------|
| 1   | 1       | 0.427   | 0.268   |
| 2   | 1       | 0.345   | 0.756   |
| 3   | 1.181   | infeasible | 1.181   |
| 4   | 1       | 0.586   | 0.710   |
| 5   | 1       | 1       | 0.779   |
| 6   | 1.254   | 1.254   | infeasible |
| 7   | 1       | 0.583   | 0.235   |
| 8   | 1       | 0.701   | 0.158   |
| 9   | 3.615   | 5.798   | 4.797   |

The projection on the efficient frontier resulted from NS-IDEA, IS-IDEA, and OS-IDEA models.

| DMU | NS-IDEA | IS-IDEA | OS-IDEA |
|-----|---------|---------|---------|
| 3   | 313.80  | 875, 40000000 | 313.80  |
| 6   | 58.07, 126, 3761904 | 126, 3761904 | - |
| 9   | 228.50, 287, 18431190 | 632, 40587160 | 65.41 |

The performance of the three efficient DMUs from highest to lowest should be DMU 9, DMU 6, and DMU 3. Within the group of efficient pallet rental companies, DMU 9 should be regarded as a super-efficient company.

Table 6 shows the projection of the efficient DMUs on the efficient frontier generated by the remaining DMUs resulted from NS-IDEA, IS-IDEA, and OS-IDEA models. It’s worth noting that the target values of integer variables are integer-valued.

We can calculate the difference between the DMU under evaluation and its projection on the efficient frontier resulted from the NS-IDEA model. Let \( \Delta x_{jk} \) and \( \Delta y_{lk} \) indicate the input difference and output difference between \( DMU_k \) and its projection on the frontier, respectively. They can be calculated by formulas (6), (7), and (8).

\[
\Delta x_{jk} = \frac{x_{jk} - x^*_{jk} - s_{jk}^-}{t_k^+} - \Delta x_{jk}, \quad j = 1, 2, \ldots, n \quad (6)
\]

\[
\Delta x_{jk} = \bar{x}_{jk} - x_{jk}, \quad j = n + 1, n + 2, \ldots, p \quad (7)
\]

\[
\Delta y_{lk} = \frac{y_{lk} - y^*_{lk} - s_{lk}^+}{t_k^+} - y_{lk}, \quad l = 1, 2, \ldots, m \quad (8)
\]

As shown in formulas (9), (10), and (11), we can also calculate the difference between \( DMU_k \) and its efficiency projection on the frontier resulted from IS-IDEA and OS-IDEA models.

\[
\Delta x_{jk} = x_{jk} - x^*_{jk} - s_{jk}, \quad j = 1, 2, \ldots, n \quad (9)
\]

\[
\Delta x_{jk} = \bar{x}_{jk} - x_{jk}, \quad j = n + 1, n + 2, \ldots, p \quad (10)
\]

\[
\Delta y_{lk} = y_{lk} - y^*_{lk} - s_{lk}, \quad l = 1, 2, \ldots, m \quad (11)
\]

The difference between \( DMU_k \) and its efficiency projection on the frontier resulted from NS-IDEA, IS-IDEA, and OS-IDEA models is shown in Table 7.

According to NS-IDEA, IS-IDEA, and OS-IDEA models, each efficient DMU should decrease (expand) one or more of the outputs (or the inputs) to move onto the efficient frontier. The results are the same as Lin and Liu [37]. In other words, input saving or output surpluses exist in efficient pallet rental companies. For instance, according to the NS-IDEA model, DMU 9 generates 85.30 million dollars in revenue more than its projection on the efficient frontier and saves 178 employees and 11431190 pallets. It is obvious that the NS-IDEA model can provide more information than IS-IDEA and OS-IDEA models.

**V. CONCLUSION**

The contribution of this work is in developing a non-oriented super-efficiency integer-valued DEA model. Furthermore, to
our best knowledge, we are the first to build models for measuring the performance of pallet rental companies.

We have collected nine pallet rental companies’ information including the number of employees, the number of pallets, and annual revenue. The proposed model is applied to measure the performance of the nine companies. The results prove the advantages of our model. It is suggested that pallet rental companies should improve their performance on a continuous basis. The non-oriented super-efficiency integer-valued DEA model will be of great help to pallet rental companies. In fact, it will also be beneficial to their customers, because they can decide which pallet rental company to choose based on the performance of pallet rental companies. However, there are still some limitations. For example, in the case study, we only select two input variables and one output variable because there are very few public data about the pallet rental industry. In the future, we will collect more data and measure the performance of pallet rental companies in more detail.

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