Data Envelopment Analysis Model for Assessment of Safety and Security of Intermodal Transportation Facilities

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Abstract: Following September 11, 2001, numerous security policies have been created which have caused a number of unique challenges in planning for transportation networks. Transportation policy and funding to improve the transportation infrastructure has historically been addressed as individual modes not as intermodal transportation. As a consequence of this inopportune allocation, it is now apparent that the transportation modes are disconnected and have unequal levels of security and efficiency. Improved intermodal connectivity has therefore been identified as one of the main challenges to achieve a safer, secure, and productive transportation network. Tools need to be refined for collaboration and consensus building to serve as catalysts for efficient transportation solutions. In this study, a mathematical model using data envelopment analysis (DEA) was developed and investigated to assess the safety and security of intermodal transportation facilities. The model identifies the best and worst performers by assessing several safety and security-related variables. The DEA model can assess the efficiency level of safety and security of intermodal facilities and identify potential solutions for improvement. The DEA methodology presented is general in its framework and can be applied to any network of intermodal transportation systems. Availability of credible data, complemented with DEA methodology will help in management decisions making concrete safety and security decisions for intermodal transportation facilities.

Key words: Intermodal transportation, security, safety, data envelopment analysis (DEA).

1. Introduction

One of the main challenges the federal government is facing regarding the U.S. transportation infrastructure today is the disconnection of transportation modes. Intermodal connectivity has been pointed out as one of the main challenges to achieve a secure, safe, and more productive transportation network. This is also critical to the growth of the American economy. The Department of Transportation’s (DOT) Strategic Plan for FY 2006 – 2011 emphasizes collaboration and intermodal transportation as key factors to achieve an improved transportation structure [1]. It is important to keep the intermodal connections up to date with efficient security systems to ensure a smooth flow of people and goods since both passengers and freight most often are moved by more than one transportation mode from origin to destination. The intermodal facilities emphasized in this study include; airports, seaports, and major train stations.

A mathematical optimization tool, Data Envelopment Analysis (DEA), will be applied in this study to assess the problems linked with the vulnerability and weaknesses of the United States’ intermodal facilities. A DEA model will be
formulated and investigated to address the security and safety operations of intermodal transportation facilities. To demonstrate the capabilities of the model, the authors will identify the relative efficiency of the safety and security systems of selected intermodal transportation facilities in the state of Florida, United States of America. The results will thereafter be analyzed to verify the reliability and limitations of DEA. The goal is to develop an optimization model that management can apply in decision-making regarding safety and security solutions for intermodal facilities and eventually enhance the overall security of the nation’s transportation network.

DEA is a nonparametric method for analyzing and organizing data to measure the relative efficiency of a decision-making unit (DMU). A DMU is a unit of assessment, which is the entity whose efficiency is to be measured compared to other entities of its kind. DEA was first introduced by Charnes, Cooper, and Rhodes in 1978, the CCR model that was an optimization method for measuring relative efficiency by multiple-output/multiple-input cases [2]. They generalized Farrell’s (1957) single-output/input technical-efficiency measure to a multiple-output/multiple-input case by constructing a single “virtual” output to a single “virtual” input relative-efficiency measure. According to Charnes et al. [3] the relative efficiency of any DMU is measured by forming the ratio of a weighted sum of outputs to a weighted sum of inputs, where the weights for both outputs and inputs are to be selected in a manner that calculates the Pareto efficiency measure of each DMU subject to the constraint that no DMU can have a relative efficiency score greater than one. The efficiencies captured by a DEA model are relative because they reflect scope for resource conservation or output augmentation at one unit relative to other comparable benchmark units rather than in some absolute sense. In many practical situations there is a lack of sufficient information to derive the absolute efficiency [4].

Nyquist and Bergsten [5] cited that since the introduction of DEA in 1978, researchers in a number of fields have quickly recognized its usefulness and applicability. In recent years, there have been a great variety of applications of DEA in evaluating the performances of many kinds of entities engaged in several different activities in a number of countries [6-8]. DEA has been applied to a wide range of areas such as banking, health care systems, schools, retail outlets, benchmarking, sports, and transportation. DEA, in conjunction with other arithmetic methods, has been applied a number of times to assess the efficiency of the transportation network, both from technical and economical standpoints. DEA has been applied to transportation to assess relative efficiency of several modes of transportation such as airports [5, 9-11], container terminals and ports [12, 13], transit systems [14-16], and highways [17].

In recent years DEA has become increasingly popular and has essentially replaced the original deterministic parametric frontier approach when measuring efficiency. Hjalmarsson et al. [18] conducted a study where a DEA model, a deterministic parametric model, and a stochastic frontier model were compared. The authors’ found that the results vary as much within each group as across models. The results from the main models, however, are relatively similar. Another important factor the authors’ accentuate is that “the choice between different approaches must be based on trade-offs concerning the purpose of the study, type of data, technology characteristics, etc.” [18].

2. Methodology

The concept of DEA is to focus on individual observations in contrast to population averages. Therefore, DEA is a methodology directed towards frontiers rather than central tendency. DEA is a method to analyze relative efficiency by optimizing on each DMU that is being assessed. If one wish to evaluate the best operating intermodal facilities, a
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regression line is not sufficient because it is measuring average production. DEA, however, tries to optimize the production of each facility and forms an efficient frontier, also called an envelopment surface; see Fig. 1. The efficient frontier illustrates the maximum possible production function that embraces all the facilities. The facilities that form the efficient frontier provide benchmarks with the significance that for a given input, \( X \), there is no other facility that gives a higher output, \( Y \).

The result from the DEA assessment provides benchmarks that the inefficient DMUs can relate to. The efficiency production for each facility is computed by the distance from the facility to the envelopment surface. A facility is less efficient the further it is from the frontier. Decision makers for inefficient intermodal facilities can refer to the benchmarks and evaluate if they have excessive input or an insufficient output level based on the given data. Banker, Charnes, and Cooper developed one of the most utilized DEA models these days, i.e. the BCC model. They extended the CCR model that only allow for constant return to scale to the BCC model that accommodates technologies that exhibit variable return to scale (VRS) [2]. For this study, the BCC model is applied because the VRS efficiency complies best with the real world conditions for measuring efficiency of safety and security systems at intermodal transportation facilities.

The following relates to the BCC approach in detail which will be applied in this study. The BCC model has two main approaches; input-oriented and output-oriented. The input-oriented BCC model focuses on maximal movement toward the frontier through proportional reduction of inputs, whereas the output-oriented approach focuses on maximal movement via proportional augmentation of outputs [3]. The primal formulations related to these BCC models are presented next.

2.1 Input-Oriented BCC Primal

The Input-Oriented BCC Primal model shown in formulation (1) was introduced in Charnes et al. [3], the BCC DEA model for assessing input efficiency of DMU\(_j\)

\[
\begin{align*}
\min_{\theta, \lambda, s^+, s^-} & \quad z_o = \theta - \varepsilon \cdot 1^{s^+} - \varepsilon \cdot 1^{s^-} \\
\text{s.t.} & \quad Y_o - \lambda^s = Y_o^s \\
& \quad \theta X_o - X_o \lambda - s^- = 0 \\
& \quad 1 \lambda \geq 1 \\
& \quad \lambda, s^+, s^- \geq 0
\end{align*}
\]

where:
- \( z_o \): efficiency score;
- \( \theta \): scalar variable by which the current input level has to be multiplied with in order to reach the envelopment surface;
- \( s^+, s^- \): vectors that contain the output and input slacks, respectively;
- \( \varepsilon \): a non-Archimedean constant that allows the minimization over \( \theta \) to preempt the optimization involving the slacks;
- \( \lambda \): intensity vector;
- \( Y, X \): \( Y \) is a non-negative output matrix and \( X \) a non-negative input matrix, with \( i \)th columns \( Y_i \) and \( X_i \), respectively.

The evaluation of each DMU\(_j\), \( j = 1, 2, ..., n \), are characterized by different parameters. The scalar variable \( \theta_j \), \( 0 < \theta_j \leq 1 \) is the proportional reduction applied to all inputs of DMU\(_o\). The subscript \( (o) \) denotes the DMU whose efficiency is being evaluated. This reduction is applied simultaneously to all inputs and results in a radial movement toward the envelopment surface, see Fig. 1. The parameter \( \lambda_j = (\lambda_{j1}, \lambda_{j2}, ..., \lambda_{jn}) \) is a vector describing the percentages of reference to the efficient DMUs. Since \( \varepsilon \) allows the minimization over \( \theta \) to preempt the optimization involving the slacks, the optimization can be computed in two stages: 1) maximal reduction of inputs being
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achieved first via $\theta$; and 2) movement onto the efficient frontier via the slack variable $s^+$ and $s^-$ (3).

2.2 Output-Oriented BCC Primal

In the output-oriented approach, the focus shift from minimizing the input to maximizing the output. The Output-Oriented BCC Primal model shown in equation (2) was introduced in Charnes et al. [3], the BCC DEA model for assessing output efficiency of DMU $j$

$$
\text{max } z_o = \phi + \varepsilon \cdot 1 \cdot s^+ + \varepsilon \cdot 1 \cdot s^- \tag{2}
$$

s.t. \(\phi Y_o - Y \lambda + s^+ = 0\)

$$
X \lambda + s^- = X_o
$$

$$
\lambda, s^+, s^- \geq 0
$$

where:

- $z_o$: efficiency score;
- $\phi$: scalar variable by which the current output level has to be multiplied with in order to reach the envelopment surface;
- $s^+, s^-$: vectors that contain the output and input slacks, respectively;
- $\varepsilon$: allows the maximization over $\phi$ to preempt the optimization involving the slacks;
- $\lambda$: intensity vector;
- $Y, X$: Y is a non-negative output matrix and X a non-negative input matrix, with $i$th columns $Y_i$ and $X_i$, respectively.

The output-oriented model attempts via $\phi$ to maximize the output without reducing the given input level. The non-Archimedean constant, $\varepsilon$, allows the maximization over $\phi$ to preempt the optimization involving the slacks. Thus, the optimization can be computed in two stages: 1) maximal expansion of outputs being achieved first via $\phi$; and 2) movement onto the efficient frontier via the slack variable $s^+$ and $s^-$ (3). Fig. 2 illustrates the envelopment surface and the path for inefficient DMUs onto the efficient frontier for the output-oriented BCC model.

3. Case Study

For this study the area is limited to the State of Florida because it hosts a mixture of the nations larger and smaller intermodal transportation facilities. Intermodal facilities were chosen from the following cities: Miami, Fort Lauderdale, West Palm Beach, Tampa,
Fort Myers, Jacksonville, Orlando, Cape Canaveral, and Sanford.

Table 1 represents the chosen sample of intermodal facilities and their locations. The sample selection presents an assortment of larger and smaller facilities to achieve a broad aspect of the study area. The time period for this study is from (2000–2006) is mainly chosen because of the availability of data. Moreover, the time period is interesting because it will assess the changes made to transportation safety and security following 9/11. This change will mainly be evident for aviation security because of intense focus on airport security in the aftermath of 9/11. Ports in the State of Florida, on the other hand, according to Hern [19], reorganized their safety and security systems in the latter part of the 1990’s due to the Florida Statue 311.

The 20 intermodal transportation facilities studied over a seven year period will give a maximum sample size of 140 observations. The availability of data, however, will affect the actual sample size. Because the DEA model requires numbers greater than zero, missing data within any observation will result in an exclusion of that observation from the sample.

3.1 Selection of Variables

To develop a DEA model and assess the efficiency of intermodal facilities, several safety and security related variables were selected. When the variables are selected the related data must be assembled. The selection of inputs and outputs is extremely crucial for DEA model development.

The inputs chosen must capture all the resources that impact the outcome. The aim is to measure the efficiency of the security and safety of intermodal facilities; therefore, all the variables concerned with safety and security at intermodal transportation facilities must be identified. The specific inputs selected for this study are: 1)i) area in acres; 2)i) number of security checkpoints for passengers; 3)i) number of security checkpoints for cargo; 4)i) number of police/law enforcement officers; 5)i) number of employees; 6)i) number of safety and security-related incidents; and 7)i) number of safety and security-related accidents.

When addressing the outputs, it is important to capture all the considerable outcomes that are to be assessed. Cargo in tonnage and number of passengers are selected because these are the major sources of service.

Fig. 2 Paths onto the envelopment surface for the output-oriented BCC approach.
Table 1  Sample of intermodal facilities with their locations.

| Type    | Facility Name                | Location       |
|---------|-----------------------------|----------------|
| Airport | Miami INTL (MIA)            | Miami          |
|         | Fort Lauderdale/Hollywood INTL (FLL) | Fort Lauderdale |
|         | Palm Beach INTL (PBI)       | West Palm Beach|
|         | Southwest Florida INTL (RSW) | Fort Myers     |
| Seaport | Port of Miami               | Miami          |
|         | Port Everglades             | Fort Lauderdale|
|         | Port of Palm Beach          | Palm Beach     |
|         | Jacksonville                | Jacksonville   |
|         | Tampa                       | Tampa          |
|         | Port Manatee                | Palmetto       |
|         | Port Canaveral              | Cape Canaveral |
| Auto    | Sanford Amtrak Station      | Sanford        |
| Train   | Case Study Train Station (1) | -              |
|         | Case Study Train Station (2) | -              |
|         | Case Study Train Station (3) | -              |

Table 2  Input and output variables.

| Variable # | Definition (measure)                        | Short Form       |
|------------|---------------------------------------------|------------------|
| Inputs     |                                             |                  |
| 1i         | Area (acre)                                 | Area             |
| 2i         | Number of security checkpoints for passengers | Sec. check. pass.|
| 3i         | Number of security checkpoints for cargo    | Sec. check. cargo|
| 4i         | Number of police/law enforcement officers   | Law enf. off.    |
| 5i         | Number of employees                         | Employees        |
| 6i         | Number of safety and security-related incidents | Incidents     |
| 7i         | Number of safety and security-related accidents | Accidents     |
| Outputs    |                                             |                  |
| 1*         | Number of passengers                        | Passengers       |
| 2*         | Cargo (U.S. tonnage)                        | Cargo            |

that intermodal facilities handle and provide. The objective is to measure how efficient each selected intermodal facility is in terms of how much cargo and how many passengers they can manage with a given security level. Accordingly, the outputs chosen are 1*) number of passengers and 2*) cargo in U.S. tonnage. Table 2 recapitulates and specifies the chosen variables, together with appropriate abbreviations.

3.2 Data for DEA Model

Data gathering is difficult and time consuming process for this study because the model requires sensitive security information. Several methods have therefore been used to gather the required data. Information has been obtained from publications and public information, personal communications via phone calls and e-mails to the agencies and facilities, and from site visits. Highly sensitive security information has been estimated from site visits to specific facilities. From the site visits, a database has been created to gather and estimate data from observations made at the facility. In addition to the data gathered from public sources, communication, and site visits, information from the Bureau of Transportation Statistics has been acquired.

3.3 Case Study Application

As indicated earlier, the study area selected for this
study is narrowed to major intermodal transportation facilities in the State of Florida with collection of data from FY 2000 to FY 2006. The DEA models, however, are developed in such a way that they can be applied to other intermodal facilities in the United States, or worldwide, with relative time frames for use with the specific assessment.

The State of Florida is an ideal area for this case study because of its many urban areas and its multimodal transportation infrastructure. Past knowledge shows that urban areas are attractive targets for terrorist attacks. Florida is also vulnerable to security incidents because the long coastline gives access to terrorists through many seaports in the state. Some of the largest ports in the nation, in terms of cargo transported or number of passengers, are located in Florida. Also, according to the United States-Dominican Republic-Central America Free Trade Agreement (CAFTA) Intelligence Center [20], Florida is one of the nation’s busiest states in terms of air cargo volume. Furthermore, four of Florida’s airports are among the world’s top 100 in terms of passenger travel. Florida consists of a multimodal transportation network where the airports and seaports are linked to the highways and the transit system. Efficient security solutions are therefore desirable for the state to ensure a safe, secure, and smooth flow of people and goods, and to minimize the possibility of congestion and security incidents in the highly populated areas.

In order to validate the developed DEA model for this study, several scenarios have been applied and analyzed. The relative efficiency of the chosen intermodal facilities is measured by using DEAFrontier, a Microsoft Excel add-in developed by Zhu [21]. The DEAFrontier measures the following: (i) relative efficiency; (ii) targets; (iii) slacks; and (iv) benchmarks. The DEAFrontier can calculate DEA efficiency for the VRS frontier for both input minimization and output maximization.

4. Results and Analysis

To develop a DEA model to assess the efficiency of intermodal transportation facilities, a range of scenarios have been applied, each with a distinctive set of DMUs and time frames to assess the validity and robustness of the model. Each scenario has furthermore been computed with the input-oriented and output-oriented approaches using VRS efficiency. In this paper, however, only two scenarios are demonstrated to illustrate the capability of the model.

Scenario 1

In this scenario, combinations of the airports and seaports have been applied together with the Sanford Auto train station and three case study train stations. The time period selected for this scenario is FY 2005 – 2006. Both the input-oriented and the output-oriented approaches have been applied. Given the 15 intermodal facilities studied over a two year period, the sample size consists of 30 observations. The intermodal facilities together with the selected variables and the given data for FY 2005~2006 are presented in Table 3. For this scenario, however, the two variables; 6i) incidents and 7i) accidents, are not incorporated in the model.

Table 4 illustrates the input- and output-oriented VRS efficiency for the selected intermodal transportation facilities for FY 2005~2006 calculated by the DEAFrontier. By investigating the results provided in Table 4, it is evident that 23 of the observations under input minimization are efficient, whereas only 12 of the observations receive 100 percent relative efficiency under output maximization. Port of Palm Beach, for example, appears efficient under input minimization, whereas the port performs with the worst efficient score under output maximization for both FY 2005 and FY 2006. Also, Port Canaveral performs poorly in the output oriented approach whereas the port appears efficient in the input oriented approach. Southwest Florida International airport (RSW), on the other hand, performs...
### Table 3  Data for the selected intermodal facilities (FY 2005–2006).

| DMU No. | DMU Name            | Area | Sec. Check. | Sec. Check. | Law Enf. | Incidents | Accidents | Passengers | Cargo |
|---------|---------------------|------|-------------|-------------|----------|-----------|-----------|------------|-------|
|         |                     | (1i) | (2i)        | (3i)        | (4i)     | (6i)      | (7i)      | (1o)        | (2o)  |
| 1       | FLL 2006            | 1380 | 28          | 3           | 197      | 7         | 3         | 21369787    | 163352 |
| 2       | MIA 2006            | 3300 | 39          | 12          | 289      | 8         | 4         | 32533974    | 2020000 |
| 3       | PBI 2006            | 2120 | 14          | 1           | 101      | 5         | 2         | 6824789     | 19340   |
| 4       | RSW 2006            | 3430 | 13          | 2           | 93       | 6         | 3         | 7643217     | 21500   |
| 5       | Port of Miami 2006  | 518  | 20          | 2           | 101      | 15        | 7         | 3731456     | 8654371 |
| 6       | Port Everglades 2006| 2190 | 17          | 4           | 173      | 15        | 8         | 3239154     | 26585683 |
| 7       | Port of Palm Beach 2006| 220  | 4          | 1           | 56       | 9         | 4         | 520557     | 4300000 |
| 8       | Port of Jacksonville 2006| 1500 | 2    | 4          | 139      | 10        | 5         | 300000     | 23649730 |
| 9       | Port of Tampa 2006  | 5000 | 5          | 8           | 228      | 21        | 9         | 900000     | 48188580 |
| 10      | Port Manatee 2006   | 1100 | 1          | 2           | 77       | 12        | 6         | 900000     | 9416809 |
| 11      | Port Canaveral 2006 | 4158 | 24         | 1           | 74       | 14        | 7         | 4542056    | 4553756 |
| 12      | Sanford Auto Train St. 2006 | 31 | 1  | 1          | 12       | 22        | 11        | 207544     | 210878 |
| 13      | Train St. (1) 2006  | 80   | 1          | 1           | 30       | 24        | 12        | 500000     | 7000000 |
| 14      | Train St. (2) 2006  | 90   | 1          | 1           | 36       | 25        | 13        | 200000     | 8000000 |
| 15      | Train St. (3) 2006  | 70   | 1          | 2           | 20       | 27        | 13        | 100000     | 1000000 |
| 16      | FLL 2005            | 1380 | 28          | 3           | 207      | 8         | 4         | 22390285    | 179159 |
| 17      | MIA 2005            | 3300 | 39          | 12          | 303      | 10        | 5         | 3108453     | 1934546 |
| 18      | PBI 2005            | 2120 | 14          | 1           | 106      | 6         | 3         | 7014237     | 19514   |
| 19      | RSW 2005            | 3430 | 13          | 2           | 98       | 7         | 3         | 7400000     | 21100   |
| 20      | Port of Miami 2005  | 518  | 20          | 2           | 101      | 16        | 8         | 3605201     | 9472268 |
| 21      | Port Everglades 2005| 2190 | 17         | 4           | 173      | 17        | 8         | 3801464     | 26512293 |
| 22      | Port of Palm Beach 2005| 220  | 4          | 1           | 56       | 9         | 4         | 553692     | 4223545 |
| 23      | Port of Jacksonville 2005| 1500 | 2    | 4          | 139      | 12        | 6         | 275123     | 20728430 |
| 24      | Port of Tampa 2005  | 5000 | 5          | 8           | 228      | 19        | 9         | 771227     | 50194552 |
| 25      | Port Manatee 2005   | 1100 | 1          | 2           | 77       | 12        | 6         | 700000     | 9433076 |
| 26      | Port Canaveral 2005 | 4158 | 24         | 1           | 74       | 15        | 7         | 4388851     | 4467088 |
| 27      | Sanford Auto Train St. 2005 | 31 | 1  | 1          | 12       | 20        | 10        | 204698     | 206652 |
| 28      | Train St. (1) 2005  | 80   | 1          | 1           | 30       | 25        | 12        | 4000000     | 6000000 |
| 29      | Train St. (2) 2005  | 90   | 1          | 1           | 36       | 27        | 13        | 1800000     | 7000000 |
| 30      | Train St. (3) 2005  | 70   | 1          | 2           | 20       | 30        | 15        | 700000     | 9000000 |
Table 4  VRS efficiency results for Scenario 1.

| DMU No. | DMU Name         | Input-oriented VRS Efficiency | Output-oriented VRS Efficiency |
|---------|------------------|------------------------------|--------------------------------|
| 1       | FLL 2006         | 1.00                         | 1.00                           |
| 2       | MIA 2006         | 1.00                         | 1.00                           |
| 3       | PBI 2006         | 1.00                         | 1.01                           |
| 4       | RSW 2006         | 0.65                         | 1.47                           |
| 5       | Port of Miami 2006 | 0.60                       | 1.28                           |
| 6       | Port Everglades 2006 | 1.00                  | 1.00                           |
| 7       | Port of Palm Beach 2006 | 1.00                | 1.86                           |
| 8       | Port of Jacksonville 2006 | 1.00           | 1.00                           |
| 9       | Port of Tampa 2006 | 0.96                       | 1.02                           |
| 10      | Port Manatee 2006 | 1.00                       | 1.06                           |
| 11      | Port Canaveral 2006 | 1.00                    | 1.20                           |
| 12      | Sanford Auto Train St. 2006 | 1.00       | 1.00                           |
| 13      | Train St. (1) 2006 | 1.00                       | 1.00                           |
| 14      | Train St. (2) 2006 | 1.00                       | 1.00                           |
| 15      | Train St. (3) 2006 | 1.00                       | 1.00                           |
| 16      | FLL 2005         | 1.00                        | 1.00                           |
| 17      | MIA 2005         | 0.95                       | 1.05                           |
| 18      | PBI 2005         | 1.00                       | 1.00                           |
| 19      | RSW 2005         | 0.62                       | 1.59                           |
| 20      | Port of Miami 2005 | 0.66                    | 1.21                           |
| 21      | Port Everglades 2005 | 1.00                | 1.00                           |
| 22      | Port of Palm Beach 2005 | 1.00          | 1.89                           |
| 23      | Port of Jacksonville 2005 | 0.89       | 1.14                           |
| 24      | Port of Tampa 2005 | 1.00                       | 1.00                           |
| 25      | Port Manatee 2005 | 1.00                       | 1.06                           |
| 26      | Port Canaveral 2005 | 1.00                   | 1.24                           |
| 27      | Sanford Auto Train St. 2005 | 1.00    | 1.01                           |
| 28      | Train St. (1) 2005 | 1.00                       | 1.17                           |
| 29      | Train St. (2) 2005 | 1.00                       | 1.14                           |
| 30      | Train St. (3) 2005 | 1.00                       | 1.11                           |

poorly in both approaches. From the given results it appears that the output-oriented VRS model is more sensitive to the given data than the input-oriented model.

The efficiency scores achieved by all the intermodal facilities under input minimization are illustrated in Fig. 3 where it is apparent that RSW and Port of Miami are the worst performers. All the train stations, however, appears efficient for both FY 2005 and FY 2006 in the input-oriented approach. This can presumably be explained by the low input data used for all the train stations. The DEA model primarily tries to minimize the input in this case, and as a result, the train stations will most likely appear efficient because of their low input data. Since the train stations already have a low level of given input, it is more likely that the airports and seaports try to learn from the train stations when the input-oriented approach is applies. By looking at the benchmarks produced by the DEAFrontier for the airports and seaports, it is evident that the majority of the inefficient facilities at some extent use the train stations as benchmark. Port of Miami in both FY 2005 and FY 2006, for example, mainly uses Train St. (1) 2006 and Train St. (2) 2006 as benchmarks. Yet, the port also uses Port Everglades 2005 as benchmark to some degree. Also, RSW for both fiscal years primarily uses Train St. (1) 2006 as benchmark. Moreover, the airport uses FLL 2005 and PBI 2005 as
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Input- and output-oriented VRS efficiency for scenario 1.

According to these results, it is distinct that the airports and seaports try to learn from the train stations to intensify their efficiency level when the input-oriented VRS model is applied.

Under output maximization, however, the four train stations only appear efficient in FY 2006. All the train stations are slightly inefficient in FY 2005. Fig. 3 illustrates the efficiency achieved by all the intermodal facilities under output maximization where it is apparent that Port of Palm Beach and RSW are the worst performers. Again by looking at the benchmarks obtained by the DEAFrontier, it becomes visible that the majority of the inefficient DMUs' try to learn from the train stations. Port of Palm Beach, for example, uses Train St. (2) 2006 as a benchmark to maximize its efficiency for both FY 2005 and FY 2006. RSW uses primarily Train St. (1) 2006 and FLL 2005 as benchmarks. Moreover, the airport uses MIA 2006 as benchmarks to some extent.
benchmarks to some extent. Also when the output-oriented VRS model is applied, it is apparent that the airports and seaports try to learn from the train stations to intensify their efficiency level. On the other hand, the train stations do not use the airports and seaports as benchmarks when they try to maximize their efficiency. The train stations perform inefficient in FY 2005 under output maximization. The reason for this, however, is that the train stations are comparing themselves to the efficiency level they gained in FY 2005. The train stations for FY 2005 essentially use the train stations from FY 2006 as benchmarks.

For the optimization of all the DMUs in the assessment, the input target under input minimization is generally lower than the input target from the output-oriented approach for the inefficient observations. Conversely, the output target under output maximization is generally higher than the output target from the output-oriented approach. It is therefore apparent that the input-oriented model focuses on minimizing the input, whereas the output-oriented model tries to maximize the output variables.

Scenario 2

The selection of DMUs for this scenario includes the four airports, seven seaports, Sanford Auto train station and the three case study train stations that were used in scenario 1. The same time period, FY 2005 – 2006, is also applied. What makes this scenario differ from scenario 1 is the incorporation of safety and security related incidents and accidents as two new variables to the DEA model. This is a case study scenario where carefully assumed numbers are given to the two new variables. Number of incidents and accidents are classified as highly sensitive security information and was therefore not obtained for this study. Once again, both the input-oriented and the output-oriented approaches have been applied. Given the 15 intermodal facilities studied over a two year period, the sample size consists of 30 observations. The intermodal facilities together with the selected variables and the given data for FY 2005 - 2006 is presented in Table 3.

The airports are given the fewest number of incidents and accidents because of the intense focus on security at the airports. It is assumed that people are more reluctant to bring unauthorized possessions to the airports because of the increased airport security procedures. The ports and the train stations are given higher numbers regarding incident and accidents because these areas are easily accessible with less stringent security procedures.

Table 5 illustrates the input- and output-oriented VRS efficiency for the selected intermodal transportation facilities for FY 2005 - 2006 obtained using the DEAFrontier. By investigating Table 5, one can find that 24 of the observations are efficient under input minimization, whereas 20 of the observations are efficient under output maximization. The input-oriented model again subscribes more observations with efficiency score equal to 1 compared to the output-oriented model. The difference, however, in this scenario is not as significant as in the scenario 1.

In this scenario, the main purpose was to see how the model reacts when the two variables; incidents and accidents, are included in the DEA model. The efficiency score achieved by all the observations under input minimization and output maximization is illustrated in Fig. 4. By comparing the two graphs, it is apparent that the two models give almost the same results for the efficiency score for all the observations, except for Train St. (1) 2005, Train St. (2) 2005, and Train St. (3) 2005. Train St. (1), Train St. (2), and Train St. (3) all appears efficient in FY 2005 under input minimization, whereas the same stations appears inefficient in FY 2005 under output maximization. From the benchmarks, however, one can find that the three train stations in FY 2005 are being compared to their own operating level from FY 2006.

In the previous scenario, RSW stands out as one of the worst performers in terms of the efficiency of the safety and security system at the airport. In this scenario,
Table 5  VRS Efficiency Results for Scenario 2.

| DMU No. | DMU Name               | Input-oriented VRS Efficiency | Output-oriented VRS Efficiency |
|---------|------------------------|------------------------------|--------------------------------|
| 1       | FLL 2006               | 1.00                         | 1.00                           |
| 2       | MIA 2006               | 1.00                         | 1.00                           |
| 3       | PBI 2006               | 1.00                         | 1.00                           |
| 4       | RSW 2006               | 1.00                         | 1.00                           |
| 5       | Port of Miami 2006     | 0.99                         | 1.01                           |
| 6       | Port Everglades 2006   | 1.00                         | 1.00                           |
| 7       | Port of Palm Beach 2006| 1.00                         | 1.00                           |
| 8       | Port of Jacksonville 2006| 1.00          | 1.00                           |
| 9       | Port of Tampa 2006     | 0.98                         | 1.02                           |
| 10      | Port Manatee 2006      | 1.00                         | 1.00                           |
| 11      | Port Canaveral 2006    | 1.00                         | 1.00                           |
| 12      | Sanford Auto Train St. 2006| 1.00         | 1.00                           |
| 13      | Train St. (1) 2006     | 1.00                         | 1.00                           |
| 14      | Train St. (2) 2006     | 1.00                         | 1.00                           |
| 15      | Train St. (3) 2006     | 1.00                         | 1.00                           |
| 16      | FLL 2005               | 1.00                         | 1.00                           |
| 17      | MIA 2005               | 0.95                         | 1.05                           |
| 18      | PBI 2005               | 1.00                         | 1.00                           |
| 19      | RSW 2005               | 0.99                         | 1.03                           |
| 20      | Port of Miami 2005     | 0.97                         | 1.03                           |
| 21      | Port Everglades 2005   | 1.00                         | 1.00                           |
| 22      | Port of Palm Beach 2005| 1.00                         | 1.00                           |
| 23      | Port of Jacksonville 2005| 0.91                | 1.14                           |
| 24      | Port of Tampa 2005     | 1.00                         | 1.00                           |
| 25      | Port Manatee 2005      | 1.00                         | 1.00                           |
| 26      | Port Canaveral 2005    | 1.00                         | 1.02                           |
| 27      | Sanford Auto Train St. 2005| 1.00         | 1.00                           |
| 28      | Train St. (1) 2005     | 1.00                         | 1.17                           |
| 29      | Train St. (2) 2005     | 1.00                         | 1.14                           |
| 30      | Train St. (3) 2005     | 1.00                         | 1.11                           |
Fig. 4  Input- and output-oriented VRS efficiency for scenario 2.

however, when safety and security related accidents and incidents are incorporated to the assessment, RSW does not stick out as one of the worst performers anymore. This can be explained by the low level of safety and security related accidents and incidents assigned to the airport. In the previous scenario the airport scored low because of the high security level referenced to a lower production level compared to some of the other types of intermodal facilities. A high security level combined with few incidents and accidents, however, makes the airport more efficient in terms of the safety and security system the airport are managing. Few incidents and accidents are desirable; therefore, a low level of incidents and accidents in the input gives favorable results.

The target for the inputs and outputs for RSW has significantly changed in this scenario compared to the previous. Since the efficiency score is substantially better, the targets are also closer to the given data.

5. Conclusion

The need for efficient security solutions at
intermodal transportation facilities are important to keep the United States safe and secure from terrorist attacks and other threats. The contribution of the study is a mathematical model that can measure the efficiency of the safety and security systems at various intermodal transportation facilities.

The resulted DEA methodology can be used to assess relative efficiency of the safety and security operations of intermodal transportation facilities. The mathematical model has been developed using DEA approach in such a way that it also can be applied to any states or regions in the United States. However, the success of DEA methodology depends on the accurate and reliable data from several sources. Since the study involves sensitive security and safety information of large public transportation facilities, the accuracy of the estimated data is questionable, in some aspects. The DEA methodology presented in this study is general in its framework and can be applied to any network of intermodal transportation systems. Availability of credible data, complemented with DEA methodology will help in management decisions making concrete safety and security decisions for intermodal transportation facilities. Decision makers, however, need to carefully evaluate different aspects of the facilities operations when considering intensifying the efficiency level of an inefficient facility. The process of making the security level at an intermodal facility more efficient may involve; lowering the security level, increasing the volume of passengers and cargo that goes through the security system, or a combination of the two. Lowering the security level could be risky due to fear of terrorist threats. Therefore, an alternative that mainly focuses on maximizing the production by increasing number of passengers and tonnage of cargo at a given security level might be a better approach. In addition, Scenario 2 shows that a high security level combined with few incidents and accidents makes the observations more efficient in terms of the safety and security system the facilities are managing. Few incidents and accidents are desirable; therefore, a low level of incidents and accidents in the input gives favorable results.

The presented DEA methodology includes different transportation modes and suggests that more efficient safety and security solutions can be achieved if the weaknesses or strengths are assessed in a combined approach. Enhanced collaboration between various transportation modes is essential for improved safety and security solutions.

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