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Assessing the on-road route efficiency for an air-express courier[†]

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SUMMARY

This paper proposes an EXO-CAT data envelopment analysis (DEA) model to evaluate the efficiency of on-road activities (pickup and delivery) for an air-express courier on a route-by-route basis. The proposed model combines the constraints of exogenously fixed inputs DEA and categorical DEA to account for the continuous and discrete external environmental factors affecting the courier route efficiency. We select labor, route length (a proxy of fuel consumption), and vehicle capacity as the inputs; number of documents delivered, number of boxes delivered, number of documents picked-up, and number of boxes picked-up as the outputs. A case study with 248 on-road routes currently operated by an air-express courier in Taiwan is undertaken. It is found that stop density, travel speed, and service area type have significant influences on the couriers' route efficiency. Based on the detailed DEA results, the managers do not need to perform check-rides for all routes; instead, they need only to focus on the most inefficient ones. Such DEA results can also be applied to develop new projects or make judgments on investing any new on-road routes. Copyright © 2010 John Wiley & Sons, Ltd.

KEY WORDS: air-express courier; data envelopment analysis; on-road pickup and delivery route efficiency

1. INTRODUCTION

Air-express couriers provide fast, reliable, and time-definite logistics for time-sensitive objects, such as overnight-delivered documents and boxes, from one country to another throughout the world. In addition to dense air network with hundreds of jets globally operated, the systems also operate with intensive ground activities including the consolidation, sorting, and documentation at the ground stations as well as the on-road pickup and delivery at both ends (origin and destination). Of the ground activities, the on-road pickup and delivery can take up more than 70% of the total working hours. As such, the companies must pay attention to the ground operation, especially to the on-road route efficiency so as to level up the overall efficiency of the entire courier service. Without an objective assessment tool, however, the managers may not be able to gain insights into how efficiently their resources have been allocated or what have caused the operational inefficiency, on a route basis.

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When assessing a courier's on-road efficiency, two measurements can be considered: cost efficiency and technical efficiency. The former requires both factor prices and factor quantities information while the later only requires the factor quantities data. In this paper we only take in hand the technical efficiency measurement mainly because the route-based cost details of the study company are confidential.

In the past, various data envelopment analysis (DEA) approaches have been widely used in the performance evaluation of transport services, including ferry [1], seaport [2], bus transit [3–7], rail [8,9], airport [10,11], and airline [12]. Most of the works measured the transport efficiency at a company level. In practice, the managers of an air-express courier often perform check-rides for the on-road routes and make judgments based on their subjective personal experiences in goal setting, performance assessing, and route structuring. Check-ride is inevitably strenuous and time-consuming, thus, cannot be implemented frequently for all routes. Without frequent check-rides, however, the managers may not have concrete knowledge about the route performance or about the key factors causing the route inefficiency. As such, providing a guideline and benchmark as a managerial tool is of essential importance to the air-express companies. If one can scrutinize the sources of route inefficiency, one would perhaps be capable of proposing more practical tactics to ameliorate the operational efficiency of the on-road courier activities.

The present paper attempts to evaluate the on-road route efficiency for an air-express courier on a route-by-route basis by using appropriate DEA approaches. It is expected that with reference to the DEA results, the managers can easily identify the most efficient routes and use them to benchmark the less efficient ones. The managers can also scrutinize some significant factors affecting the route efficiency and propose more effective tactics to increase the route efficiency by rearranging the inputs or outputs. The company can even consider outsourcing the most inefficient routes or service territories (stations) provided that the outsourcing cost is justified.

The remaining of this paper is organized as follows. Section 2 describes the proposed DEA models. Section 3 briefly introduces the air-express couriers' ground operation and performs the case study. Based on the findings, some managerial implications are discussed in Section 4. In the last section, we summarize the conclusions and propose avenues for future study.

2. METHODOLOGY

DEA is a linear programming method for measuring the relative efficiency of a set of decision making units (DMUs) that perform similar tasks. The most renowned CCR DEA model was introduced by Charnes *et al*. [13] who constructed performance measures for non-profit units under assumption of constant returns to scale technology. Later, Banker *et al*. [14] added a convexity constraint to the CCR DEA model to measure the efficiency under variable returns to scale technology, which was known as BCC DEA model. There can be input-oriented or output-oriented DEA modeling and this study will use input-oriented modeling to examine the resource utilization and savings for the on-road activities of an air-express courier. The relevant DEA models used in this paper are briefly described as follows.

2.1. BCC DEA model

Assume that there is k DMUs to be evaluated. Each of them produces s outputs by utilizing m inputs. The input-oriented BCC model can be formulated as the following linear program (LP).

$$\begin{aligned} &\mathrm{Min}_{\theta,\lambda}\theta \\ &s.t. -y_i + Y\cdot\lambda \geq 0, \\ &\theta\cdot x_i - X\cdot\lambda \geq 0, \\ &\textstyle\sum\lambda = 1, \lambda \geq 0 \end{aligned} \tag{M1}$$

In model (M1), X and Y are the $m \times k$ input matrix and the $s \times k$ output matrix (for the ith DMU these are represented by the vector x_i and y_i), respectively. λ is a $k \times 1$ vector of constant and θ is a scalar, which stands for efficiency of ith DMU. Solving this LP for each of k DMUs, one obtains the efficiency score for each DMU. The DMU with θ equal to one is evaluated as relatively efficient, while the DMU with θ less than one is viewed as inefficient.

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2.2. *EXO-CAT DEA model*

When we attempt to estimate relative efficiency of each DMUs, there might be some environmental factors that cannot be controlled by the DMUs. To account for such exogenous factors in the efficiency measurement, Banker and Morey [15] proposed the exogenously fixed inputs DEA model (termed as EXO model). Furthermore, some of the non-controllable inputs may be discrete; for example, x_m is further classified into four distinct levels—none, low, average, and high, where ''high'' denotes the most favorable situation. Banker and Morey [16] further introduced the descriptor binary variables into model (M1) and termed this categorical DEA model or CAT model in short. In order to simultaneously consider the continuous and discrete environmental variables that may influence the route performance of an air-express courier, this paper proposes an EXO-CAT DEA model by combining the constraints in EXO and CAT into one model, formulated as model (M2):

$$\begin{aligned}&\mathrm{Min}_{\theta,\lambda}\theta\\&s.t. -y_i + Y\cdot\lambda \geq 0,\\&\theta\cdot x_i - X\cdot\lambda \geq 0,\ (i = 1, 2, ..., m')\\&x_i - X\cdot\lambda \geq 0,\ (i = m'+1, m'+2, ..., m)\\&\sum_{j=1}^{N}\lambda_j d_j \leq d_i,\ \sum\lambda = 1,\ \lambda \geq 0\end{aligned} \tag{M2}$$

The variables $x_{m'+1}$, $x_{m'+2}$,. . ., x_m in the third constraint denote exogenously fixed factors, which reflect the fact that these factors cannot be controlled (reduced) by the DMUs. In the fourth constraint, $d_j = 1$ represents the DMUs in the industrial zones wherein more boxes are expected and $d_j = 0$denotes the DMUs in the non-industrial (commercial) zones wherein more documents are anticipated.

3. CASE STUDY

3.1. *Courier operations*

We take one of the world's largest international air-express couriers, called it T-company for anonymous, as an example for our case study. The company moves over three million packages (including boxes and documents) a day, equipped with several hundred airplanes and several thousand vans, serving over 220 countries and territories globally. At the end of 2005, T-company has seven stations for ground operations, serving nearly 260 on-road routes by 300 couriers and handling more than 24 000 packages in a typical workday in Taiwan. The service areas, as indicated in Figure 1, cover the northern, western, and southern parts of the island. These areas, containing 12 counties and seven metropolitan cities, are the primary industrial and commercial zones, wherein major global manufacturing and international trading activities are taking place. Since the economic activities of eastern Taiwan and off-shore islands are more focusing on tourism business, T-company has defined those districts as the non-service areas.

Delivery and pickup services are the two main tasks for station couriers during their on-road working hours. Delivery is to handle the inbound packages from the station, while pickup is to handle the outbound packages from the customer orders. While couriers are delivering the inbound packages, they are also picking up the outbound orders which emerge randomly. Unlike delivery service that can be preplanned, pickup service is more complicated and harder to scheduling or routing in advance. In general, pickup service can be divided into two categories: regular pickups and on-call orders. Regular pickups are provided only for the regular customers and these customers do not need to place the orders. The couriers will visit them everyday for pickup at the appointed time. For on-call orders, however, customers are required to make orders. Customers can always contact the T-company through several channels anytime during the service hours when they need to ship international express packages. The shipping information is recorded in the mainframe and forwarded to on-road couriers through the digital assisted dispatch (DAP) system *via* local wireless network. Couriers should arrive at the customer sites within one to two hours, depending on the designated area for pickup service, after

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Figure 1. Service coverage of T-company in Taiwan.

receiving the order. This commitment is what T-company promises to the customers in most of the service areas in Taiwan.

Couriers have to plan their own routing based on fixed delivery stops and dynamic pickup stops. Normally, couriers start at work at 8:30, sort the packages, and plan their delivery sequence based on the destination of each package on hand before leaving for delivery. Couriers often focus on the delivery during the morning because most of the customers request pickups in the afternoon approaching the cut-off time. To meet the service commitment, all the delivery packages are required to reach customer ends with customers' signatures as the proof of delivery by 18:00. After completing all the delivery and pickup orders, couriers come back to station and end the day. Figure 2 represents a typical daily itinerary of a courier.

The processes of sorting and delivery for inbound packages can be briefly described as follows. After the customs clearance at the airport, the inbound packages are categorized and shuttled to the most appropriate stations. From there, the packages are further sorted into different delivery routes according to the consignee's address information. As for the ordering process, customers can make orders through toll-free call and the order information will be recorded in the mainframe by the customer service agent in the call center or by the voice response unit (VRU) system before transmitting to on-road couriers' stations. Besides, customers can also place the orders through the Internet and the information will be recorded and transmitted to the on-road courier through the DAP system. All the pickups, including regular and on-call pickups, should be fulfilled before the cut-off time in order to catch same day flight. Customers may also drop off the packages directly at T-company's facility and enjoy the later cut-off time.

3.2. Data

This study aims to measure the relative efficiency of T-company's on-road courier routes in Taiwan. Each courier takes all the delivery and pickup activities in a designated service territory. Due to the variety of stop densities and area types, the on-road routes may cover different sizes of territories and utilize different types of vehicles. Most couriers are equipped with vans, trucks, or scooters to perform their delivery and pickup task. Some afoot couriers are working within the high-rise buildings without

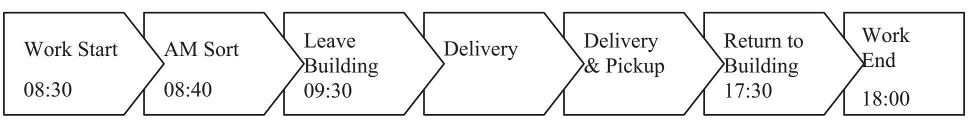

Figure 2. A typical daily itinerary of a courier.

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vehicles. The scooter couriers only provide document service due to the limited vehicular storage capacity. In this paper, we exclude the scooter- and afoot-courier routes and as a result there are 248 routes (DMUs) in the efficiency measurement framework.

Currently, the performance of each courier is measured according to their number of stops. Each attempted stop at a customer site, either for delivery or for pickup, is counted as one stop. The total stops and packages that a courier has completed at the end of workday are the output of courier route. Some locations may be counted as multiple stops in a day since the courier may be called back to the same customer site or different customers in the same building for pickup several times a day.

Choosing appropriate variables for inputs and outputs plays an important role in the DEA measurement. Based on the selection process proposed by Golany and Roll [17], we select labor, route length, and vehicle as the input factors to conduct the DEA measures. Since each route is operated by one courier, to describe the utilization of manpower more precisely, man-hour is used to represent the labor force inputted in each route. Route length in terms of mileage is selected as a proxy of fuel consumption. The capacity of a vehicle used in each route can be different depending on the service area covered, thus we adopt vehicle capacity as the third input variable.

For the air-express courier industry, the major yield of a company is the packages (boxes and documents) shipped, which can further be divided into pickup and delivery activities. It should be noted that the operating requirements (e.g., space required) for a box and a document can be different, thus documents and boxes are treated as two different outputs. Similarly, the handling processes for pickup and delivery services are also different. Consequently, four output variables are used in this study; namely, number of documents delivered, number of boxes delivered, number of documents picked-up, and number of boxes picked-up.

As we mentioned earlier, some environmental factors may affect the efficiency but are not controllable by each courier. The measured results could be biased if one neglects such non-discretionary factors. For instance, some on-road routes in downtown areas could be operated with denser pickups and deliveries than others in rural areas. The urban couriers are likely to enjoy shorter horizontal traveling (more customer stops in high-rise buildings) than the suburban couriers who require longer horizontal traveling among customer sites. To eliminate such heterogeneous environmental effects on the efficiency measurement, this study takes the following three environmental factors into account. Stop density, defined as stops per km, is retrieved from the couriers' daily scanning record. Average travel speed, surveyed on some major roads and matched into the routes, reflects the traffic conditions corresponding to each courier route. Considering the fact that the routes in industrial areas may generate a higher proportion of boxes than the routes in non-industrial (commercial) areas, where documents may take a lion's share, we introduce the third environmental factor, the zonal attribute dummy variable: 1 for industrial zones and 0 for non-industrial zones.

The raw data including three input variables, four output variables, and stop density were retrieved directly from the databank of T-company for the period from June 2005 to November 2005. The zonal (industrial or non-industrial) variable was evaluated and determined by local operators. The average travel speed in each service area was obtained from the latest survey conducted in 2004 by the Institute of Transportation, Ministry of Transportation and Communications. For confidential reason, we do not reveal the details of any routes; instead, we only present the average monthly statistics for these 248 routes studied in Table 1. Note that some low-demand routes in our study were not operated daily; the courier on these low-demand routes might perform the pickup and delivery once a week or even longer. Thus, these routes had very small numbers of monthly average inputs and outputs.Based on the handling activities (delivery and pickup) and package types (document and box), we further classify all DMUs into four groups: (1) pickup-document-oriented, (2) pickup-box-oriented, (3) delivery-document-oriented, and (4) delivery-box-oriented. Each group is jointly determined by pickup percentages and document percentages, which are defined as the ratio of pickup activities to all (pickup plus delivery) activities and the ratio of documents to total (document plus box) packages, respectively. Figure 3 presents the scattergram of all samples, which indicates that most of the routes (155 out of 248) are in group (2)—pickup-box-oriented. The major business of T-company in Taiwan agrees to the norm of export-oriented international trade of Taiwanese economy.

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Table 1. Monthly descriptive statistics for T-company.

Variables	Max.	Min.	Mean	Std. Dev.
Input variables				
Labor (man-hours per month)	215.1	3.6	142.8	47.2
Route length (km per month)	2556.2	13.0	763.3	531.9
Vehicle capacity (cubic meter)	5.87	4.59	5.05	0.62
Output variables				
Number of documents delivered per month	926.4	0.2	220.3	130.9
Number of boxes delivered per month	2282.8	1.8	365.9	260.6
Number of documents picked up per month	769.6	0.2	305.8	161.6
Number of boxes picked up per month	3680.0	0.2	603.6	471.6
Environmental variables				
Stop density (stops per km)	10.9	0.2	1.8	1.3
Average travel speed in the area (kph)	95.8	12.6	35.9	11.3
Zonal (dummy) variable	1, for industry zone (58 DMUs)		0, for non-industry zone (190 DMUs)	

To check the monotonicity, the correlation between input variables and output variables is further analyzed. The results show that, as expected, all input variables are positively correlated with the summation of four outputs. The man-hour is highly correlated with the summation of outputs (0.72), indicating that the air-express service is a labor-intensive industry. In contrast, both mileage and vehicle-capacity have relatively low correlation coefficients with the outputs. The low correlation coefficient between mileage and outputs (0.15) suggests the heterogeneous environments served by courier routes; thus, introduction of exogenous variables, such as stop density and zonal attribute into the model, is essential. As to the low correlation coefficient between vehicle-capacity and outputs (0.29), it can be ascribed to lack of variety of vehicle sizes because there are only two types of vehicles used by all routes.

3.3. Results

The computer programs: GAMS Release 2.50, developed by Brooke *et al*. [18], is adopted in this study. We evaluate the efficiency of each route by using BCC DEA model (M1) and EXO-CAT DEA model (M2). Table 2 presents the distribution frequencies of efficiency scores and descriptive statistics evaluated by each model. As expected, the average efficiency score and the number of efficient DMUs (score = 1.0) based on model (M2) are higher than those based on Ml, while the standard deviation of efficiency scores based on model (M2) is smaller than that based on model (M1). Furthermore, there are 58 routes with efficiency scores less than 0.8 based on model (M1), in contrast to 33 routes based on model (M2). The courier managers may wish to perform intensive check-rides on these inefficient routes and make critical strategic decisions about them.

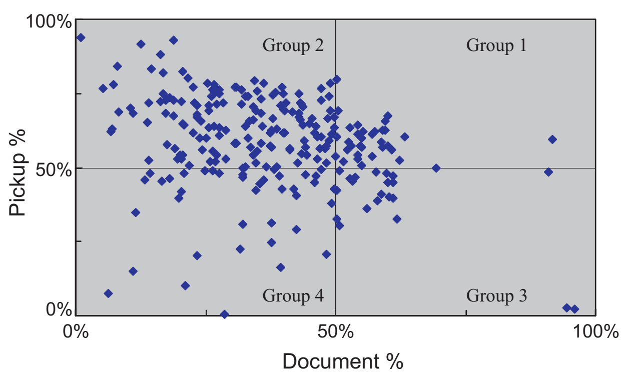

Figure 3. Scattergram of all DMUs based on percentages of document and pickup.

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Table 2. Summary of technical efficiencies.

Range of TE	BCC DEA model (M1)	EXO-CAT DEA model (M2)
Less than 0.799	58	33
0.800–0.899	21	25
0.900–0.999	3	1
1.000	166	189
Total DMUs	248	248
Max.	1.000	1.000
Min.	0.782	0.782
Avg.	0.934	0.953
Std. Dev.	0.096	0.085

3.4. Comparisons

3.4.1. Efficiency between pickup- and delivery-oriented routes

In order to gain more insights into the efficiency between pickup and delivery, we further classify the on-road courier services into two categories: delivery-oriented and pickup-oriented routes, based on the major activities. A new index, pickup-delivery ratio (hereinafter PD ratio), is defined as the ratio of total pickup packages to total delivery packages in each specific route. Any route with PD ratio greater (less) than one is categorized as a pickup-oriented (delivery-oriented) route. Table 3 summarizes the frequency and descriptive statistics of efficiency scores for these two categories by using model (M2). The average efficiency score for delivery-oriented routes (0.982) is larger than that for pickup-oriented routes (0.944). The percentage of efficient DMUs for delivery-oriented routes (56 out of 62) is also higher than that for pickup-oriented routes (133 out of 186). By testing the null hypothesis of equal mean of efficiency scores between these two groups, we have rejected the null hypothesis at the 0.05 significance level ($Z = 3.90 > 1.96$). Thus, it is concluded that, the average efficiency of delivery-oriented category is higher than that of pickup-oriented category. This result is consistent with the fact that the couriers can preplan the routing strategies at station for delivering the inbound packages, but they usually alter the routing strategies for picking up the outbound packages in response to the dynamic calls from customers.

To investigate whether the samples of these two categories are drawn from the same population, the non-parametric Mann–Whitney (M-W) test is conducted. Since $Z = 2.29$, greater than the critical value (1.96) at a significant level of 0.05, the null hypothesis that the samples of these two groups drawn from the same population should be rejected. It suggests that the frontiers (technologies) of delivery-oriented routes and of pickup-oriented routes are different.

3.4.2. Efficiency between four groups

As mentioned, the handling activities (delivery and pickup) and package types (document and box) can further classify the DMUs into four groups: (1) pickup-document-oriented, (2) pickup-box-oriented, (3) delivery-document-oriented, and (4) delivery-box-oriented. Each group is jointly determined by

Table 3. Efficiency scores for delivery- and pickup-oriented routes.

Range of score	All routes	Delivery-oriented routes	Pickup-oriented routes
Less than 0.799	33	2	31
0.800–0.899	25	4	21
0.900–0.999	1	0	1
1.000	189	56	133
Total DMUs	248	62	186
Max.	1	1	1
Min.	0.782	0.782	0.782
Avg.	0.953	0.982	0.944
Std. Dev.	0.085	0.056	0.091

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Table 4. Efficiency scores for four activity-package groups.

Activity-package groups	Attributes	Number of routes	Avg. score
1	Pickup-document-oriented	31	0.993
2	Pickup-box-oriented	155	0.934
3	Delivery-document-oriented	22	0.972
4	Delivery-box-oriented	40	0.987
Overall		248	0.953

two criteria: the ratio of pickups to all (pickup plus delivery) activities and the ratio of documents to total (document plus box) packages. Here, a route with ratio of pickups over 50% of the total activities is categorized as pickup-oriented. Likewise, a route with ratio of documents over 50% of the total packages is categorized as document-oriented.

Table 4 reports the average efficiency score for each of the four groups. The results reveal that, on average, for pickup service, the efficiency of document-oriented routes (0.993) in group 1 is significantly higher than that of box-oriented routes (0.934) in group 2 (M-W test, $Z = 5.70$ at the 0.05 significance level). This is partly because handling a document is easier than handling a box for the pickup activity. For delivery service, however, the efficiency of document-oriented routes (0.972) in group 3 is not significantly different from that of box-oriented routes (0.987) in group 4 (M-W test, $Z = 0.88$ at the 0.05 significance level). It suggests that delivery for a document and for a box may require similar effort for the couriers.

Similar comparison can be made between pickup and delivery either for document or for box. For box-oriented, the average efficiency score of group 4 (0.987) is higher than that of group 2 (0.934). It coincides that pickup stops are oftentimes dynamically changed depending upon the customer orders while delivery stops are generally pre-arranged and relatively fixed. For document-oriented, however, the average efficiency score of group 1 (0.993) is slightly higher than that of group 3 (0.972). This result seems inconsistent with the pickup and delivery routing plans. Other factors affecting the efficiency of document-oriented groups deserve further examination.

3.4.3. Efficiency between low- and high-density routes

We also compare the efficiency scores based on stop density. Here, low-density routes are those DMUs with stop density less than the mean stop density of overall DMUs. High-density routes are those with stop density greater than the mean value. There are 146 low-density routes and 102 high-density routes in our samples. The results are indicated in Table 5. On average, the routes in high-density areas (0.964) are more efficient than those in low-density areas (0.946). For delivery-oriented routes, there has no significant difference between low-density groups (0.986) and high-density groups (0.979). For pickup-oriented routes, however, it shows the higher the stop density the greater the efficiency scores. As explained, delivery routing can be preplanned at the beginning of the day, while the pickup routing will be altered in response to the dynamic orders. The pickup-oriented routing has led to less efficient, especially in the low-density areas.

3.4.4. Efficiency between stations

Finally, we compare the overall on-road route efficiency among the seven stations and the results are reported in Table 6. Except for station 4, most stations have both delivery- and pickup-oriented routes

Table 5. Efficiency scores by stop density.

Stop density groups	Delivery-oriented routes		Pickup-oriented routes		All routes	
	DMUs	Avg. score	DMUs	Avg. score	DMU	Avg. score
Low-density	26	0.986	120	0.938	146	0.946
High-density	36	0.979	66	0.955	102	0.964
Overall	62	0.982	186	0.944	248	0.953

Table 6. Efficiency scores by station.

Stations	Delivery-oriented routes		Pickup-oriented routes		All routes	
	DMUs	Avg. score	DMUs	Avg. score	DMUs	Avg. score
1	3	1.000	22	0.938	25	0.946
2	5	1.000	10	0.942	15	0.962
3	2	0.927	14	0.963	16	0.958
4	0	—	10	1.000	10	1.000
5	20	0.990	53	0.908	73	0.930
6	30	0.974	52	0.971	82	0.972
7	2	1.000	25	0.937	27	0.942
Total	62	0.982	186	0.944	248	0.953

serving their territories. We have noted that station 4 is the benchmark of pickup-oriented routes as this station has been allotted with least investment, in terms of couriers and vehicles, compared with other stations. Similar reason also applies to the benchmarked delivery-oriented routes at stations 1, 2, and 7.

4. DISCUSSIONS

One of the merits of DEA approaches is that the efficient DMUs can serve as benchmarks of the less efficient ones. Therefore, analyzing the relative efficiency scores among DMUs and investigating the factors influencing the efficiency scores are equally important. Since input-oriented DEA approaches are adopted in this study, in general, emphasis should be placed upon the input reduction for the less efficient routes.

Our empirical results indicate that the frontiers (technologies) of delivery-oriented routes can differ from those of pickup-oriented routes, implying that tactics for ameliorating the efficiency of delivery-oriented routes can be different from those for pickup-oriented routes. In practice, strategies for improving the route efficiency should be developed according to handling activities and package types. To fulfill the dynamic pickup activities, the couriers often spend more time and efforts than to undertake the preplanned delivery activities. Thus, developing effective demand-responsive routing algorithms is of critical importance for the air-express company. Specifically, for those routes in group 2 (pickup-box-oriented) that are less efficient and cannot be improved by route restructuring or workload adjustment, the managers may consider outsourcing the least efficient routes or service zones provided that the outsourcing quality and cost can be justified.

For those routes with efficiency scores less than unity, a general strategy is to reduce input factors, keeping outputs unchanged. Altering the vehicle capacity can be a promising strategy. In our study samples, 166 routes are evaluated as efficient DMUs based on model (M1) (BCC model); of which, 158 routes have been equipped with small-capacity vehicle ($4.59\,m^3$). In contrast, of the remaining 90 routes which have been equipped with larger-capacity vehicle (5.87 cubit meters), only eight routes are assessed as efficient DMUs. It suggests that in case of a vehicle with surplus capacity, e.g., handling more documents than boxes, using smaller-capacity vehicles would perhaps increase the route efficiency. However, in practice, larger-capacity vehicles are still required for two reasons: one is to accommodate the oversized packages, which occur in most industrial zones; the other is to consolidate the packages at some meet-points to bring back to station the packages picked up by other smaller vehicles.

Likewise, altering workload (man-hour), route structure (mileage), and service area (size) are also promising strategies, which are associated with dynamic vehicle routing problem (DVRP). The key issues for DVRP include determining the optimal number of stops covered within a specific zone and determining the optimal routing sequences in response to the dynamic orders in a workday. For less efficient routes, overuse of man-hour and mileage imply that it is essential to adjust the number of stops and/or to rearrange the delivery and pickup sequences.

At station level, it can be observed that the highest efficiency is at station 4 while the least efficiency is at station 5. Note that station 4 is a small station containing only 10 pickup-oriented routes with no delivery-oriented route; while station 5 is a large station containing 53 pickup-oriented routes and 20 delivery-oriented routes. We also note that station 4 has been allotted with the least resources while station 5 has the largest resources, in terms of number of couriers and vehicles. For a small station, each route can be easily controlled by the station manager. In contrast, for a large station, the station manager may have difficulties in precisely allotting the resources to each route. As such, one managerial implication for the large inefficient station is to introduce more efficient dynamic vehicle routing strategy or to focus on less efficient routes with more intensive check-rides.

In general, stations with higher efficiency scores may exhibit higher returns to investment. Stations with lower efficiency scores should improve their performance before inputting more resources (couriers, vehicles, etc.). When evaluating whether a new expansion plan is introduced or not at the station level, the company can easily determine the priority based on the current station performance at hand. For example, station 4 with the highest efficiency score should have a priority in consideration of new investment over station 5, which has relatively lowest average efficiency score. Perhaps the company can consider splitting up station 5 into two or more stations so that more efficient routing plans or more effective check-rides can be exercised in the smaller service territories.

At route level, various factors, such as the courier behaviors, customer preference, and geographic factors, can lead to route inefficiency, too. For courier behaviors, the insufficient soft skill, improper vehicle routing, incorrect courier method, and erroneous coding may cause a low efficiency score. Additionally, customer preference could also profoundly affect the route inefficiency. Unprepared packages, incorrect order information, and insufficient shipping knowledge may negatively impact the couriers' on-road performance during the pick-up service. Moreover, the geographic factors could impact the route efficiency. The distance between the service station and the service area, the coverage of the service area, and the traffic condition (e.g., travel speed, parking constrain, one-way street, signalized control) could affect on-route performance. Based on our DEA results at hand, the station managers (company) can pay special attention to the relative inefficient routes or stations.

5. CONCLUDING REMARKS

The efficiency of ground operations has critically affected the overall efficiency of an air-express courier. Since the on-road activities have taken up a lion's share of the total ground working hours, gaining deep insights into the on-road pickup and delivery on a route-by-route basis is very important if one wishes to level up the overall courier efficiency. In this study, we assess the efficiency for some 248 on-road routes from an air-express courier in Taiwan by input-oriented DEA approaches. One of the contributions is that this study enhanced the practicability of DEA approaches to route level in contrast to previous works generally performing efficiency measurement at the company-wide level. The second contribution is to propose an EXO-CAT DEA model that has taken into account both continuous (stop density, traffic condition) and discrete (zone attribute) external factors as well as the internal factors (document-oriented, pick-up oriented, etc.) that may influence the route efficiency. Our results have revealed that such external factors as stop density, average travel speed, and zonal attribute have significant influence on the route efficiency. In addition, some internal factors relevant to handling activity (pickup or delivery) and package type (box or document), such as delivery percentage and document percentage, also have significant influence on the route performance.

There still exist some limitations and shortcomings with the DEA approaches. For example, measurement errors and other noise may influence the shape and position of the frontier and outliers may also affect the measured results [19]. Future research can adopt other frontier methods, such as stochastic frontier analysis [20], to evaluate the on-road couriers' route performance. If the prices for input factors are available, one can further decide the optimal bundles from the frontier estimated by the DEA, or, in turn, one can measure the overall (economic and technical) efficiency for DMUs, rather than just the technical efficiency as performed in the present paper. In practice, the on-road activities may get involved with traffic accidents; the vehicles may be ticketed or even towed-away because of illegal standing or parking. To measure the route efficiency in a fair manner, incorporating such undesirable outputs into the DEA models deserves further attempt.

In this study we have evaluated the technical efficiency for some 248 on-road courier routes from an air-express logistics service provider in Taiwan. It is of interest to further assess the performance by

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setting different peer groupings in the DEA analysis. In addition, one of the recent advances in DEA context is to measure efficiency by considering customers' satisfaction. One possible avenue for future study is to incorporate service quality factors, such as courier skill, standard operating practice, and pickup response time, into the DEA models so as to measure the route efficiency in a more impartial way. To accommodate the random on-call demands from customers, a technological tool for optimizing the routing strategies incorporated with the demand-responsive pickup services deserves further exploration.

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