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Toward Sustainable Ferry Routes in Korea: Analysis of Operational Efficiency Considering Passenger Mobility Burdens

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Abstract: With its long coastline, and numerous inlets and offshore islands, coastal ferry industries play a vital role in Korean maritime transportation. This study focuses on the southwestern part of Korea, Mokpo (which has the most inhabited islands and the highest proportion of elderly island residents), and aims to evaluate the impact of passengers' mobility burdens on the efficiency of ferry routes to achieve a better service for passengers. Integrated principal component analysis–data envelopment analysis and a fuzzy C-means clustering method were applied to analyze the efficiency of ferry routes in the Mokpo area. The efficiency results indicate that longer routes do not always achieve high-efficiency scores. The proportion of general passengers appears to influence the efficiency improvements of both general and subsidiary ferry routes. These findings can assist in better comprehending the relationship between passengers' mobility burdens and ferry route efficiencies; this will enable the authorities and ferry management departments to develop appropriate policies and strategies and to reconstruct certain features of the inefficient routes, thereby increasing operational efficiency, reducing mobility burdens, and improving the convenience of ferry travel and sustainability of Korean passenger routes.

Keywords: ferry route efficiency; passenger mobility burden; PCA-DEA; FCM

1. Introduction

Korea has a long coastline, and its southern and western sides are extremely complex, featuring numerous inlets and offshore islands. Therefore, an efficient coastal ferry industry is vital to both regional and national maritime transportation [1]. Regarding the administration of coastal ferry operations, the Korean government has implemented a management system to reorganize the operational processes; under this system, the Ministry of Oceans and Fisheries manages sea routes and issues operational licenses, and companies who wish to operate ferries must register therewith. The ferry passenger transport volume per year in Korea exceeds 14 million passengers, and it increased sharply in 2013 to 16 million passengers. However, following the sinking of the Sewol ferry in 2014, this volume decreased rapidly and has fluctuated until now; the volume is primarily affected by the fluctuation in general passengers (e.g., tourists), whilst the number of islanders remains largely unchanged (Statistical Yearbook 2019, Korean Shipping Association). According to the 2019 Statistical Yearbook of the Korean Shipping Association, the Mokpo area accounts for approximately 41.1% of total ferry transport volume; it is regarded as the busiest area in Korea in terms of ferry transport, followed by Yeosu and Masan with 13.5% and 13.0%, respectively. Mokpo is at the southwestern tip of the Korean peninsula, where the density of islands is highest; it is the busiest area for ferry operations. Moreover, Mokpo has a high proportion of elderly island residents who can easily experience mobility burdens when using transportation.

The "mobility burden" of passengers was initially defined as the physical and psychological burden incurred when passengers travel between an island and the mainland [2]; expressed otherwise, it can refer to the danger experienced in congested areas near the ferry and upon unmaintained sidewalks, the feelings of insecurity when passengers and vehicles share the same access routes inside the ferry terminals and the burdens of traversing slanting surfaces. Such environments can create situations that are dangerous to passengers. From an economic perspective, considerations of mobility burden are important for two main reasons: (1) these burdens can influence ferry usage likelihood and passenger safety, and they can negatively affect the passenger's experience; (2) if the burden factors are not identified and eliminated, transport-mode selections may be affected (e.g., passengers might choose to access the islands via airways or land bridges instead of ferries), and this could affect ferry efficiencies and directly influence the ferry operators' revenues. Moreover, it is vital for the sustainability of ferry routes in Korea; that is, we must understand how extensive the mobility burdens of ferry passengers are to maintain the mobility rights of island residents and tourists, improve their choice of transportation mode, and ensure the sustainability of ferry routes. Therefore, the mobility burdens of passengers should be more closely considered by both the ferry operators and the government.

This study uses an integrated principal component analysis–data envelopment analysis (PCA-DEA) model, to evaluate the efficiency of ferry routes by considering passenger mobility burden factors, and to solve the DEA model's limitations for a small sample space. Numerous DEA model applications have been reported in the literature under a wide range of fields. In particular, DEA models have been widely used to evaluate the performance of transportation networks, including road, railway, shipping, port, and aviation systems [3].

However, one limitation of the DEA model is that if the number of decision-making units (DMUs) is lesser than the combined number of inputs and outputs, a large portion of the DMUs will be identified as efficient; thus, efficiency discriminability between DMUs is lost [4]. Hence, the number of DMUs should significantly exceed the combined number of inputs and outputs [4]. To overcome these problems, it is useful to implement PCA. Principal components are less dependent on the measurement errors (statistical noise) of real-life data, and PCA can help retransform the original variables into a smaller number of non-correlated principal components to apply DEA models upon a small selected dataset. Therefore, Adler and Berechman [5] developed a PCA-based methodology to reduce the number of input (output) variables used in DEA into factors; this was applied to measure the quality of a west European airport from the airline's perspective. Furthermore, Chen [6] used a PCA-DEA integrated model to evaluate the operational efficiency of iron-ore logistics in the ports of Bohai Bay, China; the PCA-DEA model was found to be a practical and powerful tool for investigating the port logistics problem.

Moreover, researchers have classified selected ferry routes into clusters via the fuzzy C-means clustering method (FCM), analyzing their efficiency scores and physical characteristics separately to interpret meaningful conclusions from the clustering outcomes. Their results indicate that the method can help researchers investigate deeper into the operation of these ferry routes before a strategic decision is made. FCM is widely used in various fields as a tool for classifying data and identifying clusters and key properties therein [7].

In terms of efficiency, the present article conducts various studies to identify reasonable factors relevant to the mobility burden. The integrated PCA-DEA model is applied to measure the efficiency of all ferry routes in the Mokpo area. Finally, the FCM model is used to classify these ferry routes into clusters; to achieve this, it analyzes their efficiency scores and physical characteristics separately, to interpret the efficiency results more comprehensibly.

This article is organized as follows. Section 2 reviews the literature concerning the impacts of passengers on public transport, focusing upon ferry transport and highlighting the gaps in the existing research. Section 3 illustrates the employed methodologies. Section 4 describes the data collection process, the selection of related factors, and the model results. In Section 5, we present our discussion and some concluding remarks, which summarize the empirical findings.

2. Literature Review

Various studies have sought to assess customers' satisfaction in using public transportation and determine the factors influencing passengers' travel selections. Anderson et al. [8] presented the overall level of service (LOS) measures for airport passenger terminals in Sao Paulo, Brazil. They advised new LOS standards and their further application to other airports, to provide a more comprehensive understanding of the relationship between overall terminal measures and the LOSs associated therewith. The research of Jeon and Kim [9] considered the effects of service-scaping on customers' behavioral intentions in an international airport service environment. The results presented that functional, esthetic, safety, and social factors all influenced customers' positive emotions, whereas ambient (humidity, noise, temperature, light, etc.) and social factors affected customers' negative emotions. Bogicevic et al. [10] investigated which air travel factors were distractors and which were enhancers of passenger satisfaction in airports, by conducting a content analysis of 1095 traveler comments posted between 2010 and 2013 on an airport review website. The research of Singh [11] focused on assessing passenger satisfaction in public bus transport services in the city of Lucknow, India; he examined the service quality attributes that influence passenger satisfaction. Out of five considered factors, comfort and safety were found to have the greatest impact on overall satisfaction. Meanwhile, Wojuaden and Badiora [12] evaluated bus passengers' satisfaction with service quality attributes in Nigeria; from their results, the factors significantly influencing passenger satisfaction were accessibility and service reliability.

In the case of ferries, Mathisen, and Solvoll [13] surveyed ferry users' satisfaction with several service aspects in Norwegian ferries. Fares, discount schemes, and sufficient capacity in the summer received a low level of satisfaction from both enterprise and household respondents, though they were rated as highly important. The case of sea routes between the mainland and islands of Japan is almost the same as that of Korea. Aratani [2] initially defined the "mobility burden" as the physical and psychological burden incurred when passengers travel between the island and the mainland. He employed a questionnaire survey to determine the equivalent time parameter and psychological lost time, and to calculate the average time taken for residents of a remote island to travel thereto from the mainland. The results indicated that the mobility burden is higher in elderly residents than non-elderly residents. It was suggested that the installation of barrier-free measures in the transit facility, as well as the provision of information in the terminal and ferry boats, are most likely to reduce the average time required of passengers.

Efficiency evaluation studies using DEA have been utilized in various fields, especially in the seaport, maritime transportation, and ferry route efficiency. However, research on efficiency analysis for ferry routes has been limited with an insufficient level. In terms of seaports, Roll and Hayuth [14] implemented a DEA-CCR model to measure the efficiency of 20 ports around the world, using the labor-force size, annual investment, and uniformity of facilities and cargo as the input variables, as well as the container volume, service level, user satisfaction, and ship calls as the output parameters. Tongzon [15] used CCR and additive models to compare the operational efficiencies of four Australian ports and 12 international container ports. The results revealed that the Melbourne, Sydney, and Fremantle ports required considerable government attention to enhance their efficiencies. Wang and Cullinane [16] used DEA to measure the efficiencies of 104 European container terminals; they confirmed that the efficiencies of different container ports vary according to locations and times; consequently, they confirmed the need for different DEA panel data. Park [17] analyzed the efficiency of 11 container terminals in Busan and Gwangyang ports, and Kim and Hwang [18] analyzed the efficiency of major container ports in Korea and China, by comparing the results of the transportation process before and after the 2008 Financial Crisis. Ferreira et al. [19] measured the performances of seaports using a robust, nonparametric, output-oriented order-α model, integrating this with a stochastic multi-criteria acceptability analysis model (of order-α), to manage cases of incomplete knowledge. Zarbi et al. [20] concluded that Iranian port and shipping-line operations during the period 2012–2018 presented huge challenges to Iranian seaports and maritime trades.

In terms of maritime transportation, studies have primarily considered the efficiencies of major global shipping companies. Lun and Marlow [21] used a DEA model containing both financial and non-financial variables to evaluate the operational efficiencies of major global container-shipping companies during 2008. Their results indicated that small operators (with a market share of 5% or less) could operate their firms efficiently. Huang et al. [22] identified efficiency differences across strategic clusters of 17 global container liners, using a DEA model; their results indicated significant differences in efficiency across the following strategic clusters: proactive-prudent, proactive-chance, conservative-prudent, and conservative-chance. Meanwhile, Gong et al. [23] illustrated the impacts of pollution by measuring the economic and cargo efficiencies of 26 leading international shipping companies, both with and without the negative pollution factor. The findings were provided to public policymakers, to assist them in reducing emissions from shipping; to shipping companies, to assist in developing marketing strategies; and to shipping investors, to improve their investment strategies.

Limited studies have evaluated ferry route efficiency. Baird [24] investigated the efficiency of competing ferry services on the Pentland Firth between Scotland and the Orkney islands, offering an improved understanding from an interdisciplinary perspective. In 2010, Lee et al. [25] focused on measuring the efficiency of 14 car ferry routes between Korea and China, using a dataset (e.g., vessel size, passenger and container capacity, cargo volume, number of passengers). Meanwhile, Park et al. [1] assessed the operational efficiency of a South Korean coastal ferry by considering the impact of ferry disasters; they used a DEA-window and source-based morphometry-DEA analysis. The results revealed that the overall efficiency decreased from 2014 to 2015, following the sinking of the Sewol ferry off the coast of South Korea.

Moreover, researchers have classified selected ferry routes into clusters via the fuzzy C-means clustering method (FCM), which is widely used in various areas as a tool to categorize data and identify key clusters. In terms of economics, Zhou [26] attempted to analyze the influencing factors of the financial market on shipping lines; the study indicated that effective compartmentalizing clustering could be used to measure the standards of good and bad clustering. Yin [27] studied the clustering of supply chain units, transportation modes, and work orders into different unit-transportation-work order groups. This research proved that FCM is an efficient tool to cluster data, especially in high-dimensional datasets.

However, because ferry passengers account for a minor percentage of public transport, several previous studies have considered airway or bus passengers' satisfaction; however, none have researched the mobility burdens of passengers and their impacts on the efficiency of the ferry route. To enhance the sustainability of Korean ferry sea routes, it is vital to improving ferry passengers' convenience. Therefore, in this study, we try to fill the gap by identifying the factors related to passenger mobility burdens and applying these factors to measure the efficiency of ferry routes.

3. Methodology

3.1. Data Envelopment Analysis

DEA is one of the more practical methods of evaluating the efficiency of ferry routes; it was developed by Charnes, Cooper, and Rhodes [28]. The two most widely used DEA models are DEA-CCR [28] and DEA-BCC [29]; the CCR model assumes a constant return to scale (CRS), and the BCC model assumes a variable return to scale (VRS). A CRS implies that a change in the input will lead to a similar change in the number of outputs, and all observed production combinations can be scaled up or down proportionally. In contrast, the BCC model allows for VRS and is graphically represented by a piecewise linear convex frontier.

1. DEA-CCR model

CCR is the first DEA model to be developed, named CCR after Charnes, Cooper, and Rhodes who introduced this model in an article in the *European Journal of Operation Research* [28]. In DEA models, we evaluate n DMUs; each consumes varying proportions of m different inputs to generate s different outputs. Specifically, $\mathrm{DMU_j}$ consumes $\mathrm{X_j} = [\mathrm{x_{ij}}]$ of inputs ($i = 1, \ldots, m$) and produces $\mathrm{Y_j} = [\mathrm{y_{rj}}]$ of outputs ($r = 1, \ldots, s$). The relative efficiency for $\mathrm{DMU_0}$ is calculated by maximizing the weighted sum of the target output; this sum is equal to unity. The differences between the weighted sums of the outputs and inputs are smaller than zero and expressed as:

$$Max\ \theta = \sum_{r=1}^{s} u_r y_{rj0}$$
$$\begin{cases} s.t.\ \sum_{i=1}^{m} v_i x_{io} = 1, \\ \sum_{r=1}^{s} u_r y_{rj} - \sum\limits_{i=1}^{m} v_i x_{\mathrm{ij}} \le 0,\ j = 1, \ldots, n, \\ u_r \ge 0,\ r = 1, \ldots, s, \\ v_i \ge 0,\ i = 1, \ldots, m. \end{cases} \quad . \tag{1}$$

Here, u_r and v_i are weights assigned to output r and input i, respectively. $\mathrm{DMU_0}$ is CCR efficient if $\theta^* = 1$ and there exists at least one optimal solution such that $\mathrm{v_r}^* > 0$ and $\mathrm{u_i}^* > 0$ are optimal solutions of Equation (1). Otherwise, $\mathrm{DMU_0}$ is inefficient.

2. DEA-BCC model

The BCC model is named after Banker, Charnes, and Cooper who first introduced this model in an article published in *Management Science* [30]. The BCC model is expressed as:

$$Max\ \theta = \sum_{r=1}^{s} u_r y_{rj0} - u_0$$
$$\begin{cases} s.t.\ \sum_{i=1}^{m} v_i x_{io} = 1, \\ \sum_{r=1}^{s} u_r y_{rj} - \sum\limits_{i=1}^{m} v_i x_i - u_0 \le 0,\ j = 1, \ldots, n, \\ u_r \ge 0,\ r = 1, \ldots, s, \\ v_i \ge 0,\ i = 1, \ldots, m. \end{cases} \quad . \tag{2}$$

If DMU is CCR efficient, then it is also BCC efficient.

By computing the above model for each DMU, the BCC efficiency scores can be obtained. These scores are referred to as "pure technical efficiency scores." For each DMU, the CCR efficiency score does not exceed the BCC efficiency score; the only exception to this is $\mathrm{u_0}$, which may be positive, negative, or zero, represent the situation of scale returns; all variables of the function in Equation (2) are constrained to be non-negative. The DEA-CCR and BCC models described above were used to evaluate the efficiency of ferry routes. Through these two models, the scale of efficiency (SE) was calculated to determine the profit according to the scale. In this article, the DMUs are the 38 ferry routes, $\mathrm{x_i}$ is represented for the i input variable, and $\mathrm{y_r}$ is represented for the r output variable. The results are calculated through Max-DEA software.

3.2. Fuzzy C-Means Clustering Method

FCM is a concept clustering method that expands upon hard C-means clustering using a fuzzy set theory. FCM was developed by Dunn [31] and improved by Bezdek in 1981 to manage the problem of overlapping clusters; it employs fuzzy theory to assign data to a plurality of clusters, using the membership degree between 0 and 1 to describe states that do not completely belong to a specific cluster [30]. However, in classical FCM, users must initially designate several clusters, which might be subjectively based on users' ideals; thus, the results might not be entirely reliable. To tackle this important problem in the classification process, Park et al. [32] proposed a new fuzzy clustering algorithm that could calculate the optimal number of clusters for a dataset, and they developed a new algorithm by modifying the increment and re-initialization algorithms.

Optimal fuzzy cluster number:

Let X = {x_1, x_2, ... , x_n} be a set of data in a *p*-dimensional space, where *n* denotes the amount of data and *p* is the number of data properties.

- Step 1: Select number of cluster c (2 ≤ c < n), fuzzy factor m (1 < m < ∞), and convergence criterion ε.
- Step 2: Set the initial values of the c partitioning matrixes $U^{(l)}$ (membership) as appropriate $U^{(l)}{}_{l=0.}$
- Step 3: Calculate the center *v* of each cluster using Equation (4).

To classify the data into clusters, we express the non-inference of each cluster's center and the data as the Euclidean distance, as follows:

$$d_{ik} = \|X_k - V_i\|. \tag{3}$$

Meanwhile, the center of the cluster is expressed as:

$$v_i = \frac{\sum_{k=1}^{n} (U_{ik})^m x_k}{\sum_{k=1}^{n} (U_{ik})^m}. \tag{4}$$

We update $U_{ik}{}^{(l+1)}$ using:

$$U_{ik} = \left(\sum_{j=1}^{c} \left(\frac{x_k - v_j}{x_k - x_j} \right)^{2/(m-1)} \right)^{-1} \forall i, \forall \mathrm{j}. \tag{5}$$

The larger the value of m, the fuzzier the partition. If $\|U^{(l+1)} - U^{(l)}\| \leq \varepsilon$, the process ends; otherwise, it returns to Step 2. The results obtained are the optimal clustering results for c = 2.

- Step 4: Calculate the objective function.

The optimal number of clusters can be determined from the number of clusters minimized in Equation (6) and the increase in clusters when the difference in values is below the threshold value (i.e., the number of clusters is increased one by one):

$$\mathrm{S(c)} = \sum_{k=1}^{n} \sum_{i=1}^{c} (U_{ik})^m \left(\|x_k - v_i\|^2 - \|v_i - \overline{x}\|^2 \right), \tag{6}$$

where $\overline{x}$ denotes the average.

- Step 5: Increase number of clusters c = 3, 4, ...

We repeat Steps 1–4 until a minimal value of Equation (6) is achieved or the condition $\left| S(c+1) - S(c) \leq M \right|$ is satisfied. Here, M is a threshold number. In this article, the set data is the ferry routes with dimensional factors are efficiency scores or natural characteristics of ferry routes. The results are calculated through coding supporting software named DEV-C++.

4. Influence of Passenger Mobility Burdens on the Efficiency of Ferry Routes

In this section, we conduct a literature review to select some potential factors relating to passengers' mobility burdens; then, we evaluate the operational efficiency of all ferry routes in Mokpo, the busiest area in Korea in terms of ferry transport.

Data Collection

Generally, the ferry ships considered in this study have a deck for loading and transporting vehicles and passengers from the mainland to islands and between islands. These ferry ships can carry various types of cars on their rough-surface decks and passengers on the upper deck, which is referred to as a room for passengers to stay. The passengers aboard the ferry via its adjustable ramp, which acts as a wave guard and is lowered to a horizontal position at the terminal to connect with a permanent road segment that extends underwater; then, the passengers ascend the stairs leading to the upper deck. On long-distance routes, the ferry ship is designed as a cruise-ferry, combining the features of a cruise ship with those of a roll-on/roll-off ferry; thus, vehicles and passengers can board and disembark via separate routes. On short- and moderate-distance routes (which constitute a large part of the Korean ferry network), the ferry ship typically has an open-structured design, with only one way to board and disembark the ship; this path is shared between vehicles and passengers, as shown in Figure 1. Therefore, ferry ships on short- and moderate-distance routes present considerable dangers to passengers than long-distance ones.

(**a**) (**b**)

Figure 1. Ferry ship mainly considered in the study: (**a**) front side; (**b**) lateral side.

To identify which factors should be considered as a burden to passengers, our research team filmed more than ten videos in different ferry passenger terminals in the Mokpo area (including Wando, Songgong, and Heanam), as ferry users boarded and disembarked vessels. Through visual analysis, we identified various problems and potential dangers that might affect ferry users. For example, Figures 2 and 3 illustrate the movements of ferry passengers as they board the ferry. Figure 2 was taken in the dock of an island's ferry terminal; in the figure, four passengers can be seen walking and talking to each other, whilst being surrounded by numerous cars on both sides as they enter and leave the dock. The arrow represents the direction of the car's movement. This terminal has a narrow entry and exit walkway and no dedicated path for ferry users. Figure 3 was taken in a big terminal; a passenger boards the ferry, carrying a heavy box; however, the truck has not yet disembarked the ferry. In this terminal, the ferry operator and passenger do not abide by safety rules while using the ferry.

These situations occur not only in Mokpo but in all ferry terminals across Korea. Mokpo accounts for the highest proportion of passenger volume, and there are numerous older and smaller ferries serving the small islands; therefore, it is easier to encounter difficulties, unsafety, and discomfort. Hence, this study first focuses on Mokpo as a preliminary research area; then, it begins to consider the whole of Korea.

The analysis dataset includes 38 ferry routes, as shown in Figure 4; these include both general and subsidiary sea routes in the Mokpo area, for the year 2019. In general, a sea route is a route upon which a ferry operator operates under a business license for passenger carriage by sea; meanwhile, a subsidiary sea route is one in which the Ministry of Oceans and Fisheries orders a ferry operator to operate the ferry, to provide the necessary transportation for remote islanders; these routes receive compensation for the operational benefit losses caused by the operation. The dataset was assembled using the Statistical Yearbook of the Korean Shipping Association and the website of the Mokpo Regional Office of Oceans and Fisheries.

Figure 2. Example of ferry users not having a dedicated way when getting off the ferry.

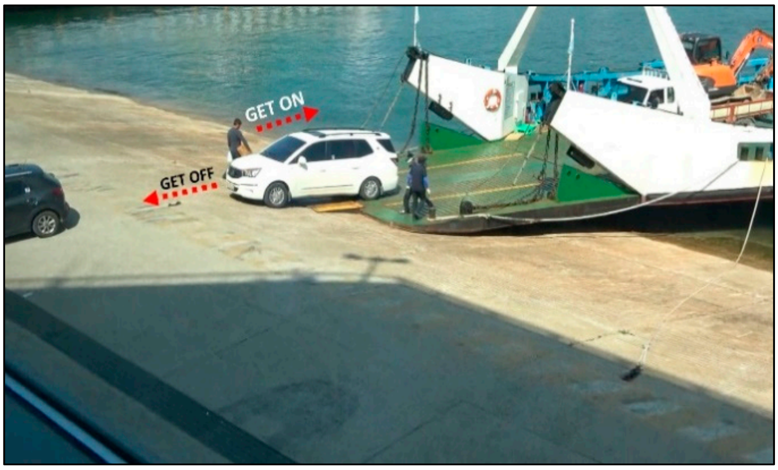

Figure 3. Example of danger when getting on/off the ferry.

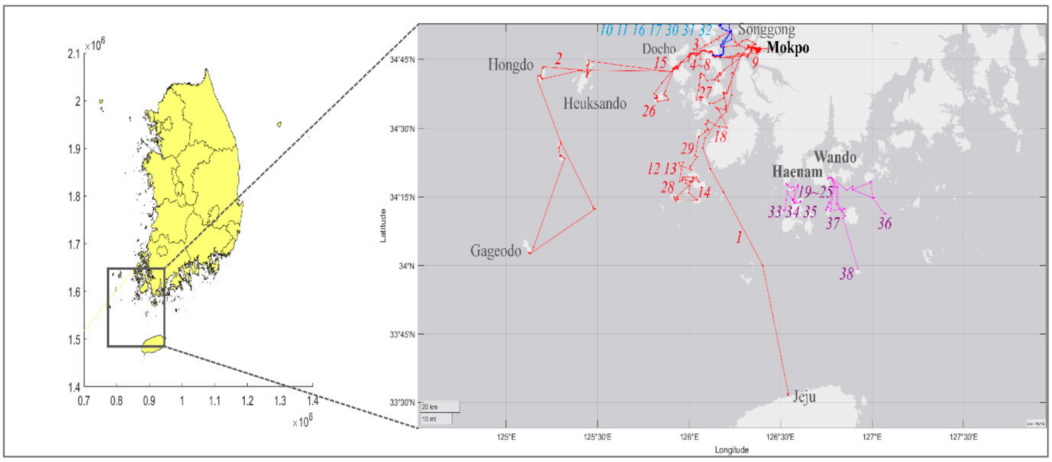

Figure 4. Coastal ferry sea routes in Mokpo, Korea. Source: Illustrated by authors.

It is essential to identify the input and output factors to measure efficiency because these can affect the analysis results. Inputs and outputs must be selected to satisfy the evaluation purpose. Heretofore, no research into ferry passengers' mobility burdens has been reported in the literature. However, it can be claimed that passenger satisfaction-related factors might also influence their mobility burdens, as shown in Table 1.

Table 1. Research into input and output factors.

Input Factors	Researches
Yearly operation and cancellation times	Thapanat [33], Mathisen and Solvoll [27], Singh [1]
Frequency of sailing per week	Correia et al. [8], Jeon and Kim [24], Mathisen and Solvoll [27]
Number of ships	Correia et al. [8], Jeon and Kim [24], Mathisen and Solvoll [27], Lee et al. [15]
Vessel gross tonnage	Singh [1], Christopher and Adewumi [12], Mathisen and Solvoll [27], Lee et al. [15]
Voyage time	Correia et al. [8], Jeon and Kim [24], Silva and Wanniarachchi [34], Weng et al. [35]
Voyage distance	Correia et al. [8], Jeon and Kim [24], Silva and Wanniarachchi [34]
Distance from the ticket office to the ramp of ferry ship	Correia et al. [8], Jeon and Kim [24], Silva and Wanniarachchi [34], Mathisen and Solvoll [27]
Output Factors	**Researches**
Number of passengers	Park et al. [7], Mathisen and Solvoll [27], Singh [1], Lee et al. [15]
The proportion of general passengers	Correia et al. [33], Jeon and Kim [24], Mathisen and Solvoll [27]
Proportion of islanders	Correia et al. [33], Jeon and Kim [24], Mathisen and Solvoll [27]

The annual operation times, cancellation times, per-week sailing frequency, number of ships, gross vessel tonnage, voyage time, voyage distance, and walking distance from the ticket office to ferry ship ramp were collected as input factors; meanwhile, the number of passengers and the proportions of general passengers and islanders were collected as output factors. In terms of input factors, the operation frequency refers to the number of ferry operations per year, excluding the cancellation times in the operation plan; the cancellation frequency refers to the number of ferry ship cancellations per year, caused by deteriorating weather conditions, a decrease in passenger numbers, or maintenance requirements; meanwhile, the per-week sailing frequency is the number of regular operations per week. These three factors can influence the likelihood of passenger selection and mobility.

The number of ships, gross vessel tonnage, voyage time and distance (the time and distance took to complete a ferry route), and walking distance from the ticket office to the ferry ship ramp can affect passengers' fatigue. In particular, the walking distance (shown in Figures 5 and 6) refers to the distance that passengers must traverse from the ticket office to the ferry ship's ramp. This distance was directly measured in the Mokpo terminal and those of several nearby islands. Some large ferry terminals (illustrated in Figure 5) have separate queueing lines for vehicles, allowing passengers to board the ferry first; furthermore, the location of the ferry terminal is on the side, isolating the passengers and vehicles from each other. Meanwhile, several small ferry terminals [especially those located on islands (as illustrated in Figure 6)] do not have separate queueing lines for vehicles. Although the passengers and vehicles can board the ferry ship more rapidly, accidents are more likely as a result of the intersecting paths. Therefore, the walking distance is directly proportional to the inconvenience measured as a burdening factor for the passengers. The longer the walking distance, the greater the fatigue and the more tired the passengers. Moreover, the walking distance crosses various terrains and correspondingly presents further problems [e.g., the burden of transfer movement (e.g., moving up or downstairs, passing through a rough or dipped road, etc.] and hazards arising from other vehicles moving on the same path. Therefore, these factors are also regarded as relevant to passengers' mobility burdens and route efficiency. As the output factors, the number of passengers, the proportion of general passengers, and the proportion of islanders were measured according to the ferry's purpose.

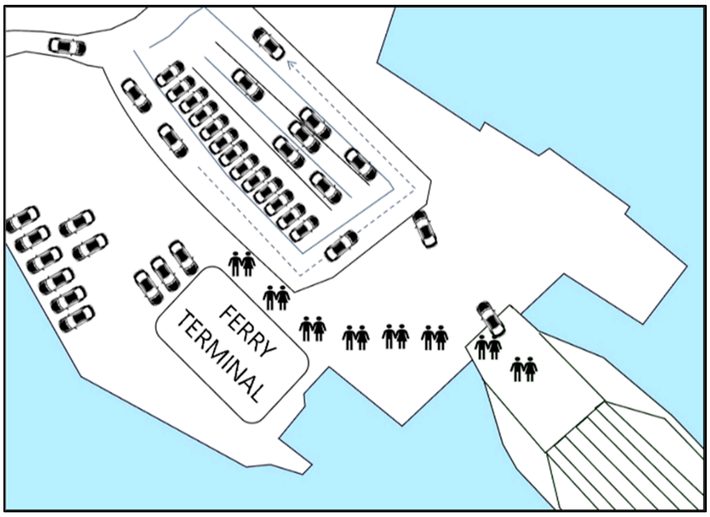

Figure 5. Example of a big ferry terminal. Source: Illustrated by authors.

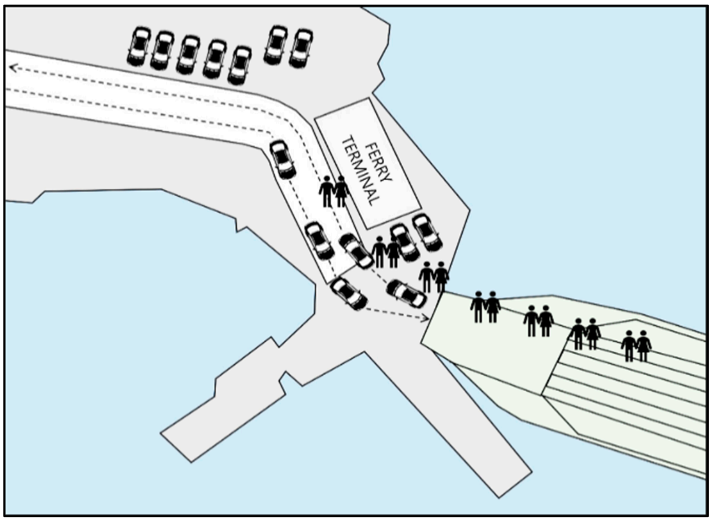

Figure 6. Example of a small ferry terminal. Source: Illustrated by authors.

The data were assembled through the Statistical Yearbook of the Korean Shipping Association and the website of the Mokpo Regional Office of Oceans and Fisheries. It is essential to verify the correlations (i.e., the extent of the relationships connecting two factors) before applying the model. Table 2 shows that significant correlations pertain among the input factors and output factors; the most notable examples are those between the per-week sailing frequency(Fr) and annual operation times (OT) (0.947), the annual operation times (OT) and cancellation times (CT) (0.866), the voyage distance (VD) and voyage time (VT) (0.78), and the proportion of general passengers (PG) and proportion of islanders (PI) (complete correlation). In this case, it is beneficial to eliminate one of the complete correlation factors; because most ferry routes concentrate on attracting more tourists, the proportion of general passengers is maintained whilst eliminating the proportion of islanders. In terms of inputs, several factors exhibit a high correlation, and we propose to transform them into a smaller number of uncorrelated factors. PCA was first introduced by Pearson [36] to describe the variation of a set of uncorrelated variables—so-called "principal components"—in a multivariable data set; here, we apply it to implement the proposed idea. To this end, PCA uses the eigenvectors and eigenvalues of the covariance matrix to compute principal components, and the initial input data are expressed as a linear combination of these principal components. The principal components are sorted in order of decreasing "significance" or strength; thus, the size of the data can be reduced by either eliminating the weak components or reconstructing a favorable approximation of the original data with a smaller number of factors.

Table 2. Correlation between factors.

Factors	Considered Input Factors								Considered Output Factors			
	VD	VT	OT	CT	NV	GT	Fr	WD	Factors	NP	PG	PI
VD	1.000								**NP**	1.000		
VT	0.780 *	1.000							**PP**	0.372 **	1.000	
OT	−0.414 *	−0.395 **	1.000						**PI**	−0.372 **	−1.000 *	1.000
CT	−0.214	−0.243	0.866 *	1.000								
NS	0.162 *	−0.052	0.581 *	0.771 *	1.000							
GT	0.577 *	0.172	−0.001	0.011	0.148	1.000						
Fr	−0.525 *	−0.489 *	0.947 *	0.755 *	0.450 *	−0.027	1.000					
WD	0.007	−0.139	−0.046	0.023	−0.046	0.174	−0.003	1.000				

* $p < 0.01$; ** $p < 0.05$. Note: VD: voyage distance; VT: voyage time; OT: operation times; CT: cancellation times; NS: number of ships; GT: gross tonnage; Fr: frequency; WD: walking distance from ticket box to the ramp; NP: number of passengers; PG: the proportion of general passengers; PI: the proportion of islanders.

In Table 3, the eigenvalues that exceed 1 are used to determine the number of principal components. Eight factors were reduced to three components, with more than 86% of the total variance explained. The Kaiser–Meyer–Olkin measure sampling adequacy (KMOMSA) varies between 0 and 1, and a value of 0.6 was suggested as a minimum. In this case, both samples' KMOMSA indicators exceeded 0.6, implying the results are reasonable. Table 3 details the component loadings; these are the correlations between the original factors and principal components. The principal components are interpreted by identifying which factors are most strongly correlated with each component (correlation > 0.5). The first principal component for general sea routes (which is the second principal component for subsidiary sea routes) strongly correlates with three original factors (annual cancellation times, operation times, and per-week sailing frequency). This suggests that these three factors vary together, and if one is increased, then the remaining factors will also increase. This component can be viewed as a measure of service availability, which represents the percentage of time a ferry ship remains operational under normal circumstances. Furthermore, the first principal component correlates strongest with the cancellation times; therefore, the cancellation time has the most significant influence on service availability.

The second principal component for general sea routes increases under an increase in four original factors: number of vessels, gross tonnage, voyage distance, and voyage time. It is viewed as a measure of service adaptability, which refers to the ability of the service to adapt to changing circumstances. Thus, the components that affect passenger comfort during the voyage include the number and sizes of vessels and the duration they remain on-board. This component correlates strongly to voyage distance and voyage time; thus, the duration that the passengers must remain on board is directly proportional to their fatigue or tiredness.

The final principal component increases with only one of the values: walking distance from the ticket office to the ferry's adjustable ramp. This component can be viewed as a measure of accessibility inside the passenger terminal, which can influence passengers'—especially elderly passengers—mobility burdens. It refers to the distance passengers must walk to access ferry services.

After transforming the original input factors to the principal components (service availability, service adaptability, and service accessibility) and combining them with the output factors, the DEA model is used to measure the efficiency of ferry routes in Mokpo. The details of the original data and calculated principal components are shown in Tables A1 and A2 (see Appendix A). The results are as follows.

Table 3. Results of PCA for general sea routes and subsidiary sea routes.

Factor	Load of the Principal Components of the Input Indicators (General Sea Routes *)			Factor	Load of the Principal Components of the Input Indicators (Subsidiary Sea Routes **)		
	Principal Component 1	Principal Component 2	Principal Component 3		Principal Component 1	Principal Component 2	Principal Component 3
Cancellation times	0.950	−0.043	0.002	Voyage times	0.947	−0.182	−0.175
Operation times	0.917	−0.303	−0.026	Gross tonnage	0.925	−0.083	−0.047
Frequency	0.817	−0.465	0.047	Number of ships	0.916	−0.181	0.094
Number of ships	0.347	0.782	−0.214	Voyage distance	0.871	−0.103	−0.315
Voyage distance	−0.126	0.977	0.032	Cancellation times	−0.012	0.882	−0.237
Voyage Time	−0.262	0.888	−0.050	Operation Times	−0.221	0.860	0.379
Gross tonnage	0.083	0.766	0.231	Frequency	−0.257	0.726	0.343
Walking distance	−0.077	0.125	0.960	Walking distance	−0.105	0.119	0.910
Eigenvalues	3.722	2.200	1.001	Eigenvalues	4.174	1.723	1.008
% variance explained	46.528	27.495	12.475	% variance explained	52.170	21.541	12.602

Note: * Kaiser Meyer Olkin Measure Sampling Adequacy = 0.617, X = 189.18, Bartlet's Test of Sphericity Significance = 0.00, df = 28; ** Kaiser Meyer Olkin Measure Sampling Adequacy = 0.688, X = 72.673, Bartlet's Test of Sphericity Significance = 0.00, df = 28.

The ferry routes in the Mokpo area include the Mokpo city and Wando area routes. In Table 4, 18 and seven general sea routes can be seen currently in operation in Mokpo and Wando, respectively. The results reveal that seven routes in Mokpo (38%) and four routes in Wando (57%) are regarded as fully efficient routes. Thus, these routes are now operating effectively and should maintain their present operating scales and relatively high operational efficiencies. The general sea routes in the Wando area have a relatively high-efficiency score, with the lowest being 0.7409 (the Dangkuk-Sinyang route). The decreasing return to scale on the Dangkuk-Sinyang route implies that the route should reconstruct its input factors [e.g., reducing the cancellation times (2810 cancellations in 2019)] to obtain higher efficiency. Meanwhile, some general sea routes in Mokpo city have a relatively low-efficiency score [e.g., Songgong-Peungpong (0.478), Mokpo-Sangdaeseori (0.5143), Docho-Mokpo (0.5331), Mokpo-Sangdaedongri (0.5378), and Songgong-Sinwol (0.5659)]. These routes, except for the Docho-Mokpo route, exhibit both pure-technical and scale inefficiencies. This implies that these routes cannot serve a large number of passengers due to their inefficient use of inputs. Therefore, these routes must improve their competitive position by attracting more passengers (especially tourists) and better managing their resources.

Next, the FCM method was used to classify these ferry routes into clusters, considering their efficiency scores and physical characteristics separately to provide a more comprehensive view of the DEA results. The first classification was made using the CCR and BCC efficiency scores and the type of ferry route. In general, two types of ferry routes are in operation: one travels directly from the starting terminal to the destination, while the other visits several terminals before arriving at the final destination. The single-destination ferry routes in the Mokpo area are primarily short-distance ones, operating small ferry ships; the exceptions to this are the Mokpo-Jeju and Songgong-Heuksan routes, which are specialized for tourism purposes and operated by large ferry ships. The multi-destination ferry routes run longer distances with larger ships, in the areas containing numerous islands, see Table 5.

Table 4. The efficiency results for general sea routes.

Route ID	Area	DMU	CCR	BCC	SE	RTS
1	Mokpo	Mokpo-Jeju	1.0000	1.0000	1.0000	Constant
2		Mokpo-Hongdo	0.7855	0.7886	0.9961	Increasing
3		Mokpo-Kasan	0.7129	0.9380	0.7601	Increasing
4		Mokpo-Docho [1]	1.0000	1.0000	1.0000	Constant
5		Docho-Mokpo [1]	0.5331	1.0000	0.5331	Increasing
6		Mokpo-Sangdaeseori	0.5143	0.8687	0.5920	Increasing
7		Mokpo-Amtae	0.8827	1.0000	0.8827	Decreasing
8		Mokpo-Sangdaedongri	0.5378	0.7958	0.6758	Increasing
9		Mokpo-Waedaldo	0.8214	0.8636	0.9512	Increasing
10		Songgong-Sinwol	0.5659	0.8159	0.6936	Increasing
11		Songgong-Peungpong	0.4780	0.8228	0.5809	Increasing
12		Paengmok-Seogeocha	1.0000	1.0000	1.0000	Constant
13		Yulmok-paengmok	0.7137	0.7782	0.9171	Increasing
14		Jilli-Jeonam	1.0000	1.0000	1.0000	Constant
15		Songgong-Heuksan	1.0000	1.0000	1.0000	Constant
16		Jeungdo-Jaeundo	1.0000	1.0000	1.0000	Constant
17		Hyanghwa-Songyi	1.0000	1.0000	1.0000	Constant
18		Swimi-Kasa	0.7799	1.0000	0.7799	Increasing
19	Wando	Dangmok-Ilcheong [1]	1.0000	1.0000	1.0000	Constant
20		Ilcheong-Dangmok [1]	0.9999	1.0000	0.9999	Increasing
21		Dangkuk-Sinyang	0.7409	1.0000	0.7409	Decreasing
22		Hwahongpo-Soyan	0.9062	0.9606	0.9433	Decreasing
23		Dangmok-Seoseong	1.0000	1.0000	1.0000	Constant
24		Noryeok-Kihak	1.0000	1.0000	1.0000	Constant
25		Wando-Cheongsan	1.0000	1.0000	1.0000	Constant

Note: CCR—technical efficiency; BCC—pure technical efficiency; SE—scale efficiency; RTS—return to scale; [1] Some routes are marked separately due to different operators.

Table 5. The efficiency results for subsidiary sea routes.

Route ID	Area	DMU	CCR	BCC	SE	RTS
26	Mokpo	Mokpo-Wooyi	1.0000	1.0000	1.0000	Constant
27		Bukkang-Bukkang	1.0000	1.0000	1.0000	Constant
28		Mokpo-Yulmok	1.0000	1.0000	1.0000	Constant
29		Paengmok-Jukdo	1.0000	1.0000	1.0000	Constant
30		Hyanghwa-Nakwol	1.0000	1.0000	1.0000	Constant
31		Kyemi-Anma	0.7533	0.9105	0.8273	Increasing
32		Bongli-Jewon	0.8920	0.9813	0.9090	Increasing
33	Wando	Yimok-Eoryong	1.0000	1.0000	1.0000	Constant
34		Yimok-Dangsa	0.6603	1.0000	0.6603	Increasing
35		Yimok-Namseong	0.5857	0.8626	0.6790	Increasing
36		Wando-Deokwoodo	0.9743	1.0000	0.9743	Increasing
37		Wando-Modo	1.0000	1.0000	1.0000	Constant
38		Wando-Yeoseo	1.0000	1.0000	1.0000	Constant

Note: CCR—technical efficiency; BCC—pure technical efficiency; SE—scale efficiency; RTS—return to scale.

Table 6 presents the clustering results for general sea routes. The first cluster includes all fully efficient and several near-fully efficient general sea routes (e.g., the Hwahongpo-Soyan route); this is followed by the second cluster, which includes routes with a full BCC (pure-technical) efficiency but lacking in CCR (technical) efficiency. The other two clusters both feature technical and pure-technical inefficiencies in descending order, except for the Docho-Mokpo route.

Table 6. Clustering results by efficiency scores (general sea routes).

Cluster	Route ID	Ferry Route	CCR	BCC	Drop-by Terminals
1 (Best)	1	Mokpo-Jeju	1.000	1.000	go nonstop
	4	Mokpo-Docho	1.000	1.000	3 terminals
	12	Paengmok-Seogeocha	1.000	1.000	1 terminal
	14	Jilli-Jeonam	1.000	1.000	1 terminal
	15	Songgong-Heuksan	1.000	1.000	go nonstop
	16	Jeungdo-Jaeundo	1.000	1.000	go nonstop
	17	Hyanghwa-Songyi	1.000	1.000	go nonstop
	19	Dangmok-Ilcheong	1.000	1.000	go nonstop
	20	Ilcheong-Dangmok	1.000	1.000	1 terminal
	22	Hwahongpo-Soyan	0.906	0.961	1 terminal
	23	Dangmok-Seoseong	1.000	1.000	go nonstop
	24	Noryeok-Kihak	1.000	1.000	go nonstop
	25	Wando-Cheongsan	1.000	1.000	go nonstop
2	7	Mokpo-Amtae	0.883	1.000	6 terminals
	18	Swimi-Kasa	0.780	1.000	4 terminals
	21	Dangkuk-Sinyang	0.741	1.000	5 terminals
3	2	Mokpo-Hongdo	0.786	0.789	4~7 terminals
	9	Mokpo-Waedaldo	0.821	0.864	go nonstop
	13	Yulmok-paengmok	0.714	0.778	2 terminals
	3	Mokpo-Kasan	0.713	0.938	5 terminals
4 (Worst)	5	Docho-Mokpo	0.533	1.000	3 terminals
	6	Mokpo-Sangdaeseori	0.514	0.869	6 terminals
	8	Mokpo-Sangdaedongri	0.538	0.796	2 terminals
	10	Songgong-Sinwol	0.566	0.816	8 terminals
	11	Songgong-Peungpong	0.478	0.823	3 terminals

Thirteen routes are located in the first (best) cluster, three in the second cluster, four in the third cluster, and five in the worst cluster. All general sea routes are consistent in having high or full pure-technical efficiency scores. The primary cause for inefficiency is considered to be scale inefficiency, which forces the inefficient routes to increase their operation size to increase their efficiency (except for the Mokpo-Amtae route, which should decrease its size to adjust its efficiency). The Mokpo-Amtae route (which has the highest number of passengers) has a lower efficiency score in comparison with the Hwahongpo-Soyan route, which has a similar distance, voyage time, number of vessels, and gross tonnage characteristics. Although the Mokpo-Amtae route operates almost twice as often and has high cancellation times, its number of passengers cannot exceed 1.5 times that of the Hwahongpo-Soyan route. The Mokpo-Amtae route must re-adjust its resources to economize its input factors and simultaneously maximize its outputs.

Two other large routes, Dangkuk-Sinyang and Mokpo-Hongdo, are in the same situation: they cannot achieve high-efficiency scores owing to a lack of ensured service reliability; while the former has too many canceled services per week, the latter exhibits too many canceled services per year, when compared against similar routes (Wando-Cheongsan and Mokpo-Jeju, respectively).

Moreover, in terms of ferry route types, single-destination general sea routes seem to have higher efficiency scores in comparison with multi-destination routes. It is confirmed that eight of the thirteen routes in the best cluster are single-destination routes, four routes have only two destinations, and one route has four destinations. The ferry routes with several destination terminals [e.g., Mokpo-Hongdo (4–7 terminals) and Songgong-Sinwol (8 terminals)] have low-efficiency scores.

Similar to the general sea routes' results, Table 7 presents the clustering results for subsidiary sea routes. The best cluster includes all fully efficient general sea routes; the second cluster includes routes exhibiting moderate technical efficiency scores and high pure-technical efficiency scores. The final cluster exhibits technical and pure-technical inefficient routes in descending order.

Table 7. Clustering results by efficiency scores (subsidiary sea routes).

Cluster	Route ID	Ferry Route	CCR	BCC	Drop-by Terminals
1 (Best)	26	Mokpo-Wooyi	1.000	1.000	6 terminals
	27	Bukkang-Bukkang [1]	1.000	1.000	5 terminals
	28	Mokpo-Yulmok	1.000	1.000	32 terminals
	29	Paengmok-Jukdo	1.000	1.000	14 terminals
	30	Hyanghwa-Nakwol	1.000	1.000	3 terminals
	33	Yimok-Eoryong	1.000	1.000	8 terminals
	37	Wando-Modo	1.000	1.000	5 terminals
	38	Wando-Yeoseo	1.000	1.000	7 terminals
2	31	Kyemi-Anma	0.753	0.911	3 terminals
	32	Bongli-Jewon	0.892	0.981	4 terminals
	36	Wando-Deokwoodo	0.974	1.000	3 terminals
3 (Worst)	34	Yimok-Dangsa [2]	0.660	1.000	1 terminals
	35	Yimok-Namseong [2]	0.586	0.863	7 terminals

[1] Route trip from Bukhang; [2] 2 routes share 1 ferryboat.

Eight routes belong to the first (best) cluster, three to the second cluster, and two to the worst cluster. By considering some similar routes, we notice that while the Wando-Modo route has a full efficiency score and a low operation time, the Yimok-Dangsa route cannot achieve higher efficiency, because of its operation times are twice as large but its passenger numbers are more than four times smaller. This also occurs for the Wando-Yeoseo and Yinmok-Namseong routes: while the Wando-Yeoseo route is regarded as fully efficient, the Yimok-Namseong route is regarded as the worst in the subsidiary cluster. In particular, the last two ferry routes in this cluster now share one vessel, which makes it considerably difficult for them to increase their efficiency. It is recommended that these routes enhance service reliability, improve efficiency, and attract more passengers.

In terms of ferry route types, subsidiary sea routes—in contrast to the general sea routes—are typically operated between various islands, involving many destination terminals. The results indicate that such routes achieve a better operation than those with fewer destination terminals. For example, the Mokpo-Yulmok route (with 32 interim destination terminals) exhibits a full efficiency score, whereas the Yimok-Dangsa route—which passes by only one terminal—has a lower efficiency score.

The second classification was performed, according to the natural characteristics of ferry routes. Because various related factors can cause difficulties when clustering ferry routes, the principal components (service availability, service adaptability, and service accessibility) calculated by applied PCA were used as input data for classification. After running the calculation software, the general ferry routes were divided into four desirable clusters, as shown in Table 8.

It is difficult to identify the real characteristics of the aforementioned clusters because they are classified by various factors. Therefore, to validate the results and identify the key factors determining the clustering results, a one-way analysis of variance (ANOVA) test was applied. ANOVA was developed by Fisher [37]; it is used to identify whether a significant difference exists between the means of two or more clusters. The test makes decisions by comparing the p-value and significance level α (which is typically 0.05). If $p \leq \alpha$, we reject the null hypothesis; if $p \geq \alpha$, we accept the null hypothesis.

Table 9 shows that, in terms of general sea routes, all factors (except service adaptability) strongly determine the formation of clusters. Thus, the four clusters are given the following meanings: Cluster 1 includes general ferry routes with a high level of service availability and high output performance; Cluster 2 consists of ferry routes with average levels of service availability and output performance; Clusters 3 and 4 both feature relatively low service availabilities and output performances, though Cluster 4 has the highest service accessibility burden. For large general ferry routes (e.g., Mokpo-Jeju), the service accessibility–walking distance correlation does not have a significant effect on efficiency, whereas it does for small ferry routes. For example, in the comparison between the Mokpo-Waedaldo and Dangmok-Seoseong routes, the similarities in service adaptability (number of ships, gross tonnage, voyage time, etc.) can be observed; the Dangmok-Seoseong route exhibits full efficiency with a short walking distance, whereas the Mokpo-Waedaldo route exhibits both technical and scale inefficiencies and a much longer walking distance.

Table 8. Clustering results according to natural characteristics of general sea routes.

Cluster	Route ID	Route	Input Variables			Output Variables	
			Service Availability	Service Adaptability	Service Accessibility	No. Passenger	General * %
Cluster1	1	Mokpo-Jeju	1224	22,469	119	617,679	98
	2	Mokpo-Hongdo	3543	2363	89	567,954	73
	7	Mokpo-Amtae	15,458	843	73	646,992	59
	14	Jilli-Jeonam	10,644	465	103	478,067	62
	21	Dangkuk-Sinyang	21,098	2461	42	601,766	60
	22	Hwahongpo-Soyan	7850	1335	62	547,763	51
	25	Wando-Cheongsan	4474	1750	27	533,500	81
Cluster2	6	Mokpo-Sangdaeseori	4062	929	25	171,035	35
	13	Yulmok-paengmok	3300	711	43	147,787	61
	19	Dangmok-Ilcheong	6869	212	36	158,231	53
	20	Ilcheong-Dangmok	6796	180	38	142,172	53
	23	Dangmok-Seoseong	4881	138	24	107,856	63
	9	Mokpo-Waedaldo	3028	209	111	101,148	65
Cluster3	3	Mokpo-Kasan	3229	826	29	224,610	53
	4	Mokpo-Docho	3376	799	12	232,526	43
	6	Mokpo-Sangdaedongri	3859	1053	37	224,782	44
Cluster4	12	Paengmok-Seogeocha	2181	552	10	72,625	73
	24	Noryeok-Kihak	3478	204	12	65,609	58
	10	Songgong-Sinwol	2128	288	168	36,571	52
	15	Songgong-Heuksan	678	1875	122	15,263	86
	16	Jeungdo-Jaeundo	2449	233	248	18,015	82
	17	Hyanghwa-Songyi	1056	377	87	15,598	84
	5	Docho-Mokpo	512	508	45	47,733	33
	11	Songgong-Peungpong	2603	256	72	34,696	39
	18	Swimi-Kasa	103	289	70	891	51

* The proportion of general passengers.

Table 9. Results of one-way ANOVA tests for general sea route classification.

Test	Service Availability	Service Adaptability	Service Accessibility	No. Passenger	General * %
ANOVA (*p*)	0.012 **	0.249	0.000 *	0.000 *	0.012 **

* $p < 0.01$; ** $p < 0.05$.

After running the calculation software, the subsidiary ferry routes were divided into six desirable clusters (as shown in Table 10); the results of the one-way ANOVA test are shown in Table 11. The cluster numbers c = 3, 4, 5 were also used for reference purposes; however, after assessing the validity of these results, it was concluded that this had no correlation to the partitioning decision; expressed otherwise, it is difficult to cluster the selected subsidiary ferry routes into fewer than six clusters.

Table 11 shows that, in terms of subsidiary sea routes, only the service availability and number of passengers correlate strongly, and service accessibility has only a weak effect in determining the formation of clusters. Thus, the ferry routes were primarily divided based on service availability and the number of passengers. However, assessing the efficiencies of ferry routes within the same cluster was relatively complicated. In terms of general sea routes, the number of efficient ferry routes was allocated to all clusters approximately equally, and all efficient ferry routes had a high proportion of general passengers; this implies that the proportion of general passengers can relatively increase the efficiency of the general ferry routes. The main purpose of subsidiary sea routes is to serve small islands' residents, enabling them to travel between islands and to the mainland more comfortably;

thus, even the routes which have a low proportion of general passengers (e.g., Yimok-Eoryong) can still achieve full efficiency with their current performance. However, when comparing the routes in the same cluster, it is evident that the higher the proportion of general passengers, the higher is the efficiency score.

Table 10. Clustering results according to natural characteristics of subsidiary sea routes.

Cluster	Route ID	Route	Input Variables			Output Variables	
			Service Adaptability	Service Availability	Service Accessibility	No. Passenger	General * %
Cluster1	30	Hyanghwa-Nakwol	276.647	1893.660	131.893	20,361	67
	33	Yimok-Eoryong	314.672	1899.128	19.102	27,503	8
Cluster2	36	Wando-Deokwoodo	320.056	1261.354	16.373	14,967	40
	26	Mokpo-Wooyi	526.427	1309.592	8.186	17,681	56
Cluster3	35	Yimok-Namseong	279.968	1260.225	126.436	9940	20
	32	Bongli-Jewon	257.684	1283.880	127.345	14,601	38
Cluster4	27	Bukkang-Bukkang	212.840	1257.467	34.565	2315	57
	34	Yimok-Dangsa	167.709	1262.741	21.831	2750	29
Cluster5	28	Mokpo-Yulmok	973.764	644.534	28.198	17,469	36
	38	Wando-Yeoseo	371.938	633.292	26.379	17,028	46
Cluster6	31	Kyemi-Anma	366.091	637.111	36.384	7862	42
	37	Wando-Modo	223.368	634.496	19.102	9535	49
	29	Paengmok-Jukdo	477.991	630.735	12.735	9232	58

* The proportion of general passengers.

Table 11. Results of one-way ANOVA tests for subsidiary sea route classification.

Test	Service Adaptability	Service Availability	Service Accessibility	No. Passenger	General * %
ANOVA (p)	0.255	0.000 *	0.045 **	0.001 *	0.874

* $p < 0.01$; ** $p < 0.05$.

5. Discussion and Conclusions

To summarize, this study investigated the operational efficiency of all ferry routes in the Mokpo area, Korea, using a combination of the DEA model and other methods. Focusing on the influence of the mobility burden on ferry route efficiencies, some relevant factors were measured. The annual operation times, cancellation times, per-week sailing frequency, a number of ships, gross vessel tonnage, voyage time and distance, and walking distance from the ticket office to ferry ship ramp were collected as input factors, while the number of passengers and the proportions of general passengers and islanders were collected as output factors. In particular, from the input factors, the walking distance from the ticket box to the ferry ramp was directly measured in the Mokpo terminal and those of several other islands. This factor should be investigated because it reflects the burdens that ferry passengers might encounter before boarding the ferry. Next, to evaluate the efficiency with limited sample data, we integrated the DEA model with a dimensionality reduction scheme (i.e., PCA). As a result, the eight original input factors were reconstructed into three principal components: service availability, service adaptability, and service accessibility. By using PCA, the numbers of input and output factors were reduced to three and two, respectively; it was considered reasonable to apply the DEA model to these reduced sets of factors. The efficiency results reveal that the general sea routes in the Wando area operate more efficiently than those in Mokpo. In terms of general sea routes, while the Mokpo-Amtae route (which had the highest number of passengers) cannot achieve full efficiency, the smaller routes (e.g., Jeungdo-Jaeundo) are now managing their responsibilities well. By using the FCM method, all ferry routes were classified into several clusters according to (1) efficiency scores and

(2) natural characteristics, separately. In terms of efficiency based classification, the general sea routes that travel directly seem to obtain better efficiency scores than those that must visit several islands before their final destination; in contrast, the subsidiary sea routes featuring more stop-by terminals achieved higher efficiency scores. In terms of natural characteristics-based classification, while general sea routes were clustered based on all factors (except service availability), subsidiary sea routes were grouped primarily according to service adaptability and the number of passengers. The results show that some of the routes belong to the best cluster based on natural characteristics and also belong to the best cluster based on efficiency score (such as Mokpo-Jeju, Jilli-Jeonam, Hwahongpo-Soyan, Wando-Cheongsan). However, some of them prove that the larger route is not always the most efficient (Mokpo-Hongdo). The efficiency routes were allocated equally to all clusters, and the proportion of general passengers seems to influence the efficiency increase in both general and subsidiary sea routes.

This study has some important limitations; these make it difficult to consider factors related to ferry passengers' mobility burdens, especially the walking distance from the ticket office to the ferry ramp. Besides this, we identified early influences of passenger mobility burden-related factors on the ferry route's efficiency, and we integrated the DEA model and PCA to manage samples with fewer DMUs than the method's standard requirement. To maintain ferry routes, operators should improve the convenience of ferry passengers and their vehicles, by providing simple and safe passenger/vehicle flow routes through well-designed facilities. They should check the safety of facilities and periodically conduct satisfaction questionnaire surveys, to replace facilities which are out-of-date and maintain a best-quality service for the ferry passenger, respectively. Additionally, the authorities and ferry management departments should better comprehend the interaction between passengers' mobility burdens and ferry route efficiencies, and they should develop appropriate policies and strategies to reconstruct features of inefficient routes rather than terminals; the connection between the ferry terminal and other transportation modes (e.g., buses, taxis, personal vehicles, and railways) should be improved, increasing passengers' convenience and comfort alongside the ferry's operational efficiency.

Though this study considered the mobility burden of ferry passengers by assessing related factors (in particular, the walking distance), the fact remains that each passenger will experience different feelings and burdens while walking the same path and distance, due to differences in body characteristics, age, gender, health conditions, and other factors. Therefore, in the future, deeper research should be conducted into passengers' behaviors as they pass through different environments, to further quantify the mobility burden.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Original raw data of ferry routes in Mokpo and Wando area of Korea.

No.	Route	VD (km)	VT (mins)	OT (Times)	CT (Times)	NV (Vessels)	GT (Tons)	Fr	WD (m)	NP (Persons)	General Passenger		Islander Passenger	
											NP (Persons)	PP (%)	NI (Persons)	PI (%)
1	Mokpo-Jeju	178	240	1216	111	2	28,845	2	124.0	617,679	606,313	98	11,366	2
2	Mokpo-Hongdo	130	150	2863	956	9	2747	2	93.0	567,954	415,011	73	152,943	27
3	Mokpo-Kasan	61	110	3143	360	2	873	4	30.0	224,610	118,944	53	105,666	47
4	Mokpo-Docho	37	90	2883	765	2	888	4	12.0	232,526	100,947	43	131,579	57
5	Docho-Mokpo	46	120	497	55	1	466	4	47.0	47,733	15,879	33	31,854	67
6	Mokpo-Sangdaeseori	54	150	3870	536	3	970	2	26.0	171,035	59,748	35	111,287	65
7	Mokpo-Amtae	22	60	15,109	1,669	4	1004	16	76.0	646,992	380,713	59	266,279	41
8	Mokpo-Sangdaedongri	37	120	3758	428	2	1189	5	38.4	224,782	99,406	44	125,376	56
9	Mokpo-Waedaldo	10	45	2942	340	1	208	8	116.0	101,148	65,367	65	35,781	35
10	Songgong-Sinwol	52	120	2022	285	1	170	3	175.0	36,571	18,876	52	17,695	48
11	Songgong-Peungpong	26	120	2564	261	1	162	4	75.0	34,696	13,525	39	21,171	61
12	Paengmok-Seogeocha	48	120	1898	459	2	521	3	10.0	72,625	53,139	73	19,486	27
13	Yulmok-paengmok	26	75	2974	597	2	809	5	45.0	147,787	89,502	61	58,285	39
14	Jilli-Jeonam	4	15	10,939	631	2	585	14	107.0	478,067	295,080	62	182,987	38
15	Songgong-Heuksan	80	210	514	216	1	103	1	127.0	15,263	13,099	86	2164	14
16	Jeungdo-Jaeundo	5	15	1968	674	1	281	4	258.0	18,015	14,835	82	3180	18
17	Hyanghwa-Songyi	63	110	986	156	2	284	2	91.0	15,598	13,107	84	2491	16
18	Swimi-Kasa	61	120	90	18	1	161	3	73.0	891	451	51	440	49
19	Mokpo-Wooyi	100	290	1147	366	1	177	1	9.0	17,681	9832	56	7849	44
20	Bukkang-Bukkang	46	75	1262	194	1	109	2	38.0	2315	1308	57	1007	43
21	Mokpo-Yulmok	131	600	595	150	2	313	1	31.0	17,469	6306	36	11,163	64
22	Paengmok-Jukdo	85	280	581	148	1	149	1	14.0	9232	5333	58	3899	42
23	Hyanghwa-Nakwol	33	85	1875	317	1	180	3	145.0	20,361	13,705	67	6656	33
24	Kyemi-Anma	63	145	572	164	1	187	1	40.0	7862	3318	42	4544	58
25	Bongli-Jewon	37	115	1343	145	1	125	2	140.0	14,601	5481	38	9120	62
26	Dangmok-Ilcheong	7	15	7149	322	1	251	7	38.0	158,231	84,098	53	74,133	47
27	Ilcheong-Dangmok	7	15	7060	329	1	209	10	40.0	142,172	75,069	53	67,103	47
28	Dangkuk-Sinyang	15	50	20,070	2,810	8	3138	19	44.0	601,766	363,003	60	238,763	40
39	Hwahongpo-Soyan	17	50	7685	832	3	1664	12	65.0	547,763	281,782	51	265,981	49
30	Dangmok-Seoseong	11	30	5098	210	1	131	7	25.0	107,856	67,578	63	40,278	37
31	Noryeok-Kihak	6	20	3682	100	2	235	6	12.0	65,609	38,319	58	27,290	42
32	Wando-Cheongsan	20	50	4421	433	3	2202	7	29.0	533,500	432,651	81	100,849	19
33	Yimok-Eoryong	54	140	1946	254	1	145	3	21.0	27,503	2184	8	25,319	92
34	Yimok-Dangsa	19	60	1184	276	1	101	2	24.0	2750	791	29	1959	71
35	Yimok-Namseong	50	150	1264	196	1	101	1	139.0	9940	1994	20	7946	80
36	Wando-Deokwoodo	44	150	1246	214	1	150	2	18.0	14,967	6027	40	8940	60
37	Wando-Modo	20	70	610	124	1	150	1	21.0	9535	4717	49	4818	51
38	Wando-Yeoseo	59	190	578	153	1	151	2	29.0	17,028	7881	46	9147	54

Table A2. Principal components calculated for general and subsidiary sea routes.

General Route	Service Availability	Service Adaptability	Service Accessibility	Subsidiary Route	Service Adaptability	Service Availability	Service Accessibility
Mokpo-Jeju	1223.828	22469.383	119.019	Mokpo-Wooyi	526.427	1309.592	8.186
Mokpo-Hongdo	3542.720	2363.174	89.264	Bukkang-Bukkang	212.840	1257.467	34.565
Mokpo-Kasan	3229.268	825.608	28.795	Mokpo-Yulmok	973.764	644.534	28.198
Mokpo-Docho	3375.713	795.886	11.518	Paengmok-Jukdo	477.991	630.735	12.735
Docho-Mokpo	512.097	508.259	45.112	Hyanghwa-Nakwol	276.647	1893.660	131.893
Mokpo-Sangdaeseori	4062.374	928.557	24.956	Kyemi-Anma	366.091	637.111	36.384
Mokpo-Amtae	15458.149	843.394	72.947	Bongli-Jewon	257.684	1283.880	127.345
Mokpo-Sangdaedongri	3858.699	1052.963	36.857	Yimok-Eoryong	314.672	1899.128	19.102
Mokpo-Waedaldo	3028.420	208.971	111.340	Yimok-Dangsa	167.709	1262.741	21.831
Songgong-Sinwol	2128.370	287.516	167.970	Yimok-Namseong	279.968	1260.225	126.436
Songgong-Peungpong	2603.426	255.997	71.987	Wando-Deokwoodo	320.056	1261.354	16.373
Paengmok-Seogeocha	2180.793	552.318	9.598	Wando-Modo	223.368	634.496	19.102
Yulmok-paengmok	3300.329	711.341	43.192	Wando-Yeoseo	371.938	633.292	26.379
Jilli-Jeonam	10644.375	465.078	102.702	Noryeok-Kihak	3478.113	203.529	11.518
Songgong-Heuksan	678.238	1874.614	121.898	Wando-Cheongsan	4473.877	1749.690	27.835
Jeungdo-Jaeundo	2449.343	233.327	247.636				
Hyanghwa-Songyi	1055.669	376.651	87.344				
Swimi-Kasa	102.875	289.416	70.067				
Dangmok-Ilcheong	6868.567	212.314	36.473				
Ilcheong-Dangmok	6796.052	180.160	38.393				
Dangkuk-Sinyang	21097.580	2461.364	42.232				
Hwahongpo-Soyan	7850.425	1334.893	62.389				
Dangmok-Seoseong	4881.241	137.677	23.996				

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