CHAPTER 22

PORT PERFORMANCE: AN ECONOMICS PERSPECTIVE

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ABSTRACT

This chapter presents methodologies for evaluating the economic performance of a port. This performance may be evaluated from the standpoint of technical efficiency, cost efficiency and effectiveness by comparing the port's actual throughput with its economic technically efficient, cost efficient and effectiveness optimum throughput, respectively. The port's economic performance may also be evaluated by comparing the actual values of its performance indicators to their standards (that satisfy an economic objective of the port). If the actual values approach (depart from) the standards over time, the port's performance with respect to its economic objective has improved (deteriorated) over time.

1. INTRODUCTION

The crucial question that arises in evaluating a port's performance is how to measure performance. Should a port's performance be evaluated relative to its performance over time (a single-port approach) or relative to the performance of other ports (a multi-port approach)? Should the performance be evaluated from an engineering or an economics perspective?

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Ports have traditionally evaluated their performance by comparing their actual and optimum throughputs (measured in tonnage or number of containers handled). If a port's actual throughput approaches (departs from) its optimum throughput over time, the conclusion is that its performance has improved (deteriorated) over time. Engineering optimum throughputs have typically been used in such evaluations, defined as the maximum throughput that a port can physically handle under certain conditions.[1]

In an environment in which ports have natural hinterlands and are not in competition with one another, an engineering performance evaluation methodology of comparing actual and engineering optimum throughputs may be appropriate. In an environment in which ports are in competition with one another (where shippers and carriers are part of the port-selection process), a port should not only be concerned with whether it can physically handle cargo, but also whether it can compete for cargo. In a competitive environment, port time-related costs in addition to port charges incurred by shippers and carriers are important determinants in port selection. Since port cargo remains in the shipper's inventory (assuming the shipper retains ownership), the shipper incurs time-related inventory (or logistics) costs in port; water and inland carriers also incur port time-related costs, e.g. depreciation and insurance costs on their ships and vehicles while in port. A port can reduce these time-related costs by reducing the time that the cargo of shippers and the ships and vehicles of carriers are in port, i.e. by improving the quality of its service.

If a port's performance in a competitive environment is evaluated by comparing actual and optimum throughputs, an economic (rather than the engineering) optimum throughput should be utilized (Talley, 1988a). A port's economic optimum throughput is that throughput for which the port achieves an economic objective, e.g. maximizing port profits.

An alternative methodology to that of comparing actual and optimum throughputs for evaluating the performance of a port is one that makes use of port performance indicators. From an economics perspective, port performance indicators are choice variables (i.e. variables whose values are under the control of port management) for optimizing the port's economic objective. If the economic objective is to maximize profits, port management would select values for the port indicators that would result in maximum profits for the port. These values of the performance indicators have been referred to in the literature as performance indicator standards (or benchmarks). If the actual values of the port's performance indicators approach (depart from) their respective standards over time, the port's performance – with respect to its economic objective – has improved (deteriorated) over time.

Note that the port performance evaluation methodologies, comparing actual and optimum throughputs and comparing actual values and standards of performance indicators, are consistent with one another. For example, if the port's economic objective function (e.g. to maximize profits) is known, the port's economic optimum throughput can be determined by substituting the standards for the performance indicators and solving.

The determination of a port's economic optimum throughput and its performance indicator standards (as defined above) requires knowing or having to estimate the port's economic objective function(s). For example, to obtain a port's profit function, the port's throughput demand function must be known or estimated. However, economic objective functions (i.e. their functional form and parameter values) are not likely to be known with certainty. Further, available data may not be sufficient to obtain reliable estimates of these functions, nor to obtain reliable estimates of the port's economic optimum throughput and performance indicator standards.

The following section presents a basic economic model of a port. The model provides the theoretical structure for understanding the approaches that have been used in evaluating the performance of ports. In Section 3 the single-port approach for port evaluation is discussed. This approach may involve evaluating a port's throughput as well as the values of its performance indicators over time. In Section 4 the multi-port performance evaluation approach and the frontier statistical models that have been used in multi-port technical performance evaluations are discussed, followed by a summary of the discussions in Section 5.

2. AN ECONOMIC MODEL OF A PORT

A port's economic production function represents the relationship between the port's maximum throughput and given levels of its productive resources, i.e.

$$\text{Maximum Port Throughput} = f(\text{Port Productive Resources}) \qquad (1)$$

where throughput may be the number of containers (measured in 20-foot equivalent units or TEUs) or tons of cargo handled and port productive resources include labor, immobile capital (e.g. berths and buildings), mobile capital (e.g. cranes and vehicles), fuel and ways (e.g. port roadways and railways). If the port achieves the maximum throughput for given levels of its resources, then it is technically efficient; otherwise it is technically inefficient.

A port's economic cost function represents the relationship between the port's minimum costs to be incurred in handling a given level of throughput, i.e.

$$\text{Minimum Port Costs} = g(\text{Port Throughput}) \tag{2}$$

where the costs are those incurred in the use of the port's resources, e.g. wages paid to labor and vehicle fuel expenses. If the port provides throughput at a minimum cost (given the unit costs or resource prices to be paid), then it is cost efficient; otherwise it is cost inefficient.

In order for a port to be cost efficient, it must be technically efficient, i.e. the latter is a necessary condition for the former (Nicholson, 1992, Chapter 12). If a port is technically inefficient, it can handle more throughput with the same resources by becoming technically efficient. Further, given the same resources and thus the same resource costs, the average cost per unit of throughput will decline with the port becoming technically efficient. Alternatively, if the port is technically inefficient, it must follow that it is also cost inefficient.

A port, especially in a competitive environment, is concerned not only with whether it is efficient (technically and cost), but also with whether it is effective in providing throughput. Economic operating objectives of a port may be classified as either efficiency or effectiveness objectives. For example, port efficiency operating objectives include the technical efficiency objective of maximizing throughput in the employment of a given level of resources (exhibited by the port's economic production function) and the cost efficiency objective of minimizing cost in the provision of a given level of throughput (exhibited by the port's economic cost function). Effectiveness is concerned with how well the port provides throughput service to its users – shippers and carriers (ocean and inland). From the perspective of the port, this may be measured by its adherence to its effectiveness operating objective, e.g. maximizing profits. That is, the port's throughput service is at the level at which profits cannot be further increased.

Port effectiveness operating objectives will differ between privately-owned and government-owned ports. If the port is privately owned, its effectiveness economic operating objective might be to maximize profits or to maximize throughput subject to a minimum profit constraint. If the port is owned by government, its effectiveness economic operating objective might be to maximize throughput subject to a zero operating deficit (where port revenue equals cost) or subject to a maximum operating deficit (where port revenue is less than cost) that is to be subsidized by government.

In order for a port to be effective, it must be efficient – i.e. it must be cost efficient, which in turn requires that it must be technically efficient

(Nicholson, 1992, Chapter 13). For example, if a port has the effectiveness operating objective of maximizing profits and is cost inefficient, it can obtain greater profits for the same level of throughput service by lowering costs in becoming cost efficient. However, note that a port can be cost efficient without being effective.

A critical component of a port's effectiveness operating objective is the demand for its throughput services. A port's throughput demand function represents the relationship between the demand for the port's throughput services by its users and the generalized port price (per unit of throughput) incurred by these users, i.e.[2]

$$\text{Port Throughput} = h(\text{Generalized Port Price}) \tag{3}$$

where

$$\begin{aligned}\text{Generalized Port Price} = \ & \text{Port Price Charged} \\ & + \text{Ocean Carrier Port Time Price} \\ & + \text{Inland Carrier Port Time Price} \\ & + \text{Shipper Port Time Price}\end{aligned} \tag{4}$$

The Port Price Charged per unit of throughput represents prices charged by the port for various port services, e.g. wharfage, berthing and cargo handling charges; the Ocean Carrier Port Time Price per unit of throughput represents the time-related costs incurred by ocean carriers while their ships are in port, e.g. ship depreciation, fuel and labor costs; the Inland Carrier Port Time Price per unit of throughput represents the time-related costs incurred by inland (rail and truck) carriers while their vehicles are in port, e.g. vehicle depreciation, fuel and labor costs; and the Shipper Port Time Price per unit of throughput represents the time-related costs incurred by shippers while their shipments are in port, e.g. inventory costs such as insurance, obsolescence and depreciation costs.

If a port seeks to maximize profits, its profit (or effectiveness operating objective) function may be written as

$$\text{Profit} = \text{Port Price Charged} * \text{Port Throughput - Minimum Costs} \tag{5}$$

Substituting the port's throughput demand function (3) and economic cost function (2) into profit function (5) and rewriting, it follows that:

$$\begin{aligned}\text{Profit} = \ & \text{Port Price Charged} * h(\text{Generalized Port Price}) \\ & - g(\text{Port Throughput})\end{aligned} \tag{6}$$

Finally, substituting the economic production function (1) into profit function (6) and rewriting, it follows that:

$$\begin{aligned}\text{Profit} = {} & \text{Port Price Charged} * h(\text{Generalized Port Price}) \\ & - g[f(\text{Port Resources})]\end{aligned} \tag{7}$$

The resources in profit function (7) in turn may be expressed as functions of the port's operating options and the amounts of given types of cargo (provided by carriers and shippers) to be handled by the port. A port's operating options are the means by which it can vary the quality of its throughput service. If the functions relate the minimum amount of a given resource employed by the port to its levels of operating options and amounts of given types of cargo to be handled, such functions in the literature have been referred to as resource functions (see Talley, 1988b):

$$\begin{aligned}\text{Minimum Port Resources} = j(& \text{Port Operating Options;} \\ & \text{Amounts of Given Types of Cargo} \\ & \text{Provided by Carriers and Shippers})\end{aligned} \tag{8}$$

Substituting the resource function (8) into profit function (7) and rewriting, it follows that:

$$\begin{aligned}\text{Profit} = {} & \text{Port Price Charged} * h(\text{Generalized Port Price}) \\ & - g\{f[j(\text{Port Operating Options;} \\ & \text{Amounts of Given Types of Cargo} \\ & \text{Provided by Carriers and Shippers})]\}\end{aligned} \tag{9}$$

A port can differentiate the quality of its service with respect to such operating options as: (a) ship loading and unloading service rates – ship loading and unloading times incurred per port call, (b) ship berthing and unberthing service rates – ship berthing and unberthing times incurred per port call, (c) inland-carrier vehicle loading and unloading service rates – vehicle loading and unloading times per port call, (d) inland-carrier vehicle entrance and departure service rates – vehicle entrance and departure times per port call. Entrance (departure) time for an inland-carrier vehicle is the queuing time incurred to be cleared for entrance into (departure from) the port once arriving at the port's entrance (departure) gate.

What are the means by which port management can optimize its effectiveness-operating objective? That is to say, what are the choice variables to be utilized by port management in the optimization? For a variable to qualify as a choice variable, its value must be under the control of port management. Suppose the port's effectiveness operating objective is to maximize profits, where profits are expressed as in profit function (9). In this function, Port Price Charged is a choice variable, unless constrained by port competition. The other choice variables are the port's operating options. Changes in the values of operating options not only affect the level of resources used by the port, and thus port costs, but also the times incurred in port by ocean carriers' ships, inland carriers' vehicles and shippers' cargo. These times in turn affect the port time costs incurred by these port users – consequently, affecting the port's profits.

3. A SINGLE-PORT PERFORMANCE EVALUATION APPROACH

The single-port approach to port performance evaluation evaluates a port's performance from the perspective of its performance over time. This may be done by comparing the port's actual throughput to its optimum throughput or comparing the actual values of its performance indicators to the standards of these indicators over time.

3.1. Throughput Performance Evaluation

If a port's actual throughput departs from (approaches) its optimum throughput over time, one would conclude that its performance has deteriorated (improved) over time. While a port's optimum throughput may be a technically (or production) efficient, cost efficient or effectiveness optimum throughput, the technically efficient optimum throughput has typically been utilized in port throughput performance evaluations. A port's optimum throughput may also be an engineering or an economic optimum throughput.

A port's engineering production optimum throughput is the port's maximum throughput that physically can be handled by the port under certain conditions. This throughput has also been referred to as the port's capacity.[3] The port's engineering production optimum throughput may be measured theoretically or empirically.

The theoretical engineering production capacity (or optimum throughput) of a port has been classified as: (a) design capacity, (b) preferred capacity and (c) practical capacity (Chadwin, Pope, & Talley, 1990). A port's design capacity is its maximum utilization rate. For example, the design capacity of the storage area of a container port is the maximum number of containers that can physically be stored in the area. A port's preferred capacity is the utilization rate beyond which certain utilization characteristics or requirements cannot be obtained, e.g. the utilization rate beyond which port congestion occurs. Port congestion at the gate of a container port occurs when the waiting times for trucks to enter the gate increase beyond normal waiting times due to the increase in the number of trucks seeking entrance. A port's practical capacity is its maximum utilization rate under normal or realistic conditions. For example, the practical capacity for a container port's ship-side crane is the maximum number of containers that the crane is expected to load and unload from a ship per hour under normal working conditions.

The empirical engineering production optimum throughput is the estimated maximum throughput for the port, usually based upon the actual throughput productions of several similar ports. One exception is found in a port handbook by Hockney and Whiteneck (1986). A modular method for estimating the capability of a given port is presented, where capability is defined as the maximum annual throughput (in tons of cargo) that a port can handle under normal working conditions. To determine the capability estimate for a given port, the handbook first estimates the maximum annual throughput for the various components of the port: ship-to-apron transfer capability, apron-to-storage transfer capability, yard storage capability, storage-to-inland transport transfer capability and inland transport unit processing capability. The port's capability estimate is that estimate with the lowest throughput value among the five estimates. The lowest throughput estimate is the constraining capability of the port (or choke point) and thus is selected as the maximum annual throughput that the port can handle under normal working conditions.

A port's economic optimum throughput is that throughput that satisfies an economic objective or objectives of the port. It may be either an economic: (a) technically efficient optimum throughput (based upon the port's economic production function), (b) cost efficient optimum throughput (based upon the port's economic cost function) or (c) effectiveness optimum throughput (based upon a port's effectiveness operating objective such as maximizing profits). The economic performance of a port may be evaluated from the standpoint of technical efficiency, cost efficiency and effectiveness by comparing its actual throughput with its economic technically efficient optimum throughput, cost efficient optimum throughput and effectiveness optimum throughput, respectively.[4]

A port's economic technically efficient optimum throughput is generally more difficult to determine than its engineering production optimum throughput, especially if the latter is the theoretical engineering production optimum throughput. In general, port economic optimum throughputs are based upon estimated economic objective functions, since the specific forms of these functions are generally unknown. Estimated port production and cost functions are found in studies by Kim and Sachish (1986) and De Neufville and Tsunokawa (1981).[5] To determine a port's economic effectiveness optimum throughput, not only must a port's economic cost function be modeled and estimated, but also its demand and revenue functions. Although port pricing has been investigated, little attention has been given to estimating port demand and revenue functions.

3.2. Indicator Performance Evaluation

3.2.1. Indicator Selection

Two contrasting methodologies have appeared in the transportation literature for selecting performance indicators for transportation firms – the operating objective specification methodology and the criteria specification methodology (Talley, 1986). The operating objective specification methodology requires the specification of an operating objective for the purpose of then selecting performance indicators. The criteria specification methodology specifies the criteria that selected performance indicators must satisfy.

With respect to an economics operating objective, a port's performance indicators are those variables whose values are under the control of port management (i.e. choice variables) for optimizing the operating objective. The values of these variables that optimize the economic objective are the indicators' standards (or benchmarks). If the actual values of the indicators approach (depart from) their perspective standards over time, the port's performance with respect to the given economic objective has improved (deteriorated) over time.

Criteria of the criteria specification methodology that may be used by a port for selecting performance indicators include: (a) conciseness, (b) consistency with objectives, (c) data availability, (d) data collection time and cost, (e) measurability, (f) minimization of uncontrollable factors, and (g) robustness (Talley, 1994). The conciseness criterion requires that the redundancy and overlap among selected indicators be limited. The consistency-objective criterion requires that the indicators be consistent with the port's operating objectives, i.e. they affect these objectives. In addition to the availability of data, the time and cost to be incurred in the collection of the indicator data should be considered in the selection of port performance indicators. The measurability criterion requires that the selected indicators be measurable, i.e. having a continuous as opposed to a discrete unit of measurement. The criterion, minimizing uncontrollable factors, requires that the values of the port's selected indicators be under the control of port management. The robustness criterion requires that the selected indicators allow for the port to be evaluated under various scenarios.

Port performance indicators selected from an economic operating objective specification perspective (i.e. choice variables for optimizing the given economic objective) in general satisfy the selection criteria of the criteria specification methodology. The conciseness criterion is specifically addressed, since choice variables in optimization theory are independent variables, i.e. not a function of one another. Thus, by definition, no redundancy and overlap among selected indicators exist. The selected indicators are consistent, since they are derived from a port's economic objective. Since the performance indicators are variables whose values are under the control of management, the criterion – minimization of uncontrollable factors – will be satisfied. Also, the criteria of data availability, measurability and robustness will likely be satisfied. Although the economic operating objective specification methodology does not specifically address the time and cost commitment to collecting indicator data, it does so indirectly by generally selecting a smaller number of indicators than would be selected by the criteria specification methodology.

In Section 2, it was noted that the port's choice variables with respect to its effectiveness economic operating objective, maximizing profits, are its prices charged to users for various port services as well as port operating options – choice variables by which the port can vary the quality of its services. These port choice variables may also be labeled as the port's effectiveness performance indicators with respect to maximizing profits.

In a model of a mixed-cargo port (handling bulk and container cargo) that seeks to maximize annual throughput subject to a profit constraint, Talley (1996) found the following choice variables or effectiveness port performance indicators with respect to this effectiveness operating objective:

1. Annual average port charge per throughput ton (for a given type of cargo).
2. Annual average ship loading service rate (for a given type of cargo), i.e. tons of cargo loaded on ships per hour of loading time.
3. Annual average ship unloading service rate (for a given type of cargo), i.e. tons of cargo unloaded from ships per hour of unloading time.
4. Annual average loading service rate (for a given type of cargo) for port vehicles of inland carriers, i.e. tons of cargo loaded on port vehicles per hour of loading time.

5. Annual average unloading service rate (for a given type of cargo) for port vehicles of inland carriers, i.e. tons of cargo loaded from vehicles per hour of unloading time.
6. Annual average daily percent of time that the port's channel adheres to authorized depth and width dimensions (a port channel accessibility indicator).
7. Annual average daily percent of time that the port's berth adheres to authorized depth and width dimensions (port berth accessibility indicator).
8. Annual average daily percent of time that the port's channel is open to navigation (port channel reliability indicator).
9. Annual average daily percent of time that the port's berth is open to the berthing of ships (port berth reliability indicator).
10. Annual average daily percent of time that the port's entrance gate is open to inland-carrier vehicles (entrance gate reliability indicator).
11. Annual average daily percent of time that the port's departure gate is open to inland-carrier vehicles (departure gate reliability indicator).
12. Annual expected probability of damage to ships while in port.
13. Annual expected probability of loss of ship property while in port.
14. Annual expected probability of damage to inland-carrier vehicles while in port.
15. Annual expected probability of loss to the property of inland-carrier vehicles while in port.
16. Annual expected probability of damage to shippers' cargo while in port.
17. Annual expected probability of the loss of shippers' cargo while in port.

In Australia, port performance indicators have been used to evaluate the performance of the country's ports for waterfront reform – both single-port and multi-port evaluations – comparing indicator values for a given port over time and across ports for a given time period, respectively. The selected indicators measure the change in the utilization and productivity of port resources; thus, they can be argued to be productivity (or technical) efficiency indicators. Their selection was based upon the criteria specification methodology, using selection criteria of stevedores, shipping lines and port authorities (Talley, 1994).

The selected stevedoring performance indicators measure the productivity and utilization of a port's equipment and labor resources across stevedoring operations. Port indicators from an equipment perspective include: (a) cargo handling rate (the rate at which ships are loaded and discharged), (b) number of ships and amount of cargo handled (an indicator of workload),

(c) containers handled per crane and (d) cargo handled per man-shift (total cargo handled divided by the number of man-shifts). The indicators from a labor perspective include: (a) number of employees, (b) average age of the labor force, (c) average hours worked per week by employees and (d) labor idle time (the percentage of time employees are available for work but are not required to work).

The selected shipping-line port performance indicators reflect ship delays: (a) average delay to ships waiting for berths and (b) average delay to ships while alongside berths. The port-authority indicators reflect port utilization and throughput: (a) cargo tonnage handled, (b) truck queuing times at port gates and (c) facility utilization (as a percentage of total available time).

Note that although the intent of the Australian criteria specification methodology was to select only port production efficiency indicators, several of the selected indicators are similar to those derived by Talley (1996) with respect to the port's effectiveness operating objective of maximizing throughput subject to a profit constraint: (a) cargo handling rate, (b) average delay to ships waiting berths and (c) truck queuing times at port gates. Hence, these indicators may be both efficiency and effectiveness indicators.

In 1988, the US Army Corps of Engineers introduced performance indicators for evaluating its operation and maintenance of the national navigational waterway system, i.e. in provision of navigational aids and new and maintenance dredging of channels. The indicator-selection process was imperfect in retrospect. Six years later the US Army Corps of Engineers' National Program Proponents Workshop - Navigation (1994) was held. Among the performance indicators selected at the workshop, four relate to harbor waterways: (a) percentage of annual days wherein designed vessels may operate within the harbor, unrestricted by wave, current or shoaled conditions (unrestricted accessibility indicator), (b) percentage of annual days wherein designed vessels may operate within the harbor, restricted by tides, wave actions and shoaled conditions (restricted accessibility indicator), (c) percentage of annual days where harbor operations cease due to scheduled navigational maintenance (scheduled-maintenance accessibility indicator) and (d) percentage of annual days where harbor operations cease due to unscheduled navigational maintenance (unscheduled-maintenance accessibility indicator). These indicators were selected based upon the criteria specification methodology. Specifically, the Army Corps of Engineers specified that the selected performance indicators be able to evaluate whether it is providing a given level of navigational service for the national waterway system at the least cost.

3.2.2. Evaluation in Practice

If the specific form of a port's economic objective function is not known (or a reliable estimate is not available), the port's performance over time with respect to the economic objective can still be evaluated by means of performance indicators: it can be evaluated by just knowing the actual values of its performance indicators. Specifically, if the direction of movement in these values over time moves the port nearer to (away from) achieving its economic objective, the conclusion is that the port's performance has improved (deteriorated) over time. For one indicator, a rising trend over time in its actual values might move the port nearer to achieving its economic objective; for another indicator, it might be a declining trend in its actual values.

An advantage to a port in having individual performance indicators to evaluate its performance over time is that the performance of its various services and service areas (e.g. the dock, entrance and departure gates, and the port channel) can be evaluated, thereby allowing for the detection of port activity centers where performance is improving or declining. However, a disadvantage is the problem of how to evaluate the net impact of changes in these indicators on the port's overall performance, given that the changes in some indicators may improve performance and changes in other indicators may negatively affect performance. What is needed is an overall (or single) port performance indicator that captures the net impact of the changes in the individual performance indicators on the port's performance.

In a study by Talley (1996), where the port's economic objective is to maximize annual throughput subject to a profit constraint, this overall performance indicator is the port's annual throughput per profit dollar (given its profit constraint). If this overall indicator is rising (declining) over time, it follows that the port's performance has been improving (declining) over time; furthermore, the net impact of the changes over time in the individual performance indicators on port performance has been positive (negative).

4. MULTI-PORT PERFORMANCE EVALUATION APPROACH

Although it is tempting to compare the performance of one port to that of another, such comparisons may be misleading. Ports operate in different economic, social and fiscal environments. For example, even if ports have the same economic objective of maximizing annual throughput subject to a profit constraint, the profit constraint is likely to differ among ports. Also, one port may have a negative profit (or deficit) constraint that is to be subsidized, while another port may have a positive or break-even profit constraint. Ports may also have different economic objectives (see Suykens, 1986). Thus, in a multi-port performance evaluation approach, where the performance of one port is compared to that of another, similar ports should be used in the comparisons. A principal component analysis for identifying similar ports in a group of ports is found in a study by Tongzon (1995).

In the literature, multi-port performance evaluations of the technical efficiency of ports generally rely upon frontier statistical models. These models utilize the throughputs (or outputs) and resources (or inputs) of a group of ports to investigate whether the ports are technically efficient – i.e. whether their throughputs are the maximum throughputs for given levels of resources (or on their production frontiers) – or technically inefficient, where their throughputs are less than their maximum throughputs for given levels of resources and therefore lie below their production frontiers.

Frontier statistical models used in multi-port technical performance evaluations generally utilize data envelopment analysis (DEA) techniques – non-parametric mathematical programming techniques for deriving the specification of the frontier model. DEA techniques derive relative efficiency ratings for the ports that are used in the analysis. Thus, the development of standards against which efficiency can be measured is not required, although such standards can be incorporated into the DEA analysis. DEA techniques make no assumptions about the stochastic properties of the data. When such assumptions are made, the frontier statistical model is referred to as a stochastic frontier model. For an in-depth discussion of these models, see Cullinane (2002).

In the Tongzon (2001) study, DEA is used to investigate the relative technical efficiency of 16 international (including four Australian) container ports for the year 1996. Initially, the investigation considered two-port output and six input variables. The output variables are the total number of containers in TEUs loaded and unloaded (cargo throughput) and the number of containers moved per working hour (ship working rate). The input variables include: (a) number of cranes, (b) number of container berths, (c) number of tugs, (d) delay time (the difference between total berth time plus time waiting to berth and the time between the start and finish in working a ship), (e) terminal area and (f) the number of port authority employees. Two versions of the DEA model were used in the investigation: the CCR version that assumes constant returns to scale in production and the Additive version that allows for variable returns to scale. See Cullinane (2002) for a discussion of these two DEA versions.

Given the small sample size in the Tongzon (2001) study, only one output – cargo throughput – was used in the final analysis. More ports were found to be technically inefficient based upon the CCR version than for the Additive version. This is not surprising, since the CCR version has the restrictive assumption of constant returns to scale. For both DEA versions, the ports of Melbourne, Rotterdam, Yokohama and Osaka were identified as technically inefficient and the ports of Hong Kong, Singapore, Hamburg, Keelung, Zeebrugge and Tanjung Priok were identified as technically efficient. Since a number of the ports within each group are quite different with respect to size and function (e.g. hub versus a non-hub container port), the results suggest that the technical efficiency of ports does not depend only upon port size or function. For example, in the technically inefficient group, Rotterdam is large relative to the port of Melbourne and is a hub container port as opposed to the ports of Melbourne, Yokohama and Osaka.

Multi-port technical-efficiency performance evaluation studies that utilize stochastic frontier models include studies by Notteboom, Coeck, and van den Broeck (2000), Coto-Millan, Banos-Pino, and Rodriguez-Alvarez (2000) and Cullinane, Song, and Gray (2002).

5. SUMMARY

Should a port's performance be evaluated from an engineering or an economics perspective? Should it be evaluated relative to its performance over time (a single-port approach) or relative to the performance of other ports (a multi-port approach)? Ports have traditionally been evaluated by the engineering single-port approach of comparing their actual and engineering optimum throughputs, i.e. the maximum throughputs or cargo tonnage that ports can physically handle under certain conditions. If a port's actual throughput approaches (departs from) its optimum throughput over time, the conclusion is that its performance has improved (deteriorated) over time.

A port's economic optimum throughput is that throughput that satisfies an economic objective of the port. It may be an economic: (a) technically efficient optimum throughput (based upon the port's economic production function, representing the relationship between a port's maximum throughput and given levels of its productive resources), (b) cost efficient optimum throughput (based upon the port's economic cost function, representing the relationship between a port's minimum costs to be incurred in handling a given level of throughput) or (c) effectiveness optimum throughput (based upon a port's effectiveness operating objective such as maximizing profit).

The economic performance of a port may be evaluated from the standpoint of technical efficiency, cost efficiency and effectiveness by comparing its actual throughput with its economic technically efficient optimum throughput, cost efficient optimum throughput and effectiveness optimum throughput, respectively.

In addition to comparing a port's actual throughput to its optimum throughput, the single-port approach for evaluating a port's performance may also involve comparing the actual values of a port's performance indicators (i.e. variables whose values are under the control of port management) to their standards. The latter are values of the performance indicators that satisfy an economic objective of the port. Thus, the standards may be technically efficient standards, cost efficient standards or effectiveness standards. If the actual values of the port's performance indicators approach (depart from) their respective standards over time, the port's performance – with respect to its economic objective – has improved (deteriorated) over time. If performance indicator standards are unknown, a port's performance can be evaluated just by knowing the actual values of its performance indicators. Specifically, if the direction of movement in these values over time moves the port nearer to (away from) achieving its economic objective, the conclusion is that the port's performance has improved (deteriorated) over time.

Methodologies for selecting performance indicators include the operating objective specification methodology and the criteria specification methodology. The operating objective specification methodology requires the specification of an operating objective for the purpose of then selecting performance indicators. The criteria specification methodology specifies the criteria that selected performance indicators must satisfy.

In the literature, multi-port performance evaluations of the technical efficiency of ports generally rely upon frontier statistical models that utilize DEA techniques – non-parametric mathematical programming techniques for deriving the specification of the production frontier model. DEA techniques derive relative efficiency ratings for the ports that are used in the analysis. These ports should be similar; otherwise, the efficiency ratings may be misleading.

NOTES

1. A modular method for estimating the engineering optimum throughput of a port is found in Hockney and Whiteneck's (1986) port handbook. The module (or component) of the port with the least capability is the constraining capability component (or "choke point") of the terminal, which thus serves as the estimate of the

maximum annual throughput (or capability) that the port can handle under normal working conditions.

2. The port throughput demand function is a function of the Generalized Port Price as opposed to just the port price (or prices charged by the port to its users). The Generalized Port Price includes the latter as well as the port time prices incurred by port users. The time prices are obviously other determinants of port throughput demand, but are also functions of the capital depreciation, fuel and labor costs of carriers and the logistics costs of shippers incurred in port. Thus, the latter are indirectly considered determinants of port throughput demand in port. Thus, the latter are indirectly considered determinants of port throughput demand.

3. For a discussion of capacity with respect to a port's infrastructure, see Jansson and Shneerson (1982). For a general discussion of economic capacity, see Wilson (1980).

4. For a discussion of effectiveness and efficiency in transit performance, see Talley and Anderson (1981).

5. A discussion of port cost functions is found in studies by Jansson and Shneerson (1982), Schonfeld and Frank (1984) and De Weille and Ray (1974).

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