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A generic algorithm based data envelopment analysis to measure efficiency levels at liquid terminals of major ports of India during 2013-14 to 2017-18.

Pavan Kumar Pannala[1], Nookala Bhanu Prakash[2], B.V.Ramalingeswara Rao[3], Bhavana Anirudh.4

Abstract:

India, a vibrant economy with potential scope for development had attracted investments into multiple sectors of economy both by Indian and foreign investors. However, reliance on imports of energy requirements had put pressure on its foreign exchange. India's own petro resources are not sufficient to meet the growing demands of its economy. Petroleum, Oil, and Lubricants (POL) along with natural gas products have been the major importing cargo for India and therefore account for as a major importing bill for the nation. Shipping had been the cheapest and safest way to transport of this cargo and ports have been contributing towards the smooth movement of POL products in India. It is imperative for the Indian ports to efficiently handle this key cargo and reduce the overall logistics cost involved in the entire supply chain. With over 32% share, POL accounts to be the single largest cargo handled at Major ports of India. Considering the significance of this major cargo component, it is important to check the level of efficiency with which the ports handle. Such studies on POL terminal operations would help the major ports to learn from the efficient ports among them. Lack of existing literature measuring performances of liquid terminals at major port has motivated this study to fill the gap and check the efficiency with which these liquid terminals are actually operating. Research works addressing port performance, covering ports and container terminals, have used Data Envelopment Analysis (DEA), a popular non-parametric technique to measure efficiency levels. Taking a cue from these studies measuring port efficiency, this study has applied Genetic Algorithm based DEA to measure efficiency at liquid terminals of the major ports of India. Results at the 12 major ports handling liquid cargo show that none of the port had attained the efficiency level of 1 and that all ports have a lot of scope to improve their performance.

Key Words:
Liquid Terminals, Major Ports of India, Efficiency, Data Envelopment Analysis, Genetic Algorithm.

Introduction:

Growth of economic entities depend on their ability to continuously check their current performances and plan for future. Efficiency measurement, a comparison between output and input, refers to the ability to produce desired output with the deployment some input. Efficiency measurement becomes complex when multiple input inputs variables are put to use to get multiple outputs. Maritime ports of the modern day attract attention of various stakeholders who anticipate highest possible efficiencies in their performance. Empirical works measuring port performances had used wide variety of techniques to measure their efficiency levels. Measuring port efficiency builds confidence among stakeholders on performance of ports, improves prospects of the port's future business, and help other ports to learn and improve their performances in the long-run.

Seaports of India, handling over 90% of exports and imports, hold a special place in promotion of ever growing foreign trade. Buoyant economic outlook mandates existence of robust ports that compete with one another in performance enhancement. Port sector in India, for a long time after independence, is dominated by publicly owned major ports. A total of 12 major ports spread across 9 maritime states of India contribute to a lion's share of Indian sea trade. However, growing cargo volumes at non-major ports is putting more pressure on these major ports to improve their efficiency levels. To create a level playing field between the major and non-major ports, government of India had allowed private participation, through PPP projects, at these major ports (Government of India - Ministry of Shipping, 2011). Greater autonomy to the managements of all the 12 major ports coupled with privatization of port operations are expected to enhance the efficiency levels of these ports.

Numerous researchers (Chudasama, 2009; De, 2006; De & Ghosh, 2002, 2003; Janardhana Rao, Bangar Raju, Roy, & Bhanu Prakash, 2017) had studied the port reform performance scenarios of these major ports and had found improvements in their efficiency levels. Efficiency, a comparison between output and input variables, is represented by the ability of a port to utilize its input variables to maximize the output variables. Researchers had used numerous techniques to measure the efficiency levels of ports including Data Envelopment Technique (DEA), Malmquist Productivity Index (MPI), Principle Component Method (PCM), Financial Ratios etc. to measure efficiency levels at these ports. Techniques used hitherto traced relative efficiencies of the ports to find one or few efficient ports among the ports considered for the study. Ports scoring 1 as efficiency are considered to be efficient ports and all ports scoring less than 1 are considered to be not-so-efficient (or relatively inefficient) in comparison to the efficiency port. The efficient port thus, derived is best among the ports in relative terms. However, the technique does not guarantee that the efficient port so derived utilizes its resources to the optimal level.

At the back drop of numerous studies measuring performance of ports, the current research is an attempt to study the efficiency levels at the major ports using DEA based Generic Algorithm (GA) technique. DEA based GA technique overcomes the drawback of relative efficiency technique and find the absolute efficiencies of the ports considered.

This paper is distributed into 5 sections with section 1 giving an introduction to the topic. While section 2 reviews the existing literature on port performance and efficiency, section 3 details the data considered and methodology applied for the study. Section 4 deals with results and discussions, section 5 highlights findings, conclusions, and scope for further studies.

2.0 Literature Review:

Port efficiency had been an area of interest for regulatory agencies, policy makers, industry experts and researchers as it gives insights on the direction and pace at which these ports are contributing to economic development. Such studies would also help in envisaging future plan of actions for improvement. Numerous researchers (Antão, Guedes Soares, & Gerretsen, 2005; Chang & Tovar, 2014; De, 2006; Díaz-Hernández, Martínez-Budría, & Jara-Diaz, 2008; Janardhana Rao et al., 2017; Lu, 2014; Nwanosike, Tipi, & Warnock-Smith, 2016; Talley, 2006; J. L. Tongzon, 1995; Tovar & Wall, 2015; Wang, Song, & Cullinane, 2003; Zheng & Yin, 2015) studied port efficiency trends and found that reforms followed by privatisation had resulted in efficiency improvements at the ports. Researchers, (Baird, 1995, 2013; Cullinane & Song, 2001; Everett, 2007; S. Farrell, 2013; Ircha, 2001; Juhel, 2001, 2001; Langen & Heij, 2013; Monie, 1995; Pallis & Syriopoulos, 2007; Ray, 2004; J. Tongzon & Heng, 2005) found that strong regulatory framework and privatization would result in efficiency improvements at the ports. They suggested that, for efficiency improvement, governments should confine to control and regulatory mechanism and need not compete in the sector. Usage of genetic algorithm technique is slowly picking up and (Said & El-Horbaty, 2015) had used it solve container handling problem.

The above reviews have showed that DEA is a popular technique to measure port efficiency. It measures relative efficiency and shows one or few ports to be efficiency in comparison to other ports considered. However, DEA does not assure that the efficient port identified port to be efficient in absolute terms. Therefore, this paper, to improve the results of DEA proposes to use GA based DEA that allows to derive the true efficiencies of the ports being considered.

3.0 Data and Methodology:

Genetic Algorithm is based on the principle of natural justice. Although, it started with life sciences, the technique is slowly gaining popularity in measuring efficiencies in numerous other fields. The technique is also used in maritime sector. (H & Seyedalizadeh Ganji, 2005) applied this technique for efficient usage of cranes at container terminals. (Nishimura, Imai, & Papadimitriou, 2001) attempted to optimize berth allocation planning for efficiency gains at selected container terminals in Europe.

To overcome the shortcomings of DEA technique, this paper attempted to use DEA based genetic algorithm to check the true efficiencies of the 12 major ports of India. The study considered number of berths, average draft, storage area (in kilo liters) and average diameter of pipeline as input variables and throughput and average berth occupancy as the output variables. Data for the above variables are gathered from the annual publications of Indian Ports Association (IPA), Ministry of Shipping, Government of India.

3.1 Date Envelopment Analysis:

3.1.1 Output oriented Constant Returns to scale (CRS)

DEA is a nonparametric method to quantify efficiency of a decision-making unit (DMU) which is an organisation public or private. The concept was initially introduced in the Operations Research (OR) literature by (Charnes, Cooper, & Rhodes, 1978). DEA is considered to be a powerful tool to assess efficiency.

DEA is routed from linear programming to assess relative performance of a set of firms that use multiple of identical inputs to produce multiple of identical outputs. The basic principle of DEA is originated by (M. J. Farrell, 1957). (Cooper, Seiford, & Tone, 2007) updated and comprehended material on it. (Adler, Friedman, & Sinuany-Stern, 2002) reviewed research papers that attempted to improve differential capabilities of DEA for ranking efficient and inefficient DMUs. (Banker, R.D.; Chanes, A; Cooper, 1984) argue that with the adoption of DEA, Mathematical programming is extended for use as a tool for control and evaluation of past accomplishments and also to aid in planning future activities. They had separated efficiency on the basis of technical and scale aspects without altering the basic conditions of DEA on observed data. (Charnes, Cooper, & Rhodes, 1981) proposed model for measuring efficiency of Decision Making Units (DMUs) along with methods of implementation and interpretation. Authors suggested that results of the DEA model proposed by them facilitates validation of results and thus, helps in further studies. The following three modes of DEA are generally used for analysis.

$$(FP_0)\text{Max} = \frac{u_1 y_{10} + u_2 y_{20} + \ldots + u_n y_{no}}{v_1 x_{10} + v_2 x_{20} + \ldots + v_m x_{mo}}$$

Where:

u – weight of output; *y* – output value
v –weight of input; *x* – input value

Fractional DEA Programs:
Each of the 12 major ports of India is taken as an independent DMU and their efficiency is assessed with a mathematical model. Efficiency of each of the DMUs can be assessed with the following formula:

$$\max E_m = \frac{\sum_{j=1}^{J} v_{jm} y_{jm}}{\sum_{i=1}^{I} u_{im} x_{im}}$$

Subjected to:

$$0 \le \frac{\sum_{j=1}^{J} v_{jm} y_{jn}}{\sum_{i=1}^{I} u_{im} x_{in}} \le 1; \quad n = 1, 2, K, N$$

$$v_{jm}, \ u_{im} \ge 0; \quad i = 1, 2, K, I; \quad j = 1, 2, K, J$$

Where

E_m is the efficiency of the m^{th} DMU
y_{jm} is j^{th} output of the mth DMU
v_{jm} is the weight of that output
x_{im} is i^{th} input of the mth DMU
u_{im} is the weight of that input, and
y_{jn} and x_{jn} are j^{th} output and i^{th} input, respectively, of the nth DMU, $n = 1, 2, \ldots, N$. Note that here n includes m.

It is interesting to note that DEA employs Linear Programming (LP) technique for assessing efficiency and not the familiar Least Square Regression Analysis. At the same time DEA mathematical programs are fractional in nature and thus, are difficult to solve. So, to solve them with ease the programs are again converted into simpler formulations of linear programming (LP) formats. To avoid this long process, this study had considered to assess the efficiencies of the selected ports using Genetic Algorithm (GA) method.

3.2 Genetic Algorithm:

The concept of GA was introduced by Prof. John Holland and his students De Jong in the year 1975 (Coley, 1999; Fröhlich, Chapelle, & Schölkopf, 2003). It was a variable searching process based on the principal laws of nature selection and genetics mechanisms viz., crossover, mutation and survival of the fittest to optimization and machine learning.

GA is a popular optimization algorithm, often used to solve complex large-scale optimization problems in many fields (Al-Rabadi & Barghash, 2012; Zhang & Wu, 2015). GA solver in MATLAB is a commercial optimization solver based on Genetic Algorithms, which is commonly used in many scientific research communities (Bornschlegell et al., 2012; Dao, Abhary, & Marian, 2014; Debnath, Deb, & Dutta, 2013; Innal, Dutuit, & Chebila, 2015; Islam, Buijk, Rais-Rohani, & Motoyama, 2015). Using the solver requires an objective function and corresponding constraints. To maximize the solver performance, appropriate solver parameters such as population size, fitness scaling function, selection function, elite count, crossover fraction, mutation function, crossover function, etc. need to be chosen. There are many options of the solver parameters to choose from. When using the GA solver, selecting the right parameter set is very beneficial but it is really challenging and requires a systematic approach.

There are nine parameters that can significantly affect the performance of the GA solver in MATLAB: population size, fitness scaling function, selection function, elite count, crossover fraction, mutation function, crossover function, migration direction and hybrid function. Some of them are integer parameters such as population size, elite count, continuous parameter such as crossover fraction, and the rest are discrete ones. For the sake of simplicity, both integer and continuous parameters are referred to as continuous parameters hereafter. To maximize the solver performance, an optimal parameter set is required.

The genetic algorithm uses three main types of rules at each step to create the next generation from the current population:

- *Selection rules* select the individuals, called *parents*, which contribute to the population at the next generation.
- *Crossover rules* combine two parents to form children for the next generation.
- *Mutation rules* apply random changes to individual parents to form children.

Genetic algorithm at the command line, call the genetic algorithm function *ga* with the syntax:

```
[x fval] = ga(@fitnessfun, nvars, options)
```

Where

- @fitnessfun is a handle to the fitness function.

- nvars is the number of independent variables for the fitness function.
- options is a structure containing options for the genetic algorithm. If you do not pass in this argument, 'ga' uses its default options.

The results are given by

- x— Point at which the final value is attained
- fval—Final value of the fitness function

Default option settings as proposed in (MATLAB, 2012) include:

1. PopulationType: 'doubleVector'
2. PopInitRange: [2x1 double]
3. PopulationSize: 20
4. EliteCount: 2
5. CrossoverFraction: 0.8000
6. MigrationDirection: 'forward'
7. MigrationInterval: 20
8. MigrationFraction: 0.2000
9. Generations: 100
10. TimeLimit: Inf
11. FitnessLimit: -Inf
12. StallLimitG: 50
13. StallLimitS: 20
14. InitialPopulation: []
15. InitialScores: []
16. PlotInterval: 1
17. CreationFcn: @gacreationuniform
18. FitnessScalingFcn: @fitscalingrank
19. SelectionFcn: @selectionstochunif
20. CrossoverFcn: @crossoverscattered
21. MutationFcn: @mutationgaussian
22. HybridFcn: []
23. Display: 'final'
24. PlotFcns: []
25. OutputFcns: []
26. Vectorized: 'off

4.0 Results & Discussion:

Results derived from the analysis are shown in the following table:

Table: 1 GA based DEA efficiency scores attained by major ports of India

Port	**2017-18**	**2016-17**	**2015-16**	**2014-15**	**2013-14**
KHPT	0.500	0.500	0.500	0.500	0.500
PPT	0.831	0.858	0.500	0.500	0.556
VPT	0.500	0.500	0.500	0.500	0.500
KPC	0.500	0.500	0.500	0.500	0.673
CPT	0.500	0.500	0.500	0.500	0.500
VOC	0.500	0.500	0.500	0.500	0.500
CoPT	0.720	0.717	0.713	0.665	0.615
NMPT	0.620	0.750	0.707	0.500	0.500
MGPT	0.500	0.500	0.500	0.442	0.513
MPT	0.868	0.891	0.500	0.500	0.500
JNPT	0.614	0.582	0.601	0.613	0.616
DDPT	0.500	0.500	0.500	0.500	0.749

Source: Results derived for the current study

Results derived show that efficiency levels at berths handling petro products in the major ports throughout all the 5 years is below 1. This proves that our major ports have to strive and improve their efficiency levels. Results show that during the last two years Mumbai Port Trust (MPT) and Paradip Port Trust (PPT) had shown better efficiencies in utilizing their facilities in handling the liquid cargo. It is interesting to note that Kolkata Port Trust (KHPT), Visakhapatnam Port Trust (VPT), Chennai Port Trust (CPT), V.O. Chidamdaramnar (VOC), Mourmogao Port Trust (MGPT) had shown no improvement in their liquid cargo handling efficiencies. New Mangalore Port Trust (NMPT) and Cochin Port Trust (CoPT) had shown slight improvement in their efficiencies.

5.0 Findings & Conclusions:

Throughput handled at both MPT and PPT is relatively high in comparison to the berths that they maintain which is well supported by the strong pipe line network with them. High throughput at low level of berth occupancy at these ports prove their ability to handle greater volumes of liquid cargo. The results prove that, for greater efficiencies, ports need to build on their cargo evacuation facilities along with other infrastructural facilities to handle the ships carrying petro products. Comparison of data and results prove that the ports with lower efficiencies are able to optimally utilize their available facilities.

This current study is an attempt to check the efficiency at liquid berths where no major research is attempted till data. The results have shown absolute efficiencies at these ports and prove that all the ports need to do improve in their ability to utilize their inputs to maximize the outputs. Most of the international studies on efficiency concentrated on container ports/terminals. Considering India's dependence of petroleum products and the volumes that is handled at Indian ports, this study is expected to provide some insights on increasing efficiencies in handling this cargo and contribute to the reduction in logistics cost. Studies considering some variables and covering performance levels at non-major ports in handling petro products may be contemplated in future.

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