



Evaluating Productivity and Efficiency Contradictions of Metrorail South Africa

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Abstract: This study focusses on the efficiencies of subunits of South Africa's Metrorail services. Over the period 2015/16 to 2018/19 Metrorail implemented its corporate plan to improve operations efficiency. This study applies the Malmquist Productivity Index (MPI) to compare the performance efficiency of the three Metrorail subunits over the study period. The results indicate the variation of productivity levels amongst Metrorail subunits. Furthermore, output-oriented scale efficiency scores are used to measure the optimal scale situation of each Metrorail subunit. It is concluded that largely the KwaZulu-Natal subunit seems to be more efficient when compared to the other two subunits over the full period under analysis. Therefore, in the cognition of the relatively large size of the Gauteng and Western Cape subunits and their concomitant inefficiency levels, the findings suggest that Metrorail management should focus on correcting their inefficiencies while also considering alteration of their size to optimize production.

Keywords: South Africa, Metrorail, Efficiency, Malmquist productivity index

1. Introduction

The recent reports on poor performance outcomes of South Africa's SOEs have heightened a national discourse on the governance of SOEs. In particular, the debate borders on the productive pursuit of SOEs in South Africa that are expected to involve business activities promoting growth and fair distribution of services through an effective and just administration system of SOE governance. Trust and confidence in SOEs as apparatus of governance and social order towards development dictate the creation of good governance and operational efficiencies. Effective management of Metrorail, a subsidiary of Passenger Rail Agency of South Africa (PRASA), is likely to demonstrate observed successes that entrenches a social contract of government with its people. Alternatively, incompetence, corruption and dysfunctional Metrorail services compromise the descriptive nature and role of an ideal SOE which operates rail passenger services. Most probably the dominant narrative of management capabilities would regrettably be ascribed to the character and business practices of a South African SOE.

Accordingly, this paper examines the apparent operational outcomes of Metrorail subunits with a special focus on its transportation services. The transport sector provides a significant contribution to a country's economy both in promoting the competitiveness of businesses and growing the economy. Like other SOEs in the transportation sector in South Africa, Metrorail falls in the network industry which is featured with economies of scale, huge capital investments, oligopolistic or monopolistic nature, as well as safety standards. That includes Air Traffic and Navigation Services Company Limited (ATNS), Airports Company of South Africa Limited (ACSA), South African Airways (PTY) Limited (SAA), South African Express (Pty) Limited (SA Express), Transnet limited including Freight rail and Ports subsidiaries. As of February 2017, the National Treasury of South Africa had listed these SOEs under Schedule 2 of the Public Finance Management Act (PFMA). They are regarded as major public entities in the country with PRASA deemed as a national government business enterprise listed in Schedule 3 (b) of the PFMA (Public Finance Management Act 1999).

Available literature establishes affirmation of the mandate and critical role of PRASA and its subsidiaries in creating additional value for the South African public. PRASA falls under governmental ownership, and the aim is to advance public policy objectives anchored on South Africa's main social issues requiring development. Thus the role of

government in society is extended also through services which private business cannot or is not prepared to provide adequately. PRASA as a State Owned Enterprise (SOE) fills the gap by ensuring economic growth and expansion of services instead of government departments. The specific functional role of government through SOEs becomes a fundamental societal interest. Debatable roles of a plethora of SOEs in the context of South Africa are varying but with the main aim of addressing social ills and imbalances. This ranges from the provision of services in transport, telecommunication, water, housing and energy contributing to the welfare of society. The SOEs cover the national and provincial levels with different sizes and scope of business operation. All of these SOEs are created for the purpose of bridging the binary divide between the public sector and the private sector. Therefore, while the socio-economic mandate of an SOE as a quasi-independent agency of government is meant to address socio-economic disparities, in some instances SOEs fail to meet the expected standards of performance. In turn, the executive branch of government responsible for oversight of the performance of a particular SOE is expected to seek the reassurance of business effectiveness, efficiencies, and ethical conduct. Moreover, the corporatization of a government mandate likely contradicts the instrumental logic of managerial wealth creation of a commercial entity. Therefore, this paper appraises the efficiencies of Metrorail within the context of the Agency Theory.

The longitudinal year-to-year comparative analysis of the performance of Metrorail subunits provides a basis for an argument for their state of productive efficiency and effectiveness of business performance by management. Thus, by this means this study establishes the productivity growth of each subunit of Metrorail and proposes alternative ways to improve relative performance. This is accomplished with the use of the output-oriented Malmquist Productivity index (MPI) which assesses the efficiency change over time, and the scale efficiency calculation that informs the required relative output of passenger trips for Metrorail subunits at optimal scale.

2. Literature Review

In the literature efficiency and productivity, measurements are considered as main aspects to measure a firm's performance (Lovell, 1994; Coelli et al., 2005). Generally, in an organisation, the efficiency of operations is a result of the maximisation of resources and achieving optimal outputs. However, public administration suffers from inefficient production because of monopolistic practices and the social service imperative that results in poor measurements of outputs (Mihaiu et al., 2010; Vavrek, 2018). The management and decision-making field is progressively improving the ways of measuring government services (Lovell, 1994). Førsund (2015) posits that public sector productivity activities are non-profit making and thus are best measured by the Malmquist Productivity index (MPI) which is based on data envelopment analysis (DEA). Empirical investigations in the use of DEA productivity models and MPI analysis in some cases within South Africa are more revealing.

Along this line, a study of South Africa's public sector hospitals in three Provinces using MPI revealed a variation of performance with most hospitals being inefficient at non-optimal scales of decreasing returns to scale (United Nations, 2000). Two input variables, annual total recurrent expenditure and bed-size were used for small sized hospitals, whereas only the former input variable was used for larger hospitals due to the small sample size. The results were based on models adopted from Farrell (1957) and Charnes et al. (1978), applied by the non-parametric output technique of DEA for measuring relative technical efficiency. The study confirmed a successful application of MPI analysis with many hospitals performing at scale inefficiency levels given their relative difference in size and complexity.

Also, Brettenny and Sharp (2018) successfully conducted a study on the productivity of water services by South African municipalities through an evaluation of the service efficiency change over time using MPI analysis. The results show that the annual average decline of production over the three-year period was a product of technological change. The researchers capitalized on the use of multiple input and output variables as an advantage to use the DEA methodology. Their three inputs included annual operational expenditure, full-time personnel, as well as the physical length of main water lines. On the other hand, the two output variables were system input volumes and metered connections. The output-oriented MPI results indicate that technical change in a particular year improved/regressed the productive capacity of municipalities. The efficiency gains were in some cases deemed to be associated with scale efficiency.

Regrettably, in South Africa available literature on the use of DEA and the application of MPI of public transportation is scarce. However, there is a number of international studies on the evaluation of public transportation through the DEA methodology. Carvalho et al. (2015) evaluated public transport in the twenty-one largest cities of Brazil by the DEA technique to determine infrastructure efficiency and service effectiveness. The cities were regarded as Decision Making

Units (DMUs) with input variables as Municipal Inhabitants and Number of Urban Buses. The output was the average daily passengers transported by busses. The researchers used secondary data on three performance indicators, that is, efficiency, service effectiveness, as well as effectiveness against efficiency score. In using the Super-Efficiency DEA model the results indicated that efficiency was the focal indicator of some cities. In contrast, other cities paid importance to the effectiveness of their services. With a particular focus on the city of Campinas, the researchers were able to determine a need for the city to increase the effectiveness of the bus fleet in the years 2005 to 2010. Alternatively, the required decrease in the number of passengers to effect maximum effectiveness was calculated.

Barnum et al. (2007) have also successfully shown the application of DEA by comparing a set of subunits that perform similar activities within a public transportation agency as a parent company. Their research on pack-and-ride facilities of the Chicago Transit Authority (CTA) had two input variables, namely average Daily operating expenses and Parking capacity with outputs being average Daily revenue and average Number of Parked cars. In order to determine the efficiency of parking lots, Barnum et al. followed a two-stage method of adjusting efficiency scores to control environmental factors. Normally, a DEA procedure assumes that there is a homogeneous environment under which DMUs are assessed. However, the potential effects of environmental factors for different units should be constrained to validate the outcome (Cooper, Seiford and Zhu, 2004). Thus, in the study by Barnum et al. environmental influence on the demand for parking lots was identified as the distance from the nearest freeway / central business district. As a result, after having determined the efficiency scores from the raw data of true inputs and outputs, researchers applied regression analysis to control the environmental influence. The use of Stochastic Frontier Analysis produced adjustments for DMU inefficiency by converting environmental conditions into outputs (Barnum et al., 2007).

Other DEA-based studies on public transportation include the evaluation of efficiency of bus routes in Beijing for the period 08 March 2012 to 22 March 2012 (Li et al., 2013), and the measurement of efficiency of 19 multi-modal systems of publicly owned transport companies in cities of Czech Republic during 2010 to 2015 (Fitzová et al., 2018). The research by Li et al. (2013) amplified efficiency evaluation by the use of sensitivity analysis. On the other hand, the Czech Republic study factored correlation analysis to evaluate the strength of the relationship between the variables used in the research. The DEA-based MPI model has been used in several studies to analyze transportation production activities. Viverita and Kusumastuti (2013) applied it for measuring operational efficiency gains and productivity growth of 22 Indonesian Airports ascertained the increasing/decreasing return to scale of airports. Guner and Coskun (2013) evaluated the efficiency of four passenger ports of Turkey covering a seven-year period of the average efficiency score of each passenger port and the average efficiency scores for each year for all the ports. Both studies measured the Total Factor Productivity (TFP) using DEA-MPI analysis. The study on efficiency analysis of 31 railway firms worldwide by Kutlar et al. (2015) also followed the TFP approach with an output-oriented MPI analysis. The data set covered the period of 2000 to 2009 was analysed by CCR and BCC methods. The MPI results provided insight into the capacity of small and large firms relative to the TFP of each firm. Moreover, outcomes of efficiency change, technical change, pure efficiency change and scale efficiency change values were estimated. That also assisted Kutlar et al. to derive conclusions on efficiency changes of each railway firm in relation to the capacity level of each firm.

3. Research Methodology

This research applied a data envelopment analysis (DEA) model to evaluate the performance of Metrorail subunits assigned as decision-making units (DMUs). Researchers focused on measuring efficiency and productivity tend to use different models to evaluate productive efficiency of the mix of collected input data and produced outputs. DEA is a linear programming optimization-based technique that uses nonparametric methods for measuring relative efficiency and productivity of DMUs. Charnes, Cooper and Rhodes (1978) are credited as the creators of the basic DEA model denoted by CCR Model (Cooper, Seiford and Zhu, 2004). The use of a DEA model enables the evaluation of production efficiency since it has a small number of assumptions and it allows the combination of multiple inputs and outputs involved in DMUs (Ibid).

3.1 The Malmquist Total Factor Productivity Index

Cooper, Seiford and Tone (2007) define the Malmquist Productivity index (MPI) as having features of comparative statics that represents Total factor productivity (TFP) growth as an outcome of a DMU. TFP growth of a DMU represents efficiency progress or inefficiency of the frontier technology over a time period given the inputs and outputs structures in use. As claimed by Tone (2004) the MPI is associated with the non-parametric framework of the DEA technologies evaluating the productivity change of a DMU between two time periods. Thus, MPI explains progress or regress in

efficiency (i.e. catch-up or recovery) and the related technological changes experienced is associated with efficiency frontier or innovation measures over a time period. The computed efficiency and technological change produce TFP growth values. Accordingly, Färe *et al.* (1994) posit that when $MPI_o(\text{optimistic})$ value is >1 that indicates productivity progress. Alternatively, an $MPI_o(\text{optimistic}) = 1$ when indicating constant productivity between two time periods and $MPI_o(\text{optimistic})$ score is <1 representing a regressed productivity level. The output-orientated Optimistic Malmquist productivity index defined on a benchmark technology satisfying constant returns to scale (CRS) is given by:

$$\begin{aligned}
 MPI_o(\text{Optimistic}) &= \left[\frac{D_{0c}^t(x_{0c}^{t+1}, y_{0c}^{t+1})}{D_{0c}^t(x_{0c}^t, y_{0c}^t)} \right] \times \left[\frac{D_{0c}^{t+1}(x_{0c}^{t+1}, y_{0c}^{t+1})}{D_{0c}^{t+1}(x_{0c}^t, y_{0c}^t)} \right]^{1/2} \quad (1) \\
 &= \underbrace{\frac{D_{0c}^{t+1}(x_{0c}^{t+1}, y_{0c}^{t+1})}{D_{0c}^t(x_{0c}^t, y_{0c}^t)}}_{\text{(First Ratio) Efficiency Change}} \times \underbrace{\left[\frac{D_{0c}^t(x_{0c}^{t+1}, y_{0c}^{t+1})}{D_{0c}^{t+1}(x_{0c}^{t+1}, y_{0c}^{t+1})} \times \frac{D_{0c}^t(x_{0c}^t, y_{0c}^t)}{D_{0c}^{t+1}(x_{0c}^t, y_{0c}^t)} \right]^{1/2}}_{\text{(Second Ratio) Technical Change}}
 \end{aligned}$$

This study adopted the DEA-based MPI approach since it requires minimal suppositions in respect of the underlying technology and is able to measure the production growth of DMUs over set periods (Cooper, Seiford and Zhu, 2004). Additionally, in support of Førsund (2015) Metrorail provides public service, and as such, the use of MPI methodology is appropriate in the evaluation of its production. The *catch-up* score of a DMU is respectively represented by the efficiency improvement of each of the three Metrorail subunits. The *frontier-shift* values measure the technological change of each Metrorail subunit between period t and period $t+1$ while also defining the efficiency limits of the subunits.

3.2 Data Collection Procedure Followed

The data on Metrorail subunits were collected as secondary data mainly from PRASA’s Corporate Plan of Medium-Term Expenditure Framework (MTEF) for the period from 2015 to 2018 and Annual reports for the period 2015/16 to 2018/19. Related information on Metrorail was also collected from PRASA’s website and official presentations made to the South African Parliament. In determining the productivity levels of Metrorail subunits, the input variables are represented by (1) The total number of stations (ST) per Metrorail region, and (2) The total number of train sets (TS), of each Metrorail subunit. The output variable is defined by the Passenger trips (PT) per Metrorail Subunit over a set period of time. Table 1 provides the original data collected.

Table 1: Original Data Set Over the 4-Financial Year Period

| Region | 2015/16 | | | 2016/17 | | | 2017/18 | | | 2018/19 | | |
|---------|---------|-------|-------|---------|----|-----|---------|-----|-----|---------|-----|-----|
| DMU | (I)ST | (I)TS | (O)TP | ST | TS | TS | PT | TS | PT | ST | TS | PT |
| Gauteng | 236 | 114 | 206 | 236 | 89 | 170 | 236 | 124 | 134 | 236 | 134 | 111 |
| WCape | 123 | 76 | 166 | 123 | 68 | 135 | 123 | 55 | 75 | 123 | 51 | 45 |
| KZN | 103 | 46 | 74 | 103 | 44 | 64 | 103 | 43 | 56 | 103 | 22 | 49 |

4. Discussion of Results

4.1. Results of Descriptive Statistics

Table 2 provides the summary of descriptive statistics incorporating values of minimum, maximum, the Average (Mean) and Standard Deviation (SD) results for inputs and outputs of the three Metrorail subunits. Productivity changes are based on the two input variables, Number of Stations and Number of Train Set, and the output variable is Passenger Trips.

In terms of inputs, a sizeable variation amongst Metrorail subunits is noticeable. While the Number of Stations for each Metrorail subunit remained the same for the full study period, the constant varying stations were from a minimum of 103 (Kwazulu-Natal) to a maximum of 236 (Gauteng). Concerning the Number of Train Sets, in 2015/16 there was a variation of a minimum of 46 (Kwazulu-Natal) and a maximum of 114 (Gauteng). In the subsequent years from 2016/17 to 2018/19

Kwazulu-Natal continued to have the least number of train sets contrary to the substantial train fleet of Gauteng. With regards to Passenger trips as an output of Metrorail subunits, Kwazulu-Natal had the minimum numbers of 74 in 2015/16, 64 in 2016/17 and 56 in 2017/18. Western Cape experienced a minimum of 45 in 2018/19. Gauteng maintained varying degrees of maximum numbers of 206, 170, 134 and 111 over the study periods.

Table 2: Standard Deviation and Mean statistics for the Metrorail subunits

| Time period | | Inputs | | Output |
|-------------|---------|--------------------|------------------|----------|
| | | Stations (Input 1) | Trains (Input 2) | Trips |
| 2015/16 | Max | 236 | 114 | 206 |
| | Min | 103 | 46 | 74 |
| | Average | 154 | 78,66667 | 148,6667 |
| | SD | 58,55482 | 27,82485 | 55,26502 |
| 2016/17 | Max | 236 | 89 | 170 |
| | Min | 103 | 44 | 64 |
| | Average | 154 | 67 | 123 |
| | SD | 58,55482 | 18,38478 | 44,09837 |
| 2017/18 | Max | 236 | 124 | 134 |
| | Min | 103 | 43 | 56 |
| | Average | 154 | 74 | 88,33333 |
| | SD | 58,55482 | 35,69314 | 33,20977 |
| 2018/19 | Max | 236 | 134 | 111 |
| | Min | 103 | 22 | 45 |
| | Average | 154 | 69 | 68,33333 |
| | SD | 58,55482 | 47,46227 | 30,21405 |

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Despite some variations in the performance of individual Metrorail subunits over distinct periods, it is important to also determine whether subunits altered their relative performance over the full period of the study. Table 3: provides the comparative MPI of Metrorail Subunits and its decomposition from 2015/16 to 2018/19.

4.2. Results of the Output-Oriented Malmquist Productivity Index Based on Constant Returns to Scale Model

The hypothesis of this research is based on constant returns to scale of Total Factor Productivity (TFP) changes between three decision-making units (DMUs) of Metrorail over a period from 2015/2016 to 2018/2019. In reference to the MPIo (optimistic) formula above, efficiency change is defined by the first ratio which measures whether a Metrorail subunit in a particular period in time has changed in comparison to the previous year. The second ratio measures the technical change which represents a shift in the production technology of a Metrorail subunit. The Malmquist TFP productivity indices are calculated using the DEA model, DEA-Solver-LV (V8) / Malmquist-Radial (Malmquist-Radial-O-C) based on a non-parametric framework, developed by Kaoru Tone. This software was targeted for this research since it has the capability of DEA-MPI computation. Table 2 explains the comparative evaluation measurements of the three Metrorail subunits over the set periods.

Table 3: The comparative Malmquist Productivity Index of Metrorail Subunits

| Financial Year | Efficiency Change (Catch-up effect) | Technological Change (Frontier shift) | Total Factor Productivity Change (MPI Scores) |
|----------------------|--|--|---|
| DMU: Gauteng | | | |
| 2015/16 – 2016/17 | 1,163 | 0,909 | 1,057 |
| 2016/17 – 2017/18 | 0,968 | 0,634 | 0,613 |
| 2017/18 – 2018/19 | 1,062 | 0,780 | 0,828 |
| Average (Mean Score) | 1,064 | 0,774 | 0,833 |
| DMU: Western Cape | | | |
| 2015/16 – 2016/17 | 1 | 0,860 | 0,860 |
| 2016/17 – 2017/18 | 1 | 0,618 | 0,618 |
| 2017/18 – 2018/19 | 0,769 | 0,810 | 0,623 |
| Average (Mean Score) | 0,923 | 0,763 | 0,700 |
| DMU: KwaZulu-Natal | | | |
| 2015/16 – 2016/17 | 0,995 | 0,909 | 0,904 |
| 2016/17 – 2017/18 | 1,304 | 0,687 | 0,895 |
| 2017/18 – 2018/19 | 1,047 | 1,168 | 1,223 |
| Average (Mean Score) | 1,115 | 0,921 | 1,008 |

The catch-up values in Table 3 show the sign of recovery with the effect being either growth or deterioration in the operations of a Metrorail Subunit. Thus, the catch-up effect scores of each subunit define the efficiency change of a subunit between current and previous financial year which in turn explains the effectiveness level of a respective subunit.

Following figures 1,2 and 3 depict the comparative analysis of productivity performance of Metrorail subunits. Figure 1 shows the efficiency change, Figure 2 shows the technological change, and Figure 3 shows the Total-Factor Productivity change.

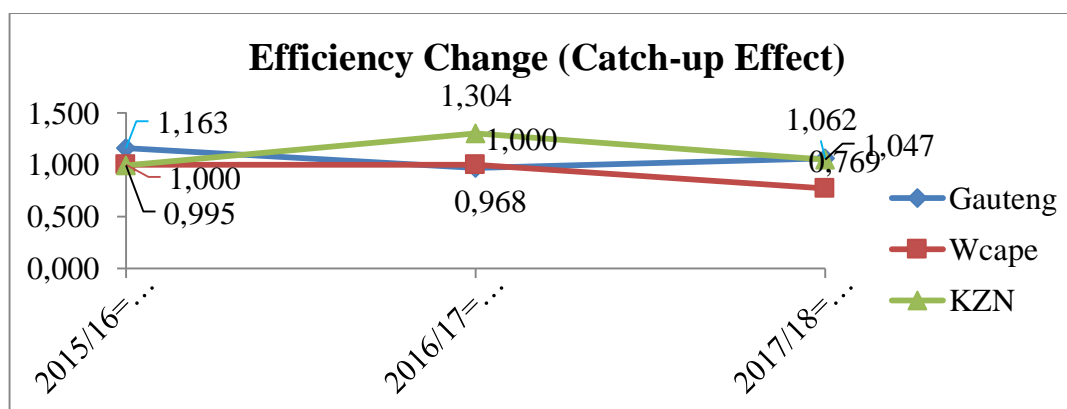


Figure 1: Efficiency Change (Catch-up Effect) of Metrorail Subunits

As shown in Figure 1, Gauteng experienced an increasing *catch-up effect score* of 1,163 in the period 2016/17 with the next period of 2017/18 regressing in efficiency to 0,968 and the 2018/19 period ending in increased efficiency with a score of 1,062. The increasing *catch-up effect scores* of Gauteng in 2016/17 and 2018/19 are deemed to explain the effectiveness of Gauteng Metrorail in those periods. Alternatively, Western Cape had a constant efficiency score of 1 in the period from 2015/16 to 2017/18 and subsequently became ineffective in the 2018/19 when its *catch-up effect score* reduced to 0,769. In contrast, KwaZulu-Natal faced a decreased efficiency from the period 2015/16 to 2016/17 with progressing efficiency occurring in the ensuing period up to 2018/19. Still, the average efficiency change of Kwazulu-Natal is at a score of 1,115 and higher than of the two subunits implying that KZN is by comparison more effective in its operations. Western Cape is the least effective subunit since its average catch-up effect is at 0,923 while that of Gauteng is at 1,064.

The *frontier-shift* effect scores in Figure 2 define production frontier shifts of each Metrorail subunit giving the difference

between current and previous financial year.

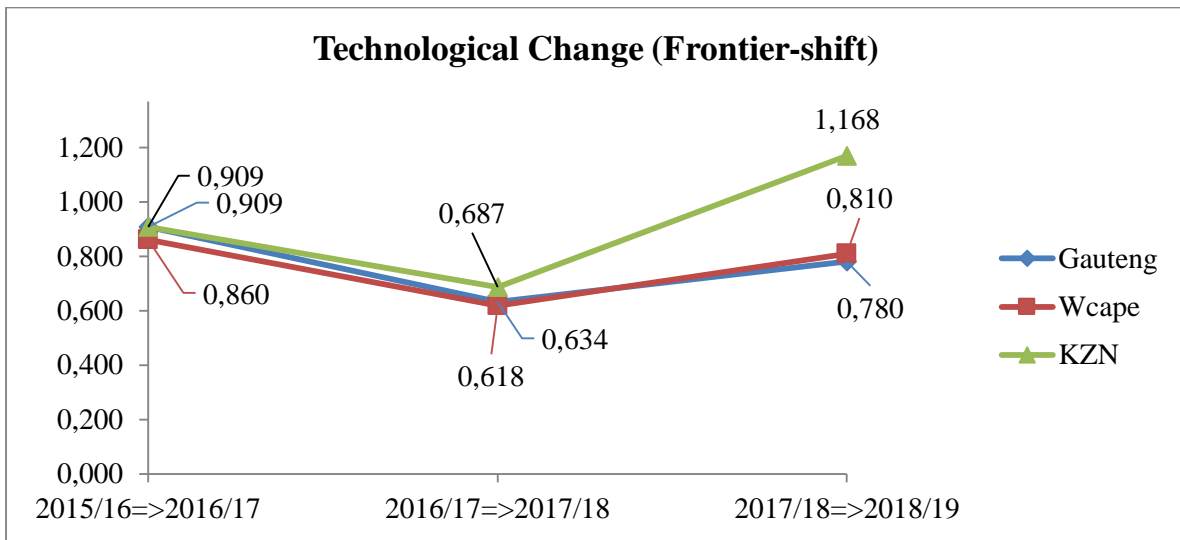


Figure 2: Technological Change (Frontier-Shift)

In Figure 2 the frontier-shift effect score of Gauteng from the frontier of 2015/16 to the frontier of 2016/17 is 0,909. This implies a decreasing performance of efficiency between period t (2015/16) and period t+1(2016/17). The technological change of Gauteng in subsequent frontier periods of 2016/17 to 2018/19 indicates a limitation of operation efficiency with the score below 0,800 in every frontier period. Western Cape also experienced the production frontier shifts of scores of less than 1 in each frontier period from 2015/16 to 2018/19. However, KwaZulu-Natal has the frontier-shift effect scores of below 1 in all frontier periods except in 2017/18-2018/19 where the score exceeded 1,000, implying a technical progression in the latter period. Notwithstanding, in the main, all Metrorail subunits experienced technical regression since their average frontier shifts were each below 1 score. Therefore, Gauteng’s average of 0,774, Western Cape’s average of 0,763, and Kwazulu-Natal’s average of 0,921, all indicates a negative/downward shift in productive efficiencies. In this study Malmquist Total factor productivity (TFP) in Table 3 and Figure 3 measures productivity from the weighted average of Number of Stations and Number of Train Set per Metrorail subunit as input variables which result in Passenger Trips as an output variable. The TFP changes of each Metrorail subunits in each subsequent financial year are the product of an output-oriented radial efficiency measurement model. Figure 3 provides a graphical presentation of TFP of Metrorail subunits with the interpretation thereof explained thereafter.

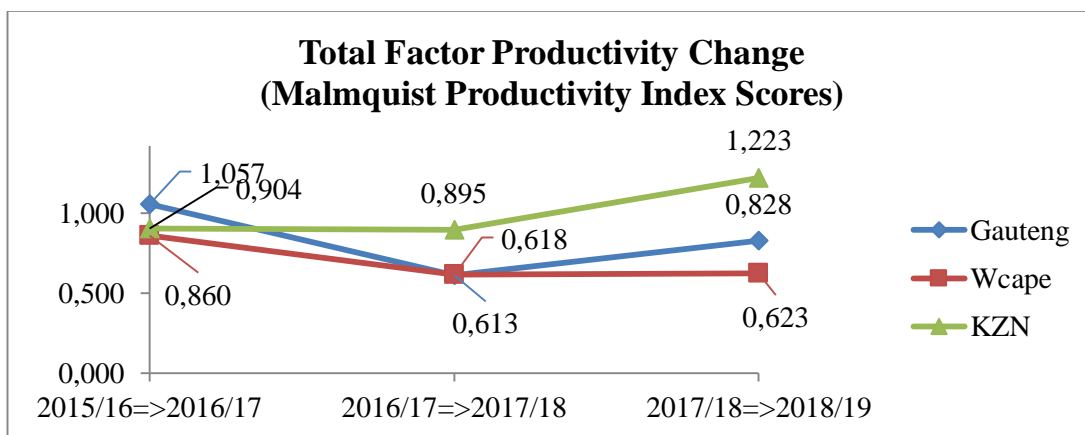


Figure 3: Total Factor Productivity Change (Malmquist Productivity Index Scores)

The measurement of Malmquist Productivity Index of Metrorail subunits revealed that on average the KZN subunit experienced near constant productivity at a score of 1,008 covering the period 2015/16 to 2018/19. Gauteng and Western Cape had fluctuating productivity and lower average levels of TFP to KZN over the same period. However, Gauteng had a marginal advantage of a mean score of 0,833 to that of Western Cape at 0,700.

As shown in Figure 3, the result of the MPI indicates that the productivity of the three Metrorail subunits from 2015/16 to 2018/19 remained below a score of ≤ 1 . The exception of MPI score being >1 was realised in 2015/16 when Gauteng was at 1,057 MPI score. KZN experienced a significant increase at 1,223 in 2018/19 despite a 95% reduction in Train sets (input variable) and no change in Passenger trips (output variable) when compared to the previous financial year. Furthermore, because in the 2018/19 KZN subunit had efficiency changes at a score of 1,047 and technological change at a score of 1,168, its MPI value was the highest above the other two subunits and also over the full period under analysis. Notwithstanding the determination of the nature and level of productivity for each of the subunits of Metrorail, it is important to further ascertain comparisons of optimal outputs in relation to the size of each subunit. Therefore, the measurement of scale efficiency would reveal the optimization of scale size of each subunit over the horizon.

4.3 Scale Efficiency of Metrorail Subunits

Førsund and Hjalmarsson (2002) posit that within the production theory in economics studies, scale properties are a feature of an efficient production function. Hence, this study measures output-oriented scale efficiency that informs the required relative output expansion/contraction of Passenger trips for Metrorail subunits at an optimal scale. Simultaneously, marginal changes at a point in output relative to the proportional increase in inputs indicate a measure of returns to scale (RTS) or scale elasticity. Banker et al. (1984)'s concept of *the most productive scale* size is associated with the notion of returns to scale and the comparison of average productivity. To obtain a measure of scale efficiency (SE) the scores of CTRS efficiency (TE^{CRS}) are compared to VRTS efficiency (TE^{VRS}) scores. The resulting difference between the scores is either a scaling efficiency or a scale inefficiency that constraints operations to gain optimal scale situation, calculated by Coelli 1996 as:

$$SE_i = TE_i^{CRS} / TE_i^{VRS} \quad (2)$$

In which $SE_i = 1$ point out full scale efficiency and $SE_i < 1$ shows the presence of scale inefficiency.

In this study, the CTRS efficiency is only relevant when all Metrorail subunits are operating at an optimal scale in each year. It is possible to avoid system inefficiency which may be the cause factor attributing to subunits not operating at optimal scales by management exercising prudence in the application of scale economies. Thus, the use of VRTS becomes appropriate in order to account for variable returns to scale circumstances (Banker *et al.*, 1984). To further delineate the scale property this study has adopted the qualitative approach of categorising the nature of RTS. Hence, RTS also indicates possible capacity of output growth when inputs are increased/decreased given the three RTS types as (1) the increase returns-to-scale (IRS), (2) the constant returns-to-scale (CRS), and (3) the decrease returns-to-scale (DRS) (Banker *et al.*, 1984; Førsund & Hjalmarsson, 2002). Table 4 indicates that the scale efficiency reveals that if the input quantity of all Metrorail subunits increases/decreases by a given proportion that results in:

Increasing returns to scale (IRS) in **Gauteng** for the financial years 2015/16-2016/17 and 2016/17-2017/18 and **Western Cape** for the financial years 2015/16-2016/17 and 2017/18 -2018/19. This implies that in the stated financial years the outputs of the Metrorail subunits of Gauteng and Western Cape increased by a greater proportion towards the optimal scale. Notably, Western Cape SE of 1,176 in 2015/16-2016/17 indicates the success of optimal scale in Passenger trips. In a situation of IRS, it is expected that the SE increases with a concomitant increase in output (passenger trips) towards an optimal scale (Banker *et al.*, 1984)

Decreasing returns to scale (DRS) in **Gauteng** for the financial years 2017/18 -2018/19, **Western Cape** for the financial years 2016/17-2017/18 and **Kwazulu-Natal** for the full period of this study covering the financial years from 2015/16 to 2018/19. This implies that in the stated financial years in order to attain the optimal scale the three Metrorail subunits should have reduced their input size. Moreover, Kwazulu-Natal should have reduced its size for the full study period in order to attain the optimal scale. Li and Cui (2008) posit that the DRS plan should follow a route that contracts output in order to reach the optimal scale.

Table 4: Determining Scale Efficiency of Metrorail ($SE_i = TE_i \text{ CRS} / TE_i \text{ VRS}$)

| Financial Year | CTRS efficiency TE_i^{CRS} | VRTS efficiency TE_i^{VRS} | Scale Efficiency SE_i | Returns to Scale |
|---------------------------|--|--|----------------------------|------------------|
| DMU: Gauteng | | | | |
| 2015/16 – 2016/17 | 0,909 | 0,947 | 0,960 | IRS |
| 2016/17 – 2017/18 | 0,634 | 0,739 | 0,858 | IRS |
| 2017/18 – 2018/19 | 0,780 | 0,902 | 0,865 | DRS |
| Average (Mean Score) | 0,774 | 0,862 | | |
| DMU: Western Cape | | | | |
| 2015/16 – 2016/17 | 0,860 | 0,731 | 1,176 | IRS |
| 2016/17 – 2017/18 | 0,618 | 0,931 | 0,664 | DRS |
| 2017/18 – 2018/19 | 0,810 | 0,883 | 0,917 | IRS |
| Average (Mean Score) | 0,763 | 0,849 | | |
| DMU: KwaZulu-Natal | | | | |
| 2015/16 – 2016/17 | 0,909 | 1,007 | 0,903 | DRS |
| 2016/17 – 2017/18 | 0,687 | 0,968 | 0,710 | DRS |
| 2017/18 – 2018/19 | 1,168 | 1,306 | 0,894 | DRS |
| Average (Mean Score) | 0,921 | 1,094 | | |

Table 5 reveals that Metrorail subunits had an overall average variable returns to scale technical efficiency (VRTS) score of 89.5% (Standard Deviation = 14.5%) in the financial year 2015/16-2016/17, meaning that inefficient subunits in this period produced on average 10,5% more Passenger trips using their current input features. The succeeding period of 2016/17-2017/18 had an average VRTS score of 87.9% (SD= 12.3%), implying that inefficient subunits in this period travelled on average 12.1% more passenger trips using their existing input endowments. Subsequently, the 2017/18 - 2018/19 period realised an average VRTS score of 103% (SD = 23.9%) deducing that subunits had a relatively full-scale performance of Passenger trips in using their prevailing inputs. Alternatively, of the three subunits, Kwazulu-Natal has shown significant average VRTS scores of 109% when compared to Gauteng (86.2%) and Western Cape (84.9%). This means that Kwazulu-Natal achieved in average an optimal scale while the inefficient performance of Gauteng necessitated 13,8% more passenger trips and Western Cape required 15,1% more passenger trips in an effort to attain optimal scale.

Table 5: Determining Overall Scores for Scale Efficiency of Metrorail Subunits

| Average (Mean Scores) | | | |
|------------------------------|-----------------|-----------------|------------------|
| Financial Year | CTRS efficiency | VRTS efficiency | Scale Efficiency |
| 2015/16 – 2016/17 | 0,893 | 0,895 | 0,998 |
| 2016/17 – 2017/18 | 0,646 | 0,879 | 0,735 |
| 2017/18 – 2018/19 | 0,92 | 1,030 | 0,893 |
| Standard Deviation | | | |
| 2015/16 – 2016/17 | 0,028 | 0,145 | 0,193 |
| 2016/17 – 2017/18 | 0,036 | 0,123 | 0,293 |
| 2017/18 – 2018/19 | 0,216 | 0,239 | 0,904 |

5. Conclusions and Further Research

This study shows that the optimistic DEA-based MPI is a useful tool to evaluate the efficiency of subunits of Metrorail of South Africa. The longitudinal data used is over the 4-Financial Year period from 2015/16 to 2018/19. The MPI

decomposed the productivity of the three Metrorail subunits into efficiency change and technological change on the basis of two inputs and one output. The results mainly reflect TFP changes of each subunit with the MPI productivity of all subunits remaining at a score of ≤ 1 . A deviation is observed when both efficiency change and technological efficiency change are comparatively high in any of the subunits. Hence, the Gauteng subunit has an MPI score of >1 from 2015/16 to 2016/17 while the KwaZulu-Natal subunit experienced the highest MPI score of 1,223 from the 2017/18 to 2018/19. Additionally, the comparatively KwaZulu-Natal subunit attained the highest average MPI value over the full period under analysis because of the combined high scores of its efficiency change and technological change.

The scale efficiency results provide insight into the relative capacity of each of the three Metrorail subunits given their difference in size. All three Metrorail subunits experienced different average variable returns to scale technical efficiency in particular periods. Notwithstanding, the KwaZulu-Natal subunit was in average able to maximise productivity, which is the level of passenger intake. However, the KwaZulu-Natal subunit should have maintained a reduced input size over the horizon to maximize its production. This is in line with Banker et al. (1984)'s notion of the most productive scale size since the KwaZulu-Natal subunit experienced comparative average productivity of prevalent decreasing returns to scale. In contrast, Gauteng and Western Cape subunits were on average performing below their optimal scales and thus are inefficient in the use of their capacity in relation to the size of their operations. Moreover, at certain periods these two subunits should have reduced their input size to achieve an optimal scale.

Measuring the efficiency of a State-Owned Enterprise is an important tool for management and decision-makers. The efficiency improvement of any of the three Metrorail subunits has a positive contribution to the overall efficiency of Metrorail. However, one way of correcting inefficiency is to pay attention to the inefficient subunits of Gauteng and Western Cape in relation to the performance efficiency of KwaZulu-Natal. The former two subunits appear to be operating below optimal capacity and are not capitalizing on their relatively large sizes. Therefore, in the cognition of the relatively large size of the two subunits and their concomitant inefficiency levels, management should consider modification of the size of their operations in order to optimise production. Thus, KwaZulu-Natal subunit is a close standard of reference against which productivity for Metrorail subunits may be compared. The main limitation of this study is the availability of data in relation to other factors of production which could have been used to evaluate efficiency performances of the three Metrorail subunits. Further research can be conducted on the determinants of other productive factors or/and environmental factors that impact on the productivity and efficiency of Metrorail and its subunits. Also, a study can be done on the reconfiguration of Metrorail and its subunits to advance operational efficiencies.

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Appendix

Professional Biography

Dr. Jeremiah Makokoane's research interests are in the areas of organisational productivity, leadership and organisational development with particular focus on the South African public sector institutions. He holds a Doctorate degree in Applied Management from Monarch Business School in Switzerland, a Master's degree in Business Administration (MBA) from the Management College of Southern Africa, and a Bachelor's degree in Commerce from the University of South Africa (UNISA). Dr. Makokoane has over 20-years' experience as a public servant. He is currently a member of The Southern Africa Institute of Management Scientists and writes as an independent researcher.