Application of Non Linear Programming to Locomotive Optimisation: A Case Study of National Railway of Zimbabwe

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Abstract This paper analysed activities undertaken in optimizing locomotive utilisation at National Railways of Zimbabwe (NRZ). Failure to attain breakeven and meet set targets is associated with underutilising resource capacity. The identified locomotive constraints in this paper do not have a linear relationship hence the application of nonlinear programming in formulating the Locomotive Optimization Model (LOM). The objective function in the model is to maximize the quantity of traffic moved by a given number of locomotives available for use which consequently converts to revenue generated. The model results show a failure by NRZ to meet breakeven targets in the year 2013. Different model scenarios are formulated using attainable locomotive figures and it is observed in the model scenario B where a 15% increase in speed, trailing load and availability of locomotives will result in attainment of breakeven targets.

Keywords Locomotives, Utilisation, Nonlinear Programming, Breakeven

1. Introduction

1.1. Introduction

Efficient capacity utilization is a primary concern for railways around the world due to the increase in demands for railway transportation in the face of road congestion, higher fuel costs and concerns for sustainable transportation. Road and railway are the two modes of transportation that face capacity constraints. The sharp decrease in the freight moved by railways organisation is an issue of concern to the managers. The figure 1 below shows quantity of goods in million tonnes moved by the organisation during years 1999-2013.

Figure 1. Freight moved (1999-2013). (Source NRZ Marketing Branch)

1.2. Problem Definition

The study was carried out at National Railways of Zimbabwe (NRZ) a company which is owned by the Government and as such operates in accordance with the public sector rules and regulations, as amended from time to time. The increase in road haulage and the decline in economy growth have led to the erosion of organisation's market share. Furthermore, the market share has been reduced because NRZ is considered to be unreliable and inefficient. This has led to customers resorting to have their goods moved by road instead of rail resulting in a decrease in the customer base. Losing customers means losing business. Back in the 1990s, rail carried the largest share of the country's traffic moving around 18 million tones and this has been reduced to 3.5million tones in 2013. The most critical restriction to expansion, has been lack of capital and long term funding over many years which has resulted in operational capacity restrictions, the consequential apparent constraints being infrastructure restrictions and reduced locomotive and wagon availability. Failure to attain breakeven and meet set targets in the freight movement is associated with underutilising resources capacity. Locomotive capacity should increase from the current annual 2, 7 million tons to 4,7 million tons the break-even target. Underutilisation of locomotives greatly affects the freight moved and subsequently revenue generated by NRZ. There is a perpetual shortfall of operational locomotives. They were 168 owned locomotives at the beginning of the 2014 financial year of which 67 were operational. The 101 non-operational locomotives, (on average these have not been operational for the past six years) have not yet been decommissioned. This position is a result of failure over many years to carry out scheduled maintenance, rehabilitation and replacement due to acute shortage of long term funding and working capital constraints. The organisation has not been able to carry out scheduled maintenance because of lack of spares. There was a plan to overhaul 23 locomotives in 2011 but only 5 were overhauled. Even with those overhauled the quality was low because of lack of spares and reduced skills level. The constant failure of locomotives to reach destinations is a reflection of delayed scheduled maintenance and reduced skills. The lack of major track replacement and rehabilitation has led to an increase in the number of areas on which trains move under speed limits and axle load restriction. In the year 2013, they were around 63 areas under speed restriction stretching roughly 335 km in a rail network covering 2 760 km. Furthermore failure to precisely articulate the strategy for boosting tonnages to the required levels and know the exact dosage for each strategy has for a long time been a problem for the organisation is management.

1.3. Significance of the Study

This paper is devoted to optimisation of tonnage that can be moved by one locomotive at a given moment. It precisely

articulates strategies for boosting tonnages to the required levels and provides exact dosage for each strategy. Management is also aimed at establishing the factors which have led to obtaining low utilisation of the railway infrastructure capacity and reduced market share. The study provides an analysis of the extent at which poor workmanship affect the performance of the organisation. It also ascertains whether the prevailing depressed economic activity in the country is adversely impacting on the volume of traffic and on the utilisation of resources in the organisation. The paper gives an analysis of the degree to which competition has affected the railway operations. It will come up with ways that will bring radical improvement in locomotive performance by identifying the key limitations affecting capacity utilisation. In addition the optimum capacity computation will also provide the marketing branch with indication of capacity available for utilisation. It also serves as bench mark for making strategies and bench mark for profitability of the organisation.

1.4. Aim

To maximize quantity of goods (traffic) moved and consequently revenue generated through efficiently utilisation of locomotives.

1.5. Objective

The objectives of the study are:

1. To precisely articulate the strategies for boosting tonnages and provide exact dosage for each strategy.
2. To optimise locomotive utilisation and align their consumption with market share and identify the actual variables that need adjustments.
3. To analyse the extent at which railway infrastructure affects locomotive utilisation.
4. To evaluate how policy and regulatory guidelines impact on the overall railway performance.

2. Literature Review

The Locomotive optimisation model (LOM) discussed in this paper is substantially different to Locomotive Assignment Models (LAM) studied previously by [1] and the locomotive scheduling models studied previously by many researchers. Single locomotive models have been studied by [2]. Multi-commodity flow based models for operational decisions have been developed by [3], and [4].The multi-commodity flow based model for planning decisions has more features than any of the existing planning models. The locomotive scheduling problem is a very large-scale combinatorial optimization problem. Reference [5] asserts that locomotives are one of the most critical fixed assets in any railway organisation and considered an operational bottleneck. Problems such as long duration of planning, low accuracy of the devised plan, low accuracy of

monitoring and control over the whole process, lengthy reporting time, lack of long term vision on freight planning and assets planning, lack of unity in commanding, repetitiveness in task performance, multiplicity of involved parties in the process within this functional area add up to improper management of this asset. The indicated problems are very common to what is being experienced at the Railway organisation over many years. Reference [6] highlights that an efficient railway from a national perspective (including freight and passenger railways) can maximise revenues and minimise costs while providing the desired level of service. Also [7] pointed out that given a planned train schedule, the locomotive assignment problem consists of assigning a set of locomotives to the scheduled trains to satisfy the requirements expressed as a number of locomotives or as a measure of the traction power needed. Locomotive scheduling (assignment) problems are among the most important problems in railroad scheduling. In 2009 [8] developed a model for master scheduling of freight railway by considering line capacity constraints, multi commodity flows and network value. Reference [9] came up with a decision support system that can optimise investing in different capacity expansion schemes.

Measuring and analysing capacity utilisation by [10] developed an integrated online capacity calculating tool and this worked well on developed countries where network is not a problem. According to [8] a common occurrence in many developing countries is that locomotive assignment and freight train scheduling considers the movement of freight trains through a passenger rail network. One of the constraints to be considered in locomotive assignment problems is that passenger trains run according to a fixed schedule while freight trains must be accommodated on the same track without interfering with passenger train movements which are fixed. In his paper [11], states that time is a better indicator of capacity than delay. He mentions that a blocking time is an efficient method of capacity estimation, indicated that capacity assessment is required to prioritize infrastructure (track, signal, and siding) development in capacity expansion projects. Locomotive and wagon scheduling in freight transport by [12] presents a model for a strategic locomotive scheduling problem. Reference [1] observes that most railway companies are using the Locomotive Assignment Model (LAM), where a set of locomotives is assigned to each train in the weekly train schedule so that each train gets sufficient tractive effort and sufficient horsepower, and the assignment can be repeated indefinitely week after week. At the same time, assigning a single locomotive to a train is undesirable because if that locomotive breaks down, the train gets stranded on the track and blocks the movement of other trains. An additional feature of the LAM is that some locomotives may be deadheaded on trains.

The variables and constraints used in the Locomotive Assignment Model (LAM) are the same as those outlined in [13] except that for the consist size constraints at most four locomotives (including the active and deadheaded) can be

assigned to a train according to the railway business policy. In their paper [14] demonstrates the application of Locomotive Assignment Problem (LAP), which is solved by assigning a fleet of locomotives to a network of trains usually minimizing the total operational cost and satisfying a rich set of constraints (both technical and economic). A study by [6] noted that one of the difficulties with achieving railway efficiency is the challenge for railways and governments to agree on what the right framework is for achieving efficiency. Reference [15] asserts that, one of the difficulties with achieving railway efficiency is the challenge for railways and governments to agree on what the right framework is for achieving efficiency. Definitions of efficient railways can vary. For some countries, a railway may be considered as efficient only when it is profitable with minimal public funding. Alternatively, another government may require the railway to support national economic and mobility policies that deviate from the direct business performance of the railway. In 2008 [16] asserts that network performance may be improved by reducing the likelihood and impact of primary delay. Reliance on high-reliability equipment will benefit service performance by reduction in likelihood of primary delay. Due to growing traffic flow and the complexity of railway control systems Automatic Train Control, (ATC) has become more popular as it is able to reduce human error problems and protect trains from collision [17].

3. Methodology

3.1. Non-linear Programming

Nonlinear programming problems come in many different shapes and forms. Unlike the simplex method for linear programming, no single algorithm can solve all the different types of nonlinear programming problems. Nonlinear programming problems can have multiple local optimal solutions, and the concern is finding the best of the local optimal solutions. A feasible solution is a global optimum if no other feasible points with a better objective function value is found in the feasible region. In the case of a maximization problem, the global optimum corresponds to a global maximum. The general maximisation forms of a nonlinear programming problem consisting of $i(i = 1, 2, 3 \dots n)$ variables and $j(1, 2, 3 \dots m)$ constraints and is of the form;

$$\left. \begin{aligned} \max imise(z) &= f(x_1, x_2, \dots, x_n) \\ \text{subject to : } g(x_1, x_2, \dots, x_n) &\leq b_i \\ (x_1, x_2, \dots, x_n) &\geq 0 \end{aligned} \right\} \quad (1)$$

The idea is to find the vector $X = (x_1, x_2 \dots \dots x_n)$ which maximizes $f(x)$

3.2. Locomotive Optimization Model (LOM)

The variables and constraints used in formulating the Locomotive Optimization Model (LOM) are similar to those outlined by [13] and [1] except that their models concentrated on the performance of both locomotives and wagon. Meanwhile (LOM) concentrate more on the performance of just the locomotive with the view that improving locomotive performance will subsequently improve the quantity of traffic moved. The identified constraints on (LOM) do not have a direct linear relationship hence the application of nonlinear programming in the formulation of a LOM. The objective function on the (LOM) is to maximize the quantity of traffic moved by a given number of locomotives available for use which consequently converts to revenue generated. An improvement on the locomotive performance results in higher revenue being realised. The constraints considered are the speed of the locomotives, the number of available locomotives for use, the average length of haul of a locomotive, and the availability of traffic.

3.3. Statistical Attributes of Locomotives

The following values are the key statistical attributes of locomotives

1. Reliability

Reliability describes the ability of a system or component to function under stated conditions during a specified period of time. It is defined mathematically as follows,

$$R_t = P(T \geq t) = \int_t^{\infty} f(x)dx \quad (2)$$

where

$R(t)$ = is the reliability at time t , $P(T \geq t)$ is the probability that a component performs adequately over the interval $[0, t]$, T is the time function value over which a system or component may fail, $f(x)$ is the probability density function and t is the time which is assumed to start from zero.

Locomotive reliability is also measured in terms of distance covered by a locomotive before failure. The thrust is to monitor the number of locomotives which can complete a specified trip. If a locomotive is unreliably it often fails to complete a trip and failure to complete planned trips has huge negative effect on the company as it results in customers failing to reach and get their goods delivered to the intended destinations on time. It is of paramount importance that railway organizations have reliable locomotives to ensure they achieve the intended objectives of timeously transporting goods and passengers.

2. Gross to Tractive (GT) Ratio

This is a measure of how well locomotives are being utilised and is given by

$$GT = \frac{l_1 d_1 + l_2 d_2 \dots l_n d_n}{TD} \quad (3)$$

l_i is the load (in tonnes) carried by a locomotive over

distance d_i .

T is the tractive power of a locomotive. Different locomotive classes have different tractive powers. $d_i = (d_1, d_2, \dots, \dots, d_n)$ is the vector of n specified sectional distances over which traffic is traversed. It takes into account the dropping and picking of traffic at different specified stations before locomotive arrives at the final destination. D is the total distance covered by the locomotive i.e. the sum of the d_i s.

3.4. Model Formulation

The objective function on the (LOM) is to maximize the quantity of traffic moved by a given number of locomotives available for use which consequently converts to revenue generated.

Model Decision Variables

The railway company has two classes of locomotives, the mainline and the shunt locomotives. The mainline locomotives consist of the DE10 locomotives and the DE11 locomotives. These locomotives have different tractive powers which give them different hauling powers. The shunt locomotives consist of the DE6 and DE9 locomotives and these are mainly used for shunting activities. For quantity (T') in tonnes of traffic provided by the market we have the following nonlinear programming model;

(a) Types of Locomotives

Let K be the total number of types of locomotives and $n D10_{(nk)}$ be number of DE10 locomotives and $m D11_{(mk)}$ be number of DE11 locomotives

(b) Quantity of Traffic Moved

Let $pD10_{(pq)}$ be maximum quantity which can be moved by a DE10 locomotive and $qD11_{(qq)}$ be maximum quantity which can be moved by a DE11 locomotive.

(c) Current Operating Figures for a Locomotive

let;
 $D10_{(sc)}$ be the current speed of a DE10 locomotive
 $D10_{(tc)}$ be the current trailing load for a DE10 locomotive
 $D10_{(hc)}$ be the current average length of haul for a DE10 locomotive
 $D10_{(dc)}$ be the number of running days for a DE10 locomotive
 $D11_{(sc)}$ be the current speed of a DE11 locomotive
 $D11_{(tc)}$ be the current trailing load for a DE11 locomotive
 $D11_{(hc)}$ be the current average length of haul for a DE11 locomotive
 $D11_{(dc)}$ be the number of running days for a DE11 locomotive

(d) Factors Affecting Capacity Utilisation for a Locomotive

let;

$D10_{(sF)}$ be the speed of a DE10 locomotive

$D10_{(tF)}$ be the trailing load for a DE10 locomotive

$D10_{(hF)}$ be the average length of haul for a DE10 locomotive

$D10_{(dF)}$ be the of running days for a DE10 locomotive

$D11_{(sF)}$ be the speed of a DE11 locomotive

$D11_{(tF)}$ be the trailing load for a DE11 locomotive

$D11_{(hF)}$ be the average length of haul for a DE11 locomotive

$D11_{(dF)}$ be the number of running days for a DE11 locomotive

$$DE10_{(sF)} \geq DE10_{(sC)}$$

$$DE10_{(tF)} \geq DE10_{(tC)}$$

$$DE10_{(dF)} \geq DE10_{(dC)}$$

$$DE10_{(hF)} \geq DE10_{(hC)}$$

$$DE11_{(sF)} \geq DE11_{(sC)}$$

$$DE11_{(tF)} \geq DE11_{(tC)}$$

$$DE11_{(dF)} \geq DE11_{(dC)}$$

$$DE11_{(hF)} \geq DE11_{(hC)}$$

The General Locomotive Optimisation Model

The objective function maximises the tonnage which can be moved by a given number of mainline locomotives. The mainline locomotives are of different classes with different tractive powers. They are DE10 and DE11 locomotives.

$$Max(z) = \sum_{n \in K} \sum_{p \in Q} (p * n) DE10 + \sum_{m \in K} \sum_{q \in Q} (q * m) DE11$$

Constraints

The first constraint is the condition that the available locomotives can at most move only what has been availed by the market.

$$\sum_{n \in K} \sum_{p \in Q} (p * n) DE10 + \sum_{m \in K} \sum_{q \in Q} (q * m) DE11 \leq T$$

The second constraint shows the tonnage which can be moved by each DE10 locomotive.

$$DE10_{(pQ)} = \frac{DE10_{(sF)} * DE10_{(tF)} * DE10_{(dF)}}{DE10_{(hF)}}$$

The third constraint shows the tonnages which can be moved by a single DE11 locomotive.

$$DE11_{(pQ)} = \frac{DE11_{(sF)} * DE11_{(tF)} * DE11_{(dF)}}{DE11_{(hF)}}$$

The following set of constraints demonstrates that the locomotive capacity factor can be at least equal or greater than the current capacity value.

The nonnegative constraint $.s, t, d, h, c, q, p, k \geq 0$

3.5. Sensitivity Analysis

In order to obtain optimal capacity utilisation of locomotives different scenarios which include adjustments in both the objective and constraint variables will be considered and one with most desired results will be recommended.

4. Data Presentation

The railway organisation resources consist of locomotives, wagons, track infrastructure, Information Technology (IT) and human resources each of which is a constraint with varying degrees to the performance of the organisation. The set of (K) locomotives used by the organisation consists of steam locomotives which are mainly used by tourist mainline (DE10A, DE11A) and the shunts (DE9A, DE6A) used in ferrying passenger and freight business. The set of wagons used consist of High Sided wagons (HIS), Drop Sided wagons

(DSI) and Covered wagons (COV). The set of coaches consist of the first class (F), the Second class (S) and Economy Class (E). The performance of the organisation is measured in terms of freight business moved, the financial performance (revenue generated and expenditure), resource utilisation and locomotive reliability.

4.1. Organisations Performance

Figure 2. Traffic moved against availed. (Source NRZ Planning Branch)

From the data it can be seen that the organisation is failing to uplift all the availed business. This seems to be the same pattern for the period 2009-2013. It is also shown by the table of average tonnes.

4.2. Availability of Locomotives

Figure 3. Availability of locomotives. (Source NRZ Traction and Rolling stock)

Mainline locomotives have been identified as a major constraint. The bulk of the DE10 locomotives has been temporarily set aside due to shortage of spares and will not be available for use in the near future.

4.3. Distance under Restriction, Reliability and Locomotive Utilisations

On average the distance under restriction for the period under review is 400.11km 14% compared to the total distance network of 2760km. The lack of major track replacement and rehabilitation has led to an increase in distances on which trains move under speed and axle load restriction. The state of the track and these speed restrictions compromises safety and impinges on availability of both locomotives and wagons as it affects turnaround times. It also affects the life span of both locomotives and wagons as wear and tear increases.

Table 1. Distance under restriction. (Source NRZ Strategic Planning Branch)

Year	2009	2010	2011	2012	2013
Total distance network	2 760	2 760	2 760	2 760	2 760
Distance under restriction	458	454	390	362.75	335.8

Source: Railway Strategic Plans - 2009-2013

4.4. Locomotive Utilisation

Comparison of distance moved by a locomotive per day with set target was done. The shorter the distance moved would result in reduced net tonne being achieved. Thus the organisation would be moving traffic over short distances.

Source: Traction and rolling stock reports

Figure 4. Locomotive utilisation

4.5. Reliability

Figure 5. Distance moved before failure

Railway organisation measure reliability in terms of distance covered by the locomotive before it fails. The objective is to move customer goods and passengers from origin to the final destination with minimum or no failures at all according to the set timetable. Figure 5 shows that in the period 2009 to 2013 the locomotives failed to attain the set target. The current target is 450km per day.

5. Data Analysis and Results

5.1. Analysis of LINGO Input Data Year 2013

Data needed for LOM was the average number of locomotives and their tractive powers which constituted the objective function. Constraint data needed was average speed, average length of haul, trailing load and the number of days over which the locomotive was in use. The LONGO model is shown in Appendix A and the results from LINGO are also shown in Appendix B. The organisation moved 2,7million tonnes against a target of 4,7million tonnes. Both locomotives moved a total of 1370747.90 tonnes each per year and the average distance covered per day by each locomotive is 303km. On average a full loaded train would move 450km. The organization failed to achieve the budgeted sales with a variance of US 88.91million (47% shortfall).

5.2. Analysis of Reasons for Failing to Attain Set Targets in Year 2013

- (a) The locomotive planned availability was 83 but only 55 locomotives were available resulting in 34 % shortfall.
- (b) The planned net tonne km distance was 2 400 000 000 km but only 1155 000 000 km amounting to 51.8% was achieve.
- (c) The planned average locomotive distance was 400km/day but only 303km/day was achieved which is 75 % of the target.
- (d) The wagon availability planned was 5472, actual wagon availability was 3617 which is 66% of the target.

5.3. Sensitivity Analysis on LOM

Using LINGO to solve and analyse the LOM under different operating environments scenario A and scenario B with year 2013 as the base year and comparing with the breakeven requirements. LINGO output for scenario A and scenario B are shown in Table 2 below.

Comparison of Locomotive Optimisation Models

The data shows the results of four different operating environments indicating the effects of small changes on the capacity factors.

Table 2. Comparison of locomotive optimisation models (Source NRZ Planning Branch)

Performance measure	LOM as at 2013	Model scenario A	Model scenario B	Breakeven requirements
Number on line locomotives	21	22	25	28
Trailing load	532	574	574	574
Average length of haul	450	450	450	450
Speed of locomotives	303	400	400	400
Number of running days	365	365	365	365
Annual tons based on locos	2,745,705	4,097,084	4,655,778	4,666,570
Annual ntkms	1,235,567,250	1,843,687,400	2,095,100,100	2,099,956,500
Rate per NTKM (US\$)	0.078	0.078	0.078	0.078
Revenue generated	96,374,245.50	143,807,617.20	163,417,807.80	163,796,607.00

Observations: Scenario A

An increase in speed by about 25% and increasing the trailing load by 7% results in an increase of quantity moved by 50% and also revenue increases by 50%. Increasing speed is associated with improving infrastructure and this starts with removal of cautions followed by replacing absolute rail. Realising that improving infrastructure is a top priority for the organisation the required breakeven speed limit can be achieved.

Observations: Scenario B

An increase in speed and trailing load to the breakeven requirements and locomotive availability by 15% results in an increase in both traffic moved and revenue generated by 70%. This will ultimately reach the breakeven revenue requirements.

5.4. Analysis of Break-even Targets and Budgeted Targets

The whole idea of performing break-even analysis is to

find out whether the optimal tonnage can financially sustain the organisation. Where the breakeven tonnage is greater than the optimal tonnage, it means that the optimal tonnage cannot financially sustain the organisation; hence the organisation has to find other means other than optimizing tonnage in order to be viable. The most imperative option is to invest in assets such as locomotives, wagons and track. The inefficiencies arising from locomotive availability, their utilisation and breakdown has a significant contribution on performance. It is observed that the organisation has been making optimistic assumptions in connection with locomotive efficiencies

6. Conclusions

The paper concludes by observing that a true assessment of existing capacity is essential to improve utilisation of available resources and identify areas of bottlenecks in the organisation. The infrastructure capacity should be reappraised under the prevailing conditions in view of the

limitations arising from track faults and the dysfunctional signals and communications network. National Railways of Zimbabwe should evaluate the matrix in respect of quantity of traffic to be moved and resources required to breakeven and in the short term, hire locomotives to achieve break-even sales. It has been observed that a 15% increase

in locomotives results in attainment of breakeven requirements. It makes sense to consider additional investments in corridors which are revenue drivers for the railway, as this may improve efficiency through increased asset utilization.

Appendices

Appendix A. LINGO Formulation

```
!the total tonnage which can be moved;
Max = (10*1300)*DE11 + (11*1100)*DE10;

!Locomotives cannot move more than the availed business;
(10*1300)*DE11 + (11*1100)*DE10 <= T;

!Capacity of a DE10 locomotive;
1300*DE10 <= ((303*DE10)*(532*DE10)*(365*DE10))/450*DE10;

!capacity of a DE11 locomotive;
1100*DE11 <= ((303*DE11)*(532*DE11)*(365*DE11))/450*DE11;

!capacity factors of a DE10 locomotive;
400*DE10 >= 300*DE10;
574*DE10 >= 500*DE10;
365*DE10 = 365*DE10;
450*DE10 >= 400*DE10;

!capacity factors of a DE11 locomotive;
400*DE11 >= 300*DE11;
574*DE11 >= 500*DE11;
365*DE11 = 365*DE11;
450*DE11 >= 400*DE11;
```

Appendix B. LINGO output results for year 2013

Optimal locomotive based tonnage year 2013

Global optimal solution found.

Objective value: 2745705.

Total solver iterations: 0

Variable	Value	Reduced Cost
Quantity moved by a DE11	130747.9	0.000000
Quantity moved by a DE10	130747.9	0.000000
Speed of a DE11	303.0000	0.000000
Trailing load of a DE11	532.0000	0.000000
Running days for a DE11	365.0000	0.000000
Average haul for a DE11	450.0000	0.000000
Speed of a DE10	303.0000	0.000000
Trailing Load for DE10	532.0000	0.000000
Running days for a DE10	365.0000	0.000000
Average haul for DE10	450.0000	0.000000

Row	Slack or Surplus	Dual Price
1	2745705.	1.000000
2	3254295.	0.000000
3	0.000000	10.00000
4	0.000000	11.00000
5	0.000000	4746.622
6	0.000000	2703.433
7	0.000000	3940.347
8	0.000000	-3196.057
9	0.000000	4315.111
10	0.000000	2457.667
11	0.000000	3582.133
12	0.000000	-2905.507

Appendix C. Quantity of Traffic Moved in Tones

Table 3. Year 2009 performance

PERFORMANCE REVIEW REPORT FOR THE MONTH OF JANUARY- DECEMBER 2009													
Monthly Totals	Jan-09	Feb-09	Mar-09	Apr-09	May-09	Jun-09	Jul-09	Aug-09	Sep-09	Oct-09	Nov-09	Dec-09	TOTAL
Budget/Target	400	400	400	500	550	550	550	600	600	550	450	450	6,000
Actual Loaded	155,000	145,000	157,000	149,000	178,000	232,000	255,000	281,000	289,000	334,000	297,000	266,000	2,738,000

Table 4. Year 2010 performance

PERFORMANCE REVIEW REPORT FOR THE MONTH OF JANUARY- DECEMBER 2010 (000)													
	Jan-10	Feb-10	Mar-10	Apr-10	May-10	Jun-10	Jul-10	Aug-10	Sep-10	Oct-10	Nov-10	Dec-10	TOTAL
Budget/Target	400	400	400	500	500	600	550	550	600	600	450	450	6,000
Actual Loaded	167	230	185	243	353	323	347	355	388	370	318	283	3,562

Table 5. Year 2011 performance

PERFORMANCE REVIEW REPORT FOR THE MONTH OF JANUARY- DECEMBER 2011 (000)													
	Jan-11	Feb-11	Mar-11	Apr-11	May-11	Jun-11	Jul-11	Aug-11	Sep-11	Oct-11	Nov-11	Dec-11	TOATAL
Budget/Target	400	400	400	500	550	631	647	500	535	526	474	437	6,000
Actual Loaded	209	247	266	299	331	366	385	349	337	366	343	255	3,753

Table 6. Year 2012 performance

PERFORMANCE REVIEW REPORT FOR THE MONTH OF JANUARY- DECEMBER 2012 (000)													
	Jan-12	Feb-12	Mar-12	Apr-12	May-12	Jun-12	Jul-12	Aug-12	Sep-12	Oct-12	Nov-12	Dec-12	TOTAL
Budget/Target	466	394	400	541	488	537	613	542	516	561	481	460	6,000
Business Available	281	261	295	313	430	424	394	362	336	356	421	257	4129
Actual Moved	246	221	259	279	373	377	386	359	322	330	349	248	3,749

Table 7. Year 2013 performance

PERFORMANCE REVIEW REPORT FOR THE MONTH OF JANUARY- DECEMBER 2013 (000)													
	Jan-13	Feb-13	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13	Dec-13	TOTAL
Budget/Target	410	348	393	478	489	524	625	599	585	555	513	481	6,000
Business Sourced	173	162	202	243	327	449	416	391	474	524	476	371	4208
Actual Loaded	172	162	192	222	316	354	371	377	384	398	379	292	3,619

Appendix D. Model Output Scenario A

Optimal tonnage based on breakeven targets

Global optimal solution found.

Objective value: 4666570.

Total solver iterations: 1

Variable	Value	Reduced Cost
Quantity moved by a DE11	190490.0	0.000000
Quantity moved by a DE10	209510.0	0.000000
Speed of a DE11	450.0000	0.000000
Trailing load of a DE11	574.0000	0.000000
Running days for a DE11	365.0000	0.000000
Average haul for a DE11	450.0000	0.000000
Speed of a DE10	450.0000	0.000000
Trailing Load for DE10	574.0000	0.000000
Running days for a DE10	365.0000	0.000000
Average haul for DE10	450.0000	0.000000

Row	Slack or Surplus	Dual Price
1	4666570.00	1.000000
2	0.000000	0.5333333
3	19020.00	0.000000
4	0.000000	7.000000
5	0.000000	3259.044
6	0.000000	2555.000
7	0.000000	4018.000
8	0.000000	-3259.043
9	0.000000	0.000000
10	0.000000	0.000000
11	0.000000	0.000000
12	0.000000	0.000000

Appendix E. Model Output Scenario B

Model A

Global optimal solution found.

Objective value: 4097084.

Total solver iterations: 0

Variable	Value	Reduced Cost
Quantity moved by a DE11	186231.1	0.000000
Quantity moved by a DE10	186231.1	0.000000
Speed of a DE11	400.0000	0.000000
Trailing load of a DE11	574.0000	0.000000
Running days of a DE11	365.0000	0.000000
Average haul of a DE11	450.0000	0.000000
Speed of a DE10	400.0000	0.000000
Trailing load of a DE10	574.0000	0.000000
Running days of a DE10	365.0000	0.000000
Average haul of a DE10	450.0000	0.000000

Row	Slack or Surplus	Dual Price
1	4097084.00	1.000000
2	413066.7	0.000000
3	0.000000	10.00000
4	0.000000	12.00000
5	0.000000	5586.933
6	0.000000	3893.333
7	0.000000	6122.667
8	0.000000	-4966.160
9	0.000000	4655.778
10	0.000000	3244.444
11	0.000000	5102.222
12	0.000000	-4138.467

Global optimal solution found.

Objective value: 4655778.

Total solver iterations: 0

Variable	Value	Reduced Cost
Quantity moved by a DE11	186231.1	0.000000
Quantity moved by a DE10	186231.1	0.000000
Speed of a DE11	400.0000	0.000000
Trailing load of a DE11	574.0000	0.000000
Running days of a DE11	365.0000	0.000000
Average haul of a DE11	450.0000	0.000000
Speed of a DE10	400.0000	0.000000
Trailing load DE10	574.0000	0.000000
Running days of a DE10	365.0000	0.000000
Average haul of a DE10	450.0000	0.000000

Row	Slack or Surplus	Dual Price
1	4655778.00	1.000000
2	413066.7	0.000000
3	0.000000	10.00000
4	0.000000	15.00000
5	0.000000	6983.667
6	0.000000	4866.667
7	0.000000	7653.333
8	0.000000	-6207.700
9	0.000000	4655.778
10	0.000000	3244.444
11	0.000000	5102.222
12	0.000000	-4138.467

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