Freight Traffic Planning and Rolling Stock Scheduling Management Tool

Vennan Sibanda, Samson Mhlanga, Charles Mbohwa, Jan Harm C Pretorius, and William M Goriwondo

***Abstract*—** A railway organisation is designed to provide economies of scale in a country's freight traffic system and it is on this understanding that a need has been observed to prompt a design for a Freight Traffic Planning and Rolling Stock Scheduling Management Tool that will ensure optimum allocation and utilisation of resources, and timely delivery of customer goods. Literature related to freight traffic planning and wagon scheduling is explored in an attempt to find the best solution alternatives in order to develop a programme for freight traffic planning and wagon scheduling that will optimise resource utilisation. However, several aspects have to be additionally taken into account, such as cyclic departures of the trains from stations, available loads at stations, types of wagons required for given commodity types, destinations, locomotive types, and transfer of wagons between or at stations i.e. attaching and or detaching wagons in transit. The model is formulated as a goal programming problem, and solutions are obtained using VB.Net on ORACLE Database. The solutions give proper knowledge of available business (freight traffic) at any station nationwide; knowledge and position of all wagons by types at anytime; proper allocation and scheduling of wagons to take available business in terms of priority and monitored wagon distribution nationwide. Locomotive and Wagon availability revolved around 74 and 66% respectively. Computational results for several test instances are presented.

***Keywords*—**Business Forecasting, Planning Freight Traffic, Wagon Distribution and Wagon Scheduling.

I. Introduction

THE National Railways of Zimbabwe (NRZ) is a transport organisation that was created to provide an economic movement of freight traffic for the nation. It is evident however, that NRZ is faced with serious viability problems most of which can be attributed to poor allocation of its resources. It is important to note that at any given time, a railway organisation's inability to make available wagons requested by a customer within a reasonable number of days may cause the latter to divert its business to a competitive mode, i.e. road transport or other railways organisations if available. Loss of revenue becomes even more serious when the railway management knows that those wagons are available in its system but its management control functions are not organised to permit a quick response in locating, routing, assigning and placing them promptly at the customer's siding. It is on this premise that a study to identify the major challenges in traffic planning and wagon scheduling is rooted and hence device a computerised traffic planning and wagon scheduling programme that will eliminate the current difficult to coordinate manual system at play.

In a commercially oriented Railway Organisation, locomotive and railway wagon management are crucial functions in the quest for profitability. Indeed, better utilisation of those assets is normally translated into a sizeable reduction in the capital investments planned for future years to expand the wagon and locomotive fleets required to satisfy eventual growth in traffic demand [1]. Similarly, inability of a Railway Organisation to provide adequate and timely motive power required to pull its trains at key points may increase total transit delays and divert movement of time sensitive goods to alternative modes. Lack of motive power also adds to the dwell time of wagons in yards and sidings, decreasing their utilisation and, therefore, causing larger fleets and capital investments which the railways can ill afford [1]. If wagon management had to be done manually and without appropriate telecommunications, it would be an almost impossible task. In fact, accounting for more than 8 000 [2], wagons of different types in systems with more than 500 km and several marshalling yards and industrial sidings, becomes a difficult task which prevents a quick response to customer's' needs and to transport managers' strategies.

NRZ had developed systems commensurate with its plans, however as the fleet gets older, the customer base gets smaller and competition increases and becomes a nightmare for the organisation, it becomes imperative that new strategies need to be formulated and implemented to redefine the best path to follow in order not only to breakeven but to ensure that profit is earned to sustain the organisation.

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II. Related Literature

A. Forecasting

Forecasting is the process of predicting the future [3]. In business, it applies to the future of a business, product, or industry. Companies specialising in service operations forecast customer arrival patterns in an effort to maintain adequate staffing to serve customer needs.

B. Planning Process

Railway transportation looked in those by-gone years quite differently from our understanding of railways today. There was no timetable at all; the numerous railway operators could run their trains whenever the trajectory was free; they literally fought for the right of using the tracks. There was no safety system; collision was only avoided by the low speed of the trains (and later, when they became faster, by sheer luck). Nevertheless, the Stockton and Darlington Railway was a financial success [4]. The steps of the railway planning process can be classified in several ways. A common criterion is the length of the planning horizon. Based on this, one usually distinguishes strategic, tactical, operational and short-term planning phases [5].

C. Operational Planning

The term operational planning is used for planning tasks with horizons of 3 days up to 2 months. In operational planning, the generic week plan (i.e. the result of tactical planning) is adjusted to the specific demands of the particular weeks. Reasons for such adjustments can be the need for extra trains because of a sudden increase in demand due to running special trains. The products of operational planning are the operational timetable, the operational rolling stock schedule and the operational crew schedule.

D. Scheduling

Train scheduling is one of the most challenging and difficult problems in railway planning. So it has been done manually for more than a century through a trial and error process. There have been many studies of more efficient scheduling methods - simulation, mathematical programming, expert systems and so on. Kim and Pack, [6] provides the mathematical formulation for a task based model for simultaneous rolling stock scheduling and rostering. It considers the position of each rolling stock unit in the timetabled trains under a number of constraints of the shunting possibilities at each station, and the minimum and maximum lengths of the compositions. The fundamental base of the train schedule is the single line plan which determines the number of trains serving the line connecting two terminal stations in a fixed time interval [6]. Many researchers have tried to solve the realistic problems by adding various constraints and conditions on this basis.

The majority of the rail scheduling literature has focused on modelling single-line operations (for example, [7]). Single-line operations may involve single or double tracks between two yards and junctions or other significant points. Thus, the network over which the trains are assumed to operate is very simple (i.e. forming a directed, simple and elementary path). Some works addressing problems with multi-line operations focusing on modifying existing schedules to increase reliability was done by [8].

E. Goal Programming

Goal programming models try to optimise more than one objective [9]. In today's business environment, profit maximisation or cost minimisation are not always the only objectives that a firm sets forth [10]. Often, maximising total profit is just one of several goals, including such contradictory objectives as maximising market share, maximising full employment, providing quality ecological management, minimising noise level in the neighbourhood, and meeting other noneconomic goals. Goal programming is capable of handling decision problems involving multiple goals [10]. It is a method that can be used to optimise solutions to problems with several goals. Goal programming is incorporated in the ORACLE DATABASE so as to meet customer needs using the following parameters; Customers, stations, sections, commodity, wagon and locomotive types.

The aim being to allocate appropriate resources at the correct time and place and thus run the most profitable trains.

Goal Programming will be used as the basis for formulating scheduling algorithms. A programming language VB.Net is used for generating the scheduling programme while ORACLE is used as the data base for the system. This application is used to provide solutions to identified gaps in scheduling. From the NRZ's target of 6.4 million tonnes of freight traffic estimated to raise US$156 284 584 per year, this will give us a quarterly target of US$52 094 861, a monthly target of US$13 023 715 and taking a 30-day month this will culminate in a daily target of $1,736,495.

Let: x_1 = Trains from Hwange through to Eastern area

x_2 = Trains from Bulawayo to Midlands area

z = Deviations

d_1^- = Underachievement - Contributing less than US$1.7million

d_1^+ = Overachievement - Contributing more than US$1.7million

Thus, we need to concentrate on avoiding underachievement by minimising d_1^-:

Minimise Z = d_1^-

Constraints:

Goal 1 $6x_1 + 8x_2 + d_1^- - d_1^+ = 1.7$

Shunt $3x_1 + x_2 \leq 8$

Turnaround $3x_1 + 5x_2 \leq 24$

$x_1, x_2, d_1^-, d_1^+ \geq 0$

Thus: $x_1 = 4$

$x_2 = 1.3$

NB: the optimal solution of the problem will be $d_1^- = 0$ and a total contribution margin of US $1.7 million.

We expand our problem to read as follows:

Objective 1: A minimum contribution margin of US $1.7 million

Objective 2: To optimise the capacity of shunting activities

Objective 3: To run 12 trains from Bulawayo because of demand.

The model can be formulated as:

Minimise $z = d_1^- + d_2^- + d_3^-$

Constraints:

Goal 1 $6x_1 + 8x_2 + d_1^- - d_1^+ = 1.7m$

Goal 2 $3x_1 + 2x_2 + d_2^- - d_2^+ = 8$

Goal 3 $x_2 + d_3^- - d_3^+ = 12$

Shunting $3x_1 + x_2 \le 8$

$$x_1, x_2, d_1^-, d_1^+, d_2^-, d_2^+, d_3^-, d_3^+ \ge 0$$

To solve this problem we will use the weighted goals.
In the weighted approach each element in the goal function is assigned a weight based on how important it is. If having a specified contribution margin is the most important objective while the number of tables produced is the least important goal, then the weights are shown in Table I. The problem can be then be reformulated as:

TABLE I
GOALS, VARIABLES AND WEIGHTS

Goal	*Deviation Variables*	*Weight*
1	d_1^-	3
2	d_2^-	2
3	d_3^-	1

NB: we will use a working value of 170 (thousand) instead of 1.7 million

Thus;

Minimise Z = $3d_1^- + 2d_2^- + d_3^-$

Constraints:

Goal 1 $6x_1 + 8x_2 + d_1^- - d_1^+ = 170$

Goal 2 $3x_1 + 2x_2 + d_2^- - d_2^+ = 8$

Goal 3 $x_2 + d_3^- - d_3^+ = 12$

Shunting $3x_1 + x_2 = \le 8$

$$x_1, x_2, d_1^-, d_1^+, d_2^-, d_2^+, d_3^-, d_3^+ \ge 0$$

III. TOOL DEVELOPMENT

A. System Flow Chart

The system developed utilise information from seven stations. Fig 1 indicates the amount of business per station in terms of commodity being moved, volume, tonnage and destination. This information is used to make decision on type of wagon, locomotive type and tractive power. The information is relayed though the Wide Area Network to the Operations Management Centre (OMC) where depending on value and priority of the loads, availability and allocation of resources, trains to be run are thus determined prior to running them.

After running the programme, various reports are produced that show solutions meant to meet specified requirements in freight traffic planning and wagon scheduling problems. The freight traffic planning and wagon scheduling programme is optimised by a visual basics.net driven system and the results will show how traffic planning is linked to wagon type scheduling and train planning.

Fig 2 below shows the database login window for the system. This enables the manipulation of the database to meet or to make the system perform functions such as saving data, clearing all information stored in the system.

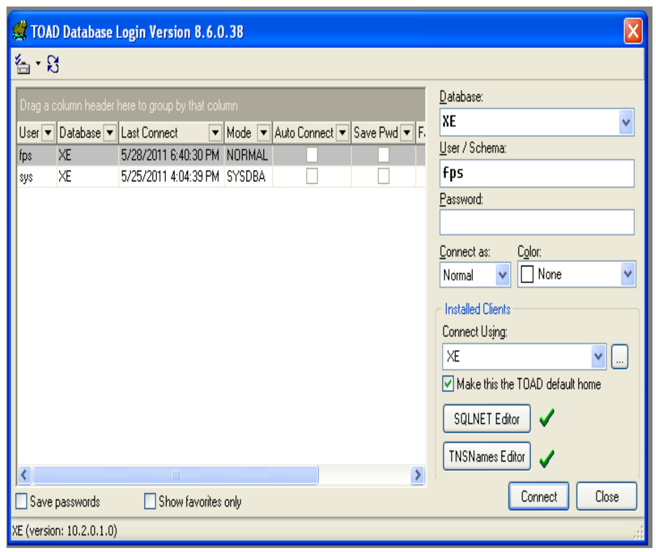

Fig. 2 Database log in window

Fig. 3 shows reports categories obtained when running the programme. Before planning any trains it is vital that traffic position is known in all stations so that proper allocation of correct resources is done. A report is printed to show the Traffic Position at all stations and that forms the basis for traffic planning.

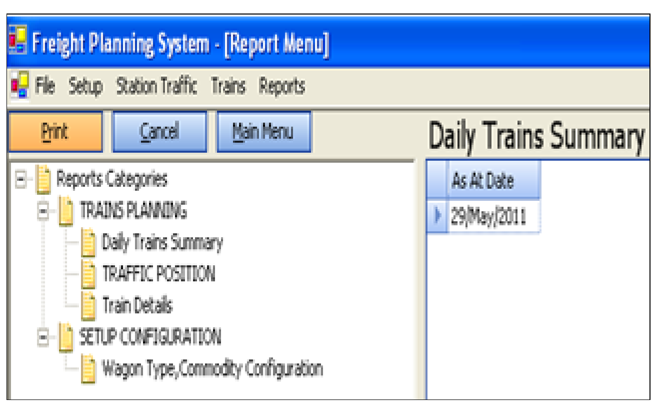

Fig. 3 Freight planning reports setup

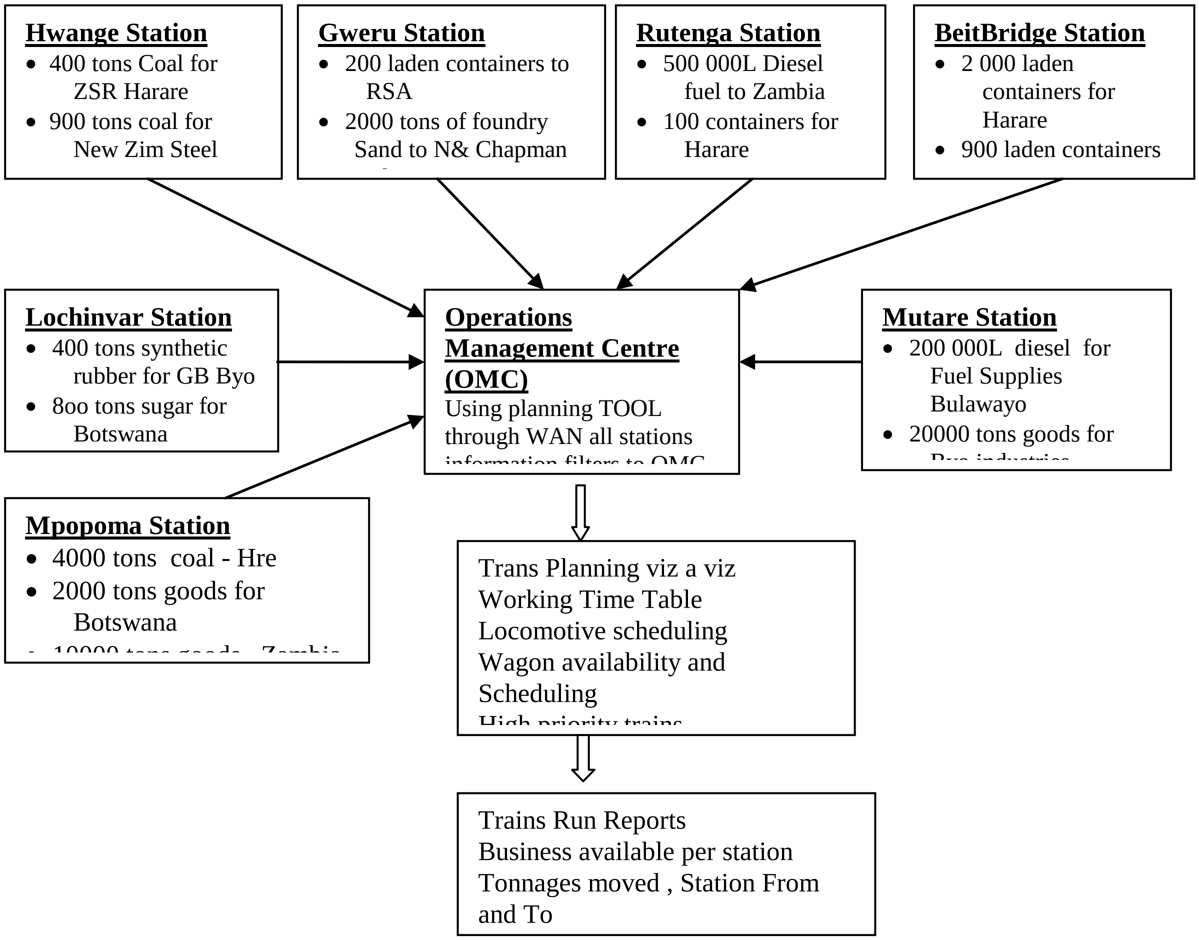

Fig. 1 Systems Flow chart

The traffic position by station report showing available traffic at various stations is shown in Fig 4. The report gives a detailed account of all traffic loads ordered by customers from and available at that station. Traffic position enables planning of train movements and prioritisation of trains in terms of destinations, or total tonnage to be moved as it shows the type of commodity, tonnage available at the station, its destination and the number of wagons required to move that load.

TRAFFIC POSITION BY STATION REPORT

STATION MPOPOMA

CODE	COMMODITY	TONNAGE	DESTINATION	WAGONS
210	COAL WK PRODUCED	133,633,333	LOCHINVAR	6,667
	STATION TOTALS :	133,633,333		6,667

STATION NYAMANDLOVU

CODE	COMMODITY	TONNAGE	DESTINATION	WAGONS
210	COAL WK PRODUCED	62,362,222	SOMABHULA	3,111
	STATION TOTALS :	62,362,222		3,111

STATION SAWMILLS

CODE	COMMODITY	TONNAGE	DESTINATION	WAGONS
210	COAL WK PRODUCED	43,341,624	MPOPOMA	2,162
	STATION TOTALS :	43,341,624		2,162

STATION SHANGANI

CODE	COMMODITY	TONNAGE	DESTINATION	WAGONS
309	SCRAP IRON/STEEL	150,000	SOMABHULA	3
	STATION TOTALS :	150,000		3

Fig. 4 Traffic position by station

Fig 5 shows the wagon type to commodity configuration. Two types of wagon types and various loads they carry are shown indicating also their commercial codes. This assists in planning wagon distribution in terms of load types as determined by customer requirements and available loads at various stations.

WAGON TYPE TO COMMODITY CONFIGURATION

WAGONTYPE Chrome Ore

COMM_CODE	COMMODITY	AVERAGE_NET
439	CHROME ORE	40

WAGONTYPE High Sided Irons

COMM_CODE	COMMODITY	AVERAGE_NET
145	OIL SUNFLOWER SEED (EXPORT)	43
103	STOCKFEEDS	45
108	OIL SEED CAKE	45
110	COTTON RAW	45
114	MAIZE	45
117	SORGHUM	45
124	MALT	45
125	SUNFLOWER SEED	45
210	COAL WK PRODUCED	45
309	SCRAP IRON/STEEL	40,000

WAGONTYPE PNN

COMM_CODE	COMMODITY	AVERAGE_NET
CONT	CONTAINERS	30

Fig. 5 Wagon type to commodity configuration

After running a train or trains, a summary report of the trains run, by train number, can be viewed. The report shows from where the train was run, its destination, the total tonnage moved and the type of locomotive used to move the train. Fig 6 shows the summary report.

TRAINS RUN IN ALL SECTIONS AS AT :: 23/Sep/2012

SECTION THOMSON JUNCTION----DABUKA

TRAIN NO	FROM_	TO_	LOCO	LOAD(Tons)
8	THOMSON JUNCTION	DABUKA	D.E.11A (DIESEL)X1	4,811,761
12	THOMSON JUNCTION	DABUKA	D.E.10A (DIESEL)X1	4,008,499
6	THOMSON JUNCTION	DABUKA	D.E.11A (DIESEL)X1	400,850
			Section Tonnage Cleared	9,221,110
			Total Tonnage Cleared	**9,221,110**

Fig. 6 Summary of trains run

To get a detailed report of the trains run, another report is available, shown in Fig 7. This report shows a detailed account of the traffic moved, that is, the initial station from where the loading was initiated to its final destination. It shows also all traffic picked up along the way as attached traffic and all traffic removed from the train along the way as detached traffic, if any. It shows the number of wagons moved, the type of commodity moved, the tonnage and all stations where detachments or attachments were made.

IV. How the System Works

The programme shall be running through the Wide Area Network (WAN) and accessed throughout the entire NRZ system. Each area will be feeding the system with customer orders and traffic planning will be centralised from the Operations Management Centre who will be responsible for the day to day decisions on which traffic to run and giving priority as the system will provide all necessary information in terms of available traffic in all stations and related customers.

DETAILS FOR TRAINS RUN AS AT : 14/Oct/2012

Text Object

SECTION MPOPOMA----DABUKA

TRAINNO 5
FROM MPOPOMA
TO DABUKA

Section Action	Station	Wagons	Commodity	Tonnage	Destination
Initial	MPOPOMA	5	DIESEL FUEL	175,000	DABUKA
Initial	MPOPOMA	1	COAL WK PRODUCED	20,047	SOMABHULA
Detach	DABUKA	5	DIESEL FUEL	175,000	DABUKA
Detach	SOMABHULA	1	COAL WK PRODUCED	20,047	SOMABHULA

SECTION THOMSON JUNCTION----LOCHINVAR

TRAINNO 6
FROM THOMSON JUNCTION
TO LOCHINVAR

Section Action	Station	Wagons	Commodity	Tonnage	Destination
Initial	THOMSON	5	COAL WK PRODUCED	100,222	DABUKA
Initial	THOMSON	30	COAL WK PRODUCED	601,332	DABUKA
Initial	THOMSON	1	AMMONIUM NITRATE	28,571	SOMABHULA
Initial	THOMSON	40	COAL WK PRODUCED	801,700	KWEKWE
Initial	THOMSON	20	COAL WK PRODUCED	400,850	KWEKWE
Initial	THOMSON	60	COAL WK PRODUCED	1,202,550	MPOPOMA
Initial	THOMSON	8	COAL WK PRODUCED	160,362	LOCHINVAR
Detach	KWEKWE	20	COAL WK PRODUCED	400,850	KWEKWE
Detach	KWEKWE	40	COAL WK PRODUCED	801,700	KWEKWE

Fig. 7 Freight traffic run position in detail

The current system relies on Station Masters getting all business in their areas and use trains scheduled to run in those areas and advising headquarters by phone. These trains were scheduled a long time ago and there has never been an assessment of its ability to meet current requirements and also the Trains Working Time Table has been in existence for a long time too without any update. There have been numerous cases where locomotives have had to move light due to this outdated method. Moving light in this case means a locomotive runs without a load or a train being cancelled due to poor planning.

V. Conclusion and Future Scope

The developed programme is able to achieve our objective of freight traffic planning and wagon scheduling. Using the programme it is possible to plan all trains to be run at any time and any decisions pertaining to the priority of trains to be run is achieved after looking at the Traffic Position by Station Report. The programme links several parameters in order to provide the decision tool required to carry out planning and scheduling of trains for freight traffic. Further developments of this programme to cover a broader spectrum are envisaged. The developments should take into account the wagon types by wagon number so that a train rake can be identified by the wagon numbers and an existing wagon tracking system when activated, be able to tell the whereabouts of each and every wagon in the system by train number. It is important to note that the Wagon Tracking System has been under development for quite some time now but is not yet functional. At the punch of a button, the scheduling of wagons at any point in time will be possible as the system will be running online making a wagon and locomotive position known to the minute. Also the costing aspect, i.e. the cost per ton/km will be incorporated to enable the awareness of the worth of each train run and thus determine in advance the value of running any train prior to running it.

References

[1] http://www.worldbank.org/transport/publicat//td-rw8.htm, 2005

[2] National Railways of Zimbabwe. Business Plan, 2011 (unpublished)

[3] Saripalli, S. S. (2011). *A Dynamic inventory optimization method applied to printer fleet management* (Doctoral dissertation, Rochester Institute of Technology).

[4] Maróti, G. (2006). Operations research models for railway rolling stock planning. *Dissertation Abstracts International*, *68*(01).

[5] Firdausiyah, N. (2010). *Timetabling optimization design considering train circulation and disturbances for high-speed rail system* (Doctoral dissertation, Master Thesis. Civil Engineering. National Central Univerisity).

[6] Kim, D. K., & Park, C. H. (2005). Development of Train Scheduling Model Accommodating Transfer Behavior. *Journal of the Eastern Asia Society for Transportation Studies*, *6*, 372-384.

[7] Zhou, X., & Zhong, M. (2007). Single-track train timetabling with guaranteed optimality: Branch-and-bound algorithms with enhanced lower bounds. *Transportation Research Part B: Methodological*, *41*(3), 320-341.

[8] Kuo, A., Miller-Hooks, E., & Mahmassani, H. (2007). Multi-Carrier Train Scheduling for Freight Transport. In *TRISTAN VI Symposium, Phuket Island, Thailand*.

[9] Helbaek M. and McLellan B., (2010). Essentials of Management Science, Harlow. ISBN: 978-0-273-72505-3.

[10] Render B., Stair M. R. Jr. and Hanna M. E. (2003), Quantitative Analysis for Management, Eighth Edition, New Jersey.