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Review of Optimisation Applications in Rail Freight Logistics with a View to Identify Possible Applications in the Southern African Region

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Abstract. Logistics is one of the most important and critical economic drivers which determines the rate at which goods can be exported at the lowest cost. The paper reviewed Southern Africa rail freight infrastructure and planning activities. It interrogated the academic and research institutes activities as related to rail freight. A review of one of the biggest freight company Transnet was done to highlight extent of application. The paper concludes by highlighting potential and the gaps in optimisation within Southern Africa rail freight, which can be addressed using operations research techniques such as ant colony and genetic algorithms with a view to inform decision making.

Key Words: Optimisation, Planning, Rail Freight.

1. Introduction

There is a need to increase export within Southern Africa. Export is through the ports, supplied by the rail and road networks. The aim is to reduce the logistics cost for all the export goods in the region. The paper looked at the railway network in the region highlighted the ports in Southern Africa which serve as the gateway to other continents. The paper proceeded to look at academic departments and research organization that have research related to freight railway. These were used as the primary sources for research in freight rail in the South Africa Region. A literature review of freight rail and optimization was carried out. Within Southern Africa, Transnet is the biggest freight company in the region thus a review of its operations was done. Factors that were considered in rail freight were crew scheduling and train scheduling.

1.1 Southern African Development Community (SADC)

SADC consists of the following fifteen countries: Angola, Botswana, Democratic Republic of Congo (DRC), Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Swaziland, United Republic of Tanzania, Zambia and Zimbabwe. The region has a population size of 257, 726,000 (257.7 Million inhabitants) and a Gross Domestic Product (GDP) of US$ 471.1 billion [1]. SADC's vision is that of a common future, a future within a regional community that will ensure economic well-being, improvement of the standards of living and quality of life, freedom and social justice and peace and security for the people of Southern Africa [2]. SADC's mission is to promote sustainable and equitable economic growth and socio-economic development through efficient productive systems, deeper co-operation and integration, good governance, and durable peace and security, so that the region emerges as a competitive and effective player in international relations and the world economy [1]. Thus rail freight optimization in SADC would not be a misnomer as rail network is the backbone for trade in any region.

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1.2 Rail Network in SADC

The use of the rail network is to link commodities from the region to a much cheaper mode of transportation, sea from the ports. The railway network in Southern Africa is summarised in [3]. The major port in Southern Africa are Luanda in Angola, Walvis Bay in Namibia, Cape Town, Port Elizabeth, East London and Durban in South Africa, Maputo and Beira in Mozambique and Dar es Salaam in Tanzania [4]. It can be seen that South Africa in the region has the highest number of ports and serves as the gateway to other continents. Thus optimisation of the rail freight would be beneficial not only to South Africa but to the region.

There is also need to differentiate the railway network into government owned and private owned through concessions. For rail to play a significant role in the general freight transport system, it must improve its service level, addressing overall transit time, reliability, security, and service frequency. Rail infrastructure and rolling-stock should be maintained "fit for purpose" [5]. This shows there is a need to optimise the rail system in the region, whether through investment in the infrastructure or through better management of the infrastructure that is there.

In any expansion or optimisation, there is need to consider the financial aspects of the freight railway transportation. Possible ways have been debated such as budget sources (deficit financing, government loans/ equity or grants), direct borrowing (Corporate borrowing, revenue-backed borrowing, and project specific borrowing), private participation (joint ventures, concessions, privatization of business units) and asset finance (export credit, leasing, and availability contracts) [6]. Thus, concessions come out of the way of financing infrastructure.

1.3 Operation Research and Logistics Research Application in Academic Institutions

Havenga and Naudé analysed freight transport demand in South Africa. Bulk Mining, Corridors, Metropolitan and Rural needed 75, 139, 53.2 and 85, billion tons kilometers respectively. These results show the potential in freight transportation [7]. Work on freight transportation model development focusing on logistics costs in freight transport was done in [8] and [9]. The length of road and rail network in SADC in terms of ton-km estimates and network length was analysed in [10]. Potential of the rail system in SADC was also highlighted as summarized in Figure 1

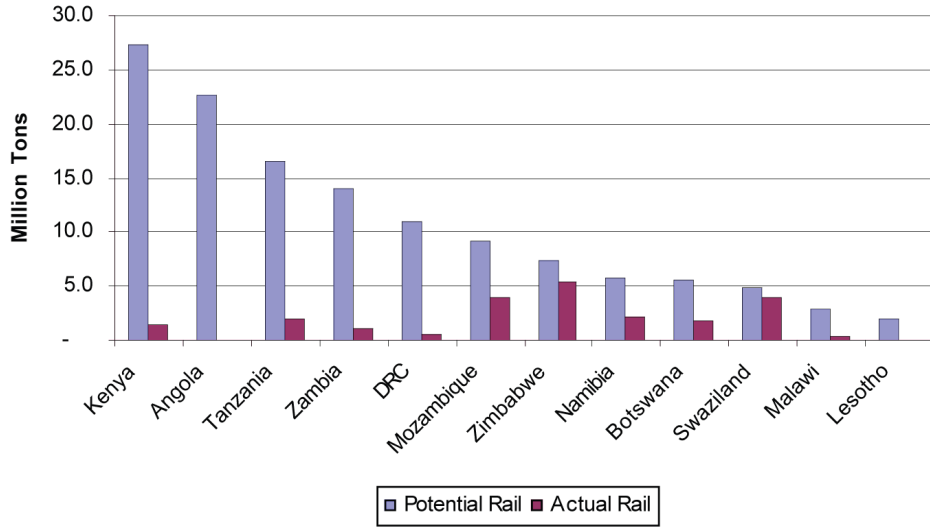

Figure 1: Actual and Potential rail volumes, [10]

A model of integrated freight transportation infrastructure was developed and suggested for the Tshwane logistics hub in South Africa [11]. Tshwane Logistic Hub could be optimised as a means to an end to reach the goal and establishing Africa in global market place [11].

The shortcomings were analysed in the Logistics Cost Model used by Centre for Supply Chain Management at University of Stellenbosch for consulting Transnet, the CSIR and other freight logistics service providers [12]. This research looked at the updates to the model and how the outcome can be interpreted by industry in making strategic decisions in future on a macroeconomic scale. Containerised

volume that needs to be handles by Transnet at the ports were analysed in [13], giving an insight of the growth of the volume which will be needed in the analysed in rail freight. The potential impact of densification on cost on the Sub-Saharan Africa's rail freight transport system, which reinforces the need to optimise rail freight [14]. Application of Operations Research has been done at the National Railways of Zimbabwe (NRZ) in the area of empty-wagon management using linear programming [15], train scheduling for the chrome line [16] and coal market [17].

2. Infrastructural Issues on Freight Rail

Van der Meulen, in 2007, highlighted factors that drive railways into clusters such as constrained railways, railways in intense competition, railways in privatization and railways in emerging economies [18]. Paper proceeded to analyse railways technologies and variable such as competitiveness, market, networkability, ownership, presence, society, sustainability and time to reduce global railway complexity to a level where usage insights emerges. Van der Meulen, in 2010, highlighted ways in which the railway renaissance will evolve in South Africa through the change of the guage width, axle load and speed. These facts would play a vital role in quantitative analysis of the rail freight optimization [19].

Rail undoubtedly plays a critical role in the southern African supply chain management context, despite the region's inefficient and inadequate terminal and rail systems. As a percentage of logistics costs, southern Africa's freight transport costs are the highest worldwide [19]. The region faces other challenges including high demand, high fuel costs, limited collaboration, process inefficiencies and skills shortages. A substantial way to address these challenges is by developing and implementing inter-modal logistics solutions that bring rail back into the transport equation. Consider that the high demand for transport is supplied by road, an expensive and unsustainable solution for certain products and geographical areas. By aligning objectives, companies can alleviate pressure on the road system, bringing back to rail heavy duty commodities such as coal, iron-ore and manganese, and containers best suited for rail transport. It is important though for road and rail sectors to complement each other through applying an optimum split between the two transport modes. Furthermore, solutions that optimise southern Africa's end-to-end supply chain must be identified, including the way that South Africa's rail, road, inland terminals and ports are integrated. Forming public private partnerships is a significant requirement to support Transnet's multibillion-rand investment plan in creating rail capacity to achieve sustainable logistics [20].

On the infrastructure, recent statistics indicate that less than 5% of annual citrus export volume in South Africa was transported by rail during the 2009 season. Brooke in 2010 highlighted how this has led to overcapacity on the national road infrastructure [21]. The improvement and use of rail would lead to potential cost benefits and obvious reduction in carbon emissions, reduce wear of the national system and reduced bottleneck at export terminals and cold storage facilities. A single freight train can replace the equivalent of 32 road trucks and drivers. Initiatives have been put in place where Transnet Freight Rail (TFR) has deployed rolling stock and traction engines for fruit export industry. In the past TFR had invested in rolling stock to handle coal and iron ore due to the seasonal fluctuations of fruit commodities. New changes to increase export volume to 35% in the next 5 years and plan to spend 35 billion rands are in place [21]. With all these initiatives there are underlying operations management techniques that uses operations research to optimally utilize the infrastructure invested.

Figure 2 shows the structural change in freight transportation from 1991 to 2004.

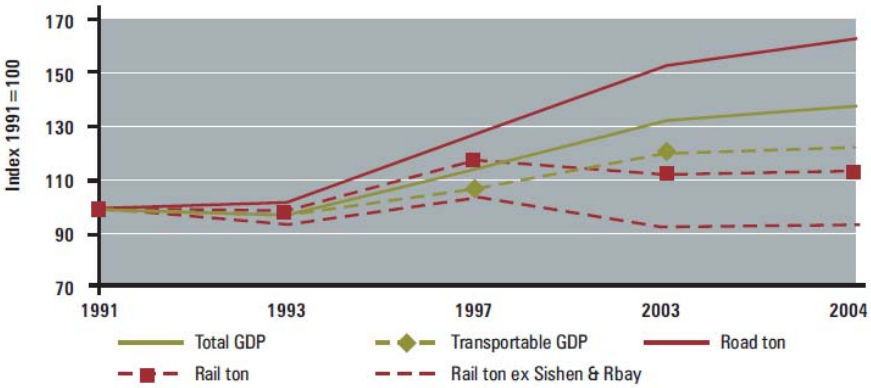

Figure 2 Structural changes in freight transportation [22]

Logistics research priorities were suggested in [23] which need to be supported by Operations Research techniques solutions. These research priorities are:

i) **Structural inefficiencies in the logistics system**

Where are the biggest structural gaps in logistics efficiencies and what strategies could contribute to alleviating the situation? How should infrastructure investment funding be spent to ensure the greatest contribution to efficiency, wealth creation, poverty alleviation and job creation in our economy?

ii) Logistics modelling

This involved development of a portfolio of cost-and-flow models that will support decision-making with respect to infrastructure investment; continued quantification of total logistics costs from a macro-economic perspective, to support strategy development; quantification of total logistics and supply-chain costs from an industry perspective and identification of the underlying drivers of inefficiency to support firm-level efficiency improvement; and benchmarking of the productivity of various elements of the national logistics system.

iii) Strategies for improved supply-chain efficiency

This involves interpreting global market trends, such as security, traceability and standardisation, and the effect thereof on local supply chains; identify and build specialist sectors within which a competitive advantage can be established within the global supply chain; follow best practice with respect to implementation of solutions based on technical and process developments in supply-chain management; follow best practice with respect to appropriate adoption of new technologies; introduce new innovative technologies; follow best practice with respect to inter-firm collaboration for demand management; and promote cross-industry collaboration to achieve more effective transport utilisation.

iv) Strategies for reducing the logistics divide

This looks at how can logistics infrastructure specifically support the second economy? Which mechanisms are required to enable the private sector to integrate small businesses into their supply chains? Which small business support models will enable small businesses to be sustainable supply-chain participants? What interventions are required to support small business channel development?

v) Logistics for improved government service delivery

What are the key elements of and solutions for efficient supply-chain design for distributed nationwide service delivery? What are appropriate models of outsourcing to enable efficient service delivery? How should government business processes be designed to enable financially sustainable interaction with small suppliers?

More work after these priorities was report in the Annual State of logistics survey in 2006 [24].

3. Research at Council for Scientific and Industrial Research (CSIR)

Reference [25] looked at a brief of the history of Operations Research at CSIR through cases. Transportation problem was applied at the Maize Board where the aim was to minimise total transportation. Ittmann et al., also sighted the application of operation research in military war gaming, long term planning in the South African Airforce and strike aircraft performance through simulation, [25]. Simulation has been applied at SASOL in 1992-93 in assessing the availability of coal at the harbour by looking at the design of

the channel that would have sufficient capacity to cope with the numerous variations along the chain without over investment.

Train scheduling for Spoornet in 1995/6 with an aim to schedule trains in the quickest and most cost-effective way was done in [25]. Due to the complexity of generating train schedule for the whole Spoornet network, a schedule for only the mainline section was investigated. Information used was the number of stations on the track, length of the train, the numbers of trains, station origin and the departure time, destination station, type of train speed, the work plan of the train (stopping stations) and the train length (stations where train was allowed to stop). The network problem was formulated with stations as nodes and arcs for the time delay of activities like travel time and crossing of trains on single lines. The train schedule was generated by calculating the longest path for each train in the network and the program was developed in C++. But since then there has been a great expansion in the Economy in the Southern Africa prompting the need for reassessment through rail freight optimization.

The total freight in 2008 increased slightly with 2% or 32 m tons, with all growth being on road again [26]. This is not ideal; not only is this the main contributor to high transportation costs, but heavy vehicles are damaging our road infrastructure. Various efforts over the past few years have not had the desired effect of getting some appropriate freight back onto rail. Thus, the great need to do an analysis to determine the reason why industry is shying from using rail freight.

4. Transnet Freight Rail (TFR-Transnet)

Transnet is current the biggest freight Rail company in Southern Africa thus the decision to concentrate on it. The strategic intent of the company is to reduce the cost of doing business, building capacity, operating safely and improving efficiency [27]. To achieve this Transnet will inject capital to the value of R35 billion rands by 2012 [28]. Implementation of this has seen Transnet purchasing 32 locomotives for the Iron Ore line [29]. Transnet has been in the transportation of the following good: Automotive, Containers, Lime and Cement, Grain, Chemicals, Chrome and Manganese, Timber, Coal, Fuel, Fertilizer, Granite and Fast Moving Consumer Goods.

With all these different commodities being transported from different venues to the different ports for export and to different local destinations there is need to optimise. Transnet in the bid to increase the amount of coal transported to the ports and different destination has looked at the hardware or infrastructural issues such as investing in new locomotives with bigger tractive power and thus increase the train length and the axle carrying capacities [30]. With all these efforts it has been realised that there was need to look into the softer side of which is the planning side. Transnet sent out a tender for the provision of a resource scheduling systems for Transnet freight rail coal traffic in 2009 [31]. The tender for resource scheduling system for Transnet freight rail coal traffic was won by OPSI systems [32]. OPSI Systems' PLATO software has been chosen for the dynamic scheduling of export coal trains between coal mines and Ermelo. Underlying all the software and the consultancy highlighted above are the algorithms and programs using operations research techniques, problem-solving, mathematics, programming, logistics and supply chain. Optimisation techniques from the family of metaheuristics such as Ant Colony Optimisation (ACO) and Genetic Algorithms are used [33], [34].

5. Potential benefits and Gap

Some of the potential benefits in rail freight optimisation include: Return on Investment (ROI), improved efficiencies, reduced operating costs through improved crew and rolling stock utilization, increased control through automatic assessment and recording of driver performance, improved cost controls through identification of delivery costs for each customer

Effective decision support systems are required to solve the planning problems related to transportation activities and processes. Crew planning problems and rail planning has had limited research in Southern Africa even though they have a significant share in overall costs. Railways need to paid particular attention to these topic as they are striving for cost-cutting competitive advantages in order to compete with other transportation modes, especially with road freight. In this project, we are looking into problems at the

strategic, tactical and operational levels of a hierarchical planning framework of a coal supply chain within Southern Africa region in rail freight optimisation.

6. Conclusion

The paper began by setting the background of the region Southern African and the railway network in the region coupled to their relationship with the ports. A highlight of the concessions in the region was given as an option to increase efficiency in rail freight in the region. Review of rail freight and logistics and general optimization in academic institutions in Southern Africa was done to show work done and gap in body of study. Highlights of research in logistics by CSIR in South Africa was done which showed the need to bring back freight to rail from road. There has been optimization work done at CSIR which has set a very good background for optimization of rail freight. Review of the biggest rail freight company in the region Transnet was done show the drive in the organization pushing for increasing amount of tonnes carried by the network by increasing the infrastructure and the gap from operations side by subcontracting OPSI to develop a scheduling system for both the locomotives and crew. This highlights the need that is still there in optimization of rail freight in Southern Africa.

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