Radially Aligning Self-Steering Bogies – an Indispensable Key to Green Heavy Haulage

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There is global consensus at all levels recognising the desperate need for “green” technologies to reduce harmful emissions worldwide. This has to happen despite the growing demand for natural and processed resources and the concomitant growth in demand for haulage. New legislation is being steadily adopted globally to incentivise and penalise carbon emitters - a significant portion of which will fall on the transport and haulage sector. The looming challenge is to deliver product at increasingly competitive rates while reducing carbon emissions and mitigating penalties.

Leveraging local and international experience gained over 30 years by Global Railway Engineering (an independent rail technology developer) and Transnet Freight Rail (South Africa’s freight rail operator) on Scheffel Self-Steering bogies, this paper examines various Carbon reducing opportunities with regard to OPEX and CAPEX and confirms that the adoption of true Self-Steering technology not only significantly reduces carbon emissions, but can significantly reduce transport OPEX (36% saving compared to non-steering) and accelerate return on CAPEX on heavy haul corridors.

Reduced consumption of steel (wheels, rail and fleet) and reduced consumption of fuel are translated into Carbon Emissions and quantified as Carbon Credits and Carbon Taxes. Further opportunities of Reducing Carbon Emissions are investigated and potential earnings/savings are quantified.

1. GREEN HOUSE GAS EMISSIONS, CARBON REDUCING TRENDS AND CLEAN MECHANISMS

Global Green House Gas (GHG) Emissions are on track to double the concentration of GHG in the atmosphere by the end of the century (~660-790 ppm CO₂). The Intergovernmental Panel on Climate change (IPCC) expects this to lead to a rise in average temperature of up to 6°C resulting in significantly adverse impacts on water supply, eco-systems, food production, land use in coastal areas and human health [1].

International research efforts to avert catastrophic climate change have suggested a target stabilisation of CO₂ concentrations at ~450 ppm on the basis that this would have a good chance of limiting global temperature rise to 2°C, which would greatly limit impacts and damage. Current trends are far from this trajectory. In order to meet such an objective, the IPCC and International Energy Agency (IEA) have suggested that a 50% reduction of GHG emissions from 2006 levels by 2050 will be necessary [1].

Current pledges and actions proposed by both developed and developing countries are not sufficient to lead GHG emissions onto a 450ppm stabilisation trajectory. Considering low and high estimates of the impact of these pledges as of August 2009, total emission reductions will fall 62% to 35% short of reaching a 450 ppm trajectory by 2020 [2].

It can therefore be expected that the already daunting and onerous emission reductions sought by policy makers around the world will only increase in the foreseeable future and, with about 25% of worldwide CO₂ emissions being attributable to transport [3,4], that governments
around the world must look to the transport sector to play a significant role.

2. THE ROLE OF FREIGHT

In 2006, Freight transport contributed around 30% of total transport emissions or 6452.78 MtCO$_2$e of which trucking made up some 70% [4]. According to projections by the International Energy Agency, trucking energy use by 2050 is projected to increase by 50%, with the quantity of freight moved by trucking worldwide expected to nearly double, and energy efficiency to improve by 20% assuming current efficiency trends continue. Rail freight volume is expected to increase by around 50% with a similar 20% improvement in rail efficiency. Much of these efficiency savings are anticipated to come from advances in efficiencies in existing technologies and clearly fall short of the required commitments.

Substantially changing transport trends will require both the widespread and rapid adoption of current best available technology, and the longer-term development and deployment of a range of new technologies at an unprecedented rate. It will also require strong policies to ensure rapid uptake and full utilisation of these technologies, and to encourage sensible changes in travel patterns and appropriate modal utilisation. It will involve industry, governments and consumers.

The challenge for the transport, and in particular the heavy haul sector, remains finding technologies that can rapidly and significantly impact CO$_2$ emissions while minimising any negative impact on competitiveness. This paper explores one of the key technologies for reducing transport related green-house gas emissions on rail transport while reducing both operational and capital costs.

3. POTENTIAL GHG SAVINGS AREAS

There are many areas to consider when investigating potential carbon savings on heavy haul, some of which can deliver substantial savings up-front while others could require a long-term, comprehensive approach and include governmental policy incentives and further Research and Development. Rather than investigating each in depth in this paper, we summarise some of the potential focus areas and highlight an example of technology which could be immediately adopted to put heavy haul on track to begin to meet it's low-carbon obligations.

3.1. Vehicle utilisation

- Vehicle availability: efficient utilisation through lower and less frequent maintenance
- Appropriate usage of modality: as discussed below.

3.2. Vehicle efficiency

- Locomotives: Higher fuel efficiency, aerodynamics, alternative fuels etc. are being investigated and hold potential for even greater CO$_2$ efficiency.
- Fuel sources: Bio-fuel, electric traction, green electricity etc. are being developed, but more research is required into ensuring that new fuels don't indirectly contribute more CO$_2$ than their traditional counterparts.
- Aerodynamics; reduced drag coefficients: As technology allows for faster transport, aerodynamic skins and covered empty trucks may lead to increases in efficiency.
- Reduced tare: Hollow axles, lighter castings, aluminium bodies, etc. should increase load-bearing capacity of trains, decreasing dead-weight haulage.
- Reduced rolling resistance: Radially aligned axle systems, improved brake systems, zero brake drag, etc will increase efficiency.
- Energy storage: Regenerative braking, train handling techniques, momentum gradients, etc can store energy temporarily to be utilised to offset power requirements.

3.3. System efficiency

- Reduced turnaround time: Reduces overall fleet size which in turn impacts CO$_2$ emissions. Here there are many factors that can be addressed. These can include loading and unloading, driver change out, driver training, refuelling, speed, maintenance inspections, etc.
- Synchronising faster empty wagon trains: Non-stop loaded trains through crossing loops
- Driver training: Driver training has been extensively researched in Brazil making significant impacts on fuel efficiency. In South Africa good driver training has been associated with higher savings especially in momentum gradients and efficient braking than was previously considered possible.
- Improved designs: To reduce losses and improve efficiencies
- Rail and wheel profiles: Special profiles are designed to improve wheel and rail life and are being used extensively throughout the world with noteworthy results.

3.4. Road to Rail

With rail transport being far less energy intensive than road and road haulage accounting for the majority of CO$_2$ emissions, it stands to reason that where distance makes it viable, moving from road to rail will achieve far faster and greater savings in emissions than purely concentrating on making rail or road transport more efficient. In fact, it is for this reason that modal shift is becoming a priority for many countries.
Although rail transport is clearly more fuel efficient than road transport and many countries’ transport policies strongly favour an increase in rail freight transport, rail’s share of the freight market in most countries has been contracting. This regressive trend is likely to continue in the absence of government policy initiatives to stimulate a shift from road to rail haulage.

4. COMPETITIVE LANDSCAPE
(INCREASING DISTANCES TO PORT, TIGHTER MARGINS, STOCKPILING)

China and India dominate the world natural resource markets. In 2000, China’s energy demand was half that of the United States, but preliminary data indicate it is now the world’s biggest energy consumer and one of the world’s fastest growing economies [5]. The developing world continues to drive global demand led by China and India accounting for about half the world increase in energy demand with a concomitant increase in natural resources demand. However as can be seen in Fig. 1, the market price does not follow the cost of extracting the ore. [World Bank - Aus Thermal Coal, China import Ore Fines].

As readily accessible coal and ore resources dwindle internationally under pressure from rapidly growing demands, mining operations must increasingly be established further from major transport hubs or ports. As distances increase and margins tighten, the transport sector will bear a heavier contribution to overall costs but also an increase in the weight of contribution of any potential economic or environmental saving.

The dichotomy of meeting Carbon reduction targets while increasing production over greater distances within tighter financial boundaries is the challenge laid before the heavy haul industry. This challenge is not insurmountable, in fact, many of the technologies required to make this a reality already exist as is evidenced by the substantial economic and carbon emission savings embodied in more efficient track friendly rolling stock discussed later in this paper.

5. LEGISLATION (INCENTIVES TO MOVE TO NEW TECHNOLOGY)

It is highly unlikely that the necessary adoption of technology and modal shifts required to meet the 2050 goals will occur without significant governmental incentive and penalty initiatives rapidly promulgated and rigorously enforced. Indeed, as mentioned before, current legislation, although already onerous on the transport sector has to increase further to meet the 2 degree or 450 ppm goal by 2060 [3].

The transport sector therefore needs to identify means of making rapid gains utilising proven technology in conjunction with modal shifts to meet and exceed the current legislative requirements while stimulating long-term projects to further reduce emissions to meet the inevitable increases.

Legislative initiatives can be broadly divided into two categories, Carbon Taxes and Carbon Trading Schemes (Also called Cap and Trade Schemes) which are outlined below.

6. CARBON TAXES

Carbon taxation is an economically efficient means to convey crucial price signals designed to spur carbon-reducing investment [6]. It is an indirect tax levied on a calculated CO₂ emission of an entity usually based on a combination of proven CO₂ emissions attributable to the entities’ direct activities.

As of 1 July 2012, Australia imposed a A$23.85 carbon tax on every tonne of CO₂ emitted by the country's top 500 emitters. This will be a fixed-price scenario until emissions trading starts in 2015. It is estimated that the new tax will cost BHP Billiton some A$300million in the 2012/13 financial year and Rio Tinto some A$202m in the same period.

Many other countries are implementing similar schemes. (Switzerland - $34.20 with voluntary cap and trade, South Africa - R120 ($14.28) increasing at 10% until 2020).
It is clear that technologies will be required that can offset this tax as rapidly as possible to ensure that heavy haul in these territories remain competitive in the global market.

7. CLEAN DEVELOPMENT MECHANISM

The purpose of the Clean Development Mechanism (CDM) is to promote clean development in developing countries, i.e., the "non-Annex I" countries (countries that aren't listed in Annex I of the Framework Convention). The CDM is one of the Protocol's "project-based" mechanisms; in that the CDM is designed to promote projects that reduce emissions [7]. The CDM is based on the idea of emission reduction "production" [8]. These reductions are "produced" and then subtracted against a hypothetical "baseline" of emissions. The emissions baseline is the emissions that are predicted to occur in the absence of a particular CDM project. CDM projects are "credited" against this baseline, in the sense that developing countries gain credit for producing these emission cuts.

This is beginning to prove to be a valuable means of offsetting some of the massive infrastructure costs involved in moving road users to rail as evidenced by the Deli Metro system which is regarded as being the first successful applicant from the rail infrastructure sector to estimate and validate savings and to now offset their costs by some $9.5 million annually.

The so-called quality of the Carbon credit determines its sale value on the Carbon market (which can range from as low as $2/tCO₂ to $25/tCO₂ [www.carbonfund.org – retrieved 07/2012]) and is a function of the transparency and rigorousness with which such savings are calculated and validated.

To earn Carbon Credits the project must also display "Additionality". Only carbon credits from projects that are "additional to" the business-as-usual scenario represent a net environmental benefit. Carbon projects that yield strong financial returns even in the absence of revenue from carbon credits; or that are compelled by regulations; or that represent common practice in an industry are usually not considered additional.

8. RADially ALIGNED BOgie IN THIS LANDSCAPE

In essence, the Radially Aligned (or self-steering) bogie "steers" around curves without the wheel flange touching the rail [14]. This "off-flange" steering is a passive action facilitated by creep forces between wheel and rail plus the ability of the bogie to allow axles to take up radial positions in the curve. This allows the bogie to steer around curves in a near PURE-ROLLING state which greatly increases efficiency and reduces wear on rail and wheel. Conversely, the conventional three-piece bogie has its axles held rigidly parallel which prevents radial alignment of the axles and hence is "forced-steered" around curves by the flange grinding against the rail at a significant angle of attack and with all wheels skidding on the rails. The resultant difference between the wear rates of wheel and rail and the reduction in curving resistance, when comparing the two bogie types, is of quantum proportions and is seen to have significant impact on cost savings as well as reduction in carbon emissions.

At this point this technology is neither compelled by regulation nor common practice outside of South Africa. Preliminary investigations suggest that new projects involving this technology could benefit from Carbon Credits but that the conversion from existing bogies to this technology fall well within the confines of carbon credit generation.

9. TRANSNET EXPERIENCE

To be able to gear up for the large-scale export of iron ore, the South Africa Railways (now Transnet Freight Rail) started upgrading its rolling stock in the 1960s. A study showed that the economics of the operation could be improved considerably if the train mass could be increased. Hence, wagons with a higher axle load (18.5 ton per axle) were designed and put into service. In the early 1970's these wagons were fitted with conventional three-piece "Spoorbarber" bogies.

After the introduction of 100 wagon air braked trains on the export line from Sishen to Port Elizabeth which contained many 200m to 250m curves, wheel flange and rail gauge face wear was unacceptably high. Recognising the need to limit wheel flange and rail gauge face wear, Dr Herbert Scheffel from Transnet Freight Rail started with a bogie development programme in the early 1970's. The focus was to improve the curving performance of the bogies. This was achieved by designing a self-steering bogie with a low bending stiffness for adequate curving ability and high shear stiffness for the required hunting stability. The theory and practical application of this novel bogie design has been described in various international papers [9 - 19].

The new design retained the three-piece bogie arrangement and the load sensitive vertical damping but introduced rubber shear pads at the journal boxes as well as an additional inter-axle shear stiffness which is independent of the shear constraint provided by the three-piece bogie frame. The first experimental "double bissel" self-steering bogie was built in 1971.

However, for the production type bogie the double bissel design was abandoned in favour of a design, which included sub-frames, mounted to the journal boxes and linked diagonally by means of cross-anchors. This design was patented as the Scheffel HS Bogie in 1972.

Presently the so-called HS Mk III and HS Mk VII (See Fig. 2) self-steering 20 ton axle load bogies are fitted to about 30500 wagons and the so-called HS Mk V self-steering bogies are fitted to 7500 wagons operating at 26 ton axle load and to 6200 wagons operating at 30 ton axle load.
Fig. 3 and Fig. 4 show the influence of the Scheffel self-steering bogie on eliminating flange wear. These measurements were made in 1977 shortly after introducing this innovative design. Bogies were tested concurrently under identical conditions.

Before the implementation of the self-steering bogie, rails in curves with a radius of 300 to 500 meters had to be replaced after about 70 million gross tons when using conventional three-piece bogies at 18.5 tons axle load. Today the rail life on the Richards Bay coal line in similar curves is about 800 million gross tons. In 800 to 1600 meter curves the rail life exceeds 1000 million gross tons, while on tangent track values of 1600 million gross tons are being exceeded while operating at 26 ton axle load.

From the 35 years of in-service experience on South African lines, the average performance improvements of Self-Steering bogies over their predecessor three-piece bogies can be summarised as follows:

- Increase in Wheel Life up to 500%
- Increase in Rail Life (curves) up to 25 times
- Reduction in Wagon Maintenance up to 70%
- Reduction in Fuel Consumption up to 5%
- Reduction in flange-related Derailments 100%
- Increased Hunting Stability 100%

10. MODEL – USING TRANSNET’S EXPERIENCE

The results obtained from the use of the Scheffel self-steering technology are impressive and despite the many published scientific papers confirming these results, the question arises: How would such technology perform on other lines with different conditions and under what conditions can such results be anticipated?

Trials utilising Scheffel self steering bogies around the world have confirmed similar results, however, implementing trials on existing heavy haul lines is difficult and time consuming and often unhelpful when planning a new line. A crude model was thus developed to quantify these results and predict savings for other line conditions.

With new data from installations and trials around the world, the program has been refined and grown to incorporate variables covering aspects from wheel/rail steel properties to locomotive efficiencies and even labour costs (with percentage curves and track length having the largest influence). While still in development, the model is verified against line conditions in South Africa and provides a first-order prediction/feasibility of potential advantages that self-steering can offer. The savings in fuel, rail and wheels led to the realisation that the self-steering technology has a significant impact on carbon emissions.

The results shown by this model are only indicative at this point, as many other factors, including peripheral impacts of support chain activities, need to be considered when analysing the carbon footprint and could contribute further to the overall savings brought about by this technology. However, the current model predicts that the carbon savings brought about by the move from conventional to Scheffel self-steering bogies is an essential part of claiming carbon offsets.

11. RESULTS

To quantify the savings inherent in this technology the South African coal export line between Ermelo and Richards bay is used as an example. As can be imagined, results will vary depending on a variety of factors including, but not limited to horizontal curve percentage, wagon tare, length of rail, axle load etc.
Currently the coal line exports about 70 million ton of coal per year over 580km, using around twelve 200 wagon long trains per day. All wagons run on 26ton/axle self-steering Scheffel MkV bogies. On this line, the comparison between operating with Scheffel Self-Steering Bogies and Non-Steering bogies provides improvements and/or savings as shown in Table 1.

Table 1. Improvements by using self-steering bogies

<table>
<thead>
<tr>
<th>Operating Aspect</th>
<th>Improvement</th>
</tr>
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<tbody>
<tr>
<td>Turn –around time (hrs)</td>
<td>4h</td>
</tr>
<tr>
<td>Wagon Availability (98.4%)</td>
<td>8%</td>
</tr>
<tr>
<td>Wheel Life</td>
<td>2 000 000 km</td>
</tr>
<tr>
<td>Rail Life (in curves)</td>
<td>1.6 billion gross ton</td>
</tr>
<tr>
<td>Wagon Fleet (reduced by)</td>
<td>502 wagons</td>
</tr>
<tr>
<td>Locomotive Fleet (reduced by)</td>
<td>9 locos</td>
</tr>
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Operating Expenditure ($ p.a.)

<table>
<thead>
<tr>
<th></th>
<th>Saving</th>
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<tbody>
<tr>
<td>Fuel</td>
<td>$10.2 million</td>
</tr>
<tr>
<td>Wagon Maintenance</td>
<td>$14 million</td>
</tr>
<tr>
<td>Track Maintenance</td>
<td>$57 million</td>
</tr>
<tr>
<td>Derailments (aver cost p.a.)</td>
<td>$58 million</td>
</tr>
<tr>
<td>Total Opex Saving ($ p.a.)</td>
<td>$139.2 million</td>
</tr>
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Capital Expenditure ($)

<table>
<thead>
<tr>
<th></th>
<th>Saving</th>
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</thead>
<tbody>
<tr>
<td>Reduced Fleet</td>
<td>$46.9 million</td>
</tr>
<tr>
<td>Carbon Emissions</td>
<td>$46.9 million</td>
</tr>
<tr>
<td>Reduced $CO_2$ emissions (fuel and steel savings only)</td>
<td>83 200 t$CO_2$</td>
</tr>
<tr>
<td>Reduced Carbon Tax</td>
<td>$2.0 million p.a.</td>
</tr>
</tbody>
</table>

Overall Savings in 20 years of operation

12. CONCLUSION

In the energy-hungry environment of our world, together with the realisation of the need to reduce $CO_2$ emissions, short term and longer term solutions are going to be needed to balance the growing demand of heavy haul transport and the need to curb environmental disaster with economic sense, i.e. not only as a responsibility to our environment, but also for pure survivability in a turbulent environment of fluctuating demands and commodity prices, as well as threatening legislation.

The self-steering bogie is one such short term, already proven, solution to aiding the curbing of Carbon Emissions, especially on longer lines in undulating terrains, and at the same time significantly offsetting Capex and Opex.

Whether regarded as a "dead weight cost", a tree hugging fad or essential investment in future generations, the reality remains that we all breathe the same air and rely on the same resources. It is widely accepted that to survive, environmentally sustainable practices need to be adopted worldwide and soon. Unfortunately, it seems that good-will alone has fallen short and policies and legislation designed to apply economic pressure to incentivise industry to invest in and adopt new low-carbon technologies is and will continue to become increasingly burdensome on industry.

There are a number of short and longer term solutions and strategies that can assist the heavy haul industry and its clients to reduce their carbon emissions. Some of these solutions will take time to investigate further. Some require new ways of thinking about freight and heavy haul modalities and logistics.

There are, however, existing technologies which can make quick-gain inroads into a low-carbon future without significant capital outlay which can not only deliver $CO_2$ reductions, but substantially increase competitiveness.

The Scheffel Self-steering technology is given as an example to demonstrate the potential for reducing carbon emissions and improving operational efficiency.

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1 These figures are extremely conservative and look purely at $CO_2$ emissions from steel and fuel consumption directly attributable to a comparison of already efficient rail systems. It does not take into consideration less efficient systems or any secondary $CO_2$ emissions directly attributable to the project, (e.g. transportation of additional rails, wheels and fuel otherwise consumed). These will need to be taken into consideration on a project to project basis.

2 Stated another way, this line offsets the same amount of carbon dioxide as planting some 66,000,000 trees in marginal land - US EPA Carbon Sequestration Estimates
that such technology exists; that Carbon reductions need not come at the expense of Capex or Opex and that bold steps can be taken on proven ground to usher in an exciting new innovative phase in heavy haulage.

This paper aims to be an encouragement to the heavy haul industry and in particular to the engineers and scientists to re-look at the validity of old axioms and the viability of non-mainstream technologies which may challenge some of the long-held assumptions.

REFERENCES


[17] H. Scheffel, The reduction in mechanical wheel rail wear and energy consumption as well as total cost benefits when using the Scheffel self steering truck, International Centre for Transportation Studies (ICTS) Conference, Amafid, Italy, June 1983

[18] H. Scheffel, R.E. Von Gericke, The development and design of the Scheffel self steering truck and in service experience gained on the South African Transport Services, Freight Car Conference, Montreal, Canada, October 1983
