CONSIDERATIONS RELATING TO COSTS OF "SUSTAINABLE" RAILWAY TRACTION OPTIONS

By Chris Newman

Introduction: In September 2008 a paper was presented at the CORE2008 rail industry conference in Perth, Australia, that compared the cost of four rail traction options for the operation of a hypothetical 100km coal haulage railway in a developing country. The paper, titled "Feasibility of Steam Traction for Coal Transportation in Developing Countries", compared the costs of operating four types of traction:

- Reconditioned 20 year old ex-China Railways steam locomotives of traditional design;
- New design of "Modern Steam" locomotive developing much higher thermal efficiency;
- Standard modern Chinese diesel traction;
- Standard modern Chinese electric traction.

The study compared the performance of each traction type to determine realistic haulage capacities for each, and then applied known or estimated costs (based on Chinese data) covering capital amortization, maintenance, labour, water and fuel. It concluded that within the assumed scenario of low labour costs and low-cost coal available directly from the mine mouth, both steam options offered very substantial cost savings compared to the diesel and electric alternatives.

A similar approach can be taken to compare the costs of "sustainable" traction options in a fossil-fuel deprived world, wherein biodiesel fuel might be used to fuel suitably modified diesel locomotives, where hydro, wind or carbon-sequestered coal-fired power stations might provide power to electric traction and where biomass (wood) products might be used to fuel high-efficiency "modern steam" locomotives.

With so many uncertainties and the need to rely on broad assumptions about future (and even present) costs, such predictions can offer no claim to accuracy. What they can do however is to initiate the development of a more meaningful costing model that could provide clearer insights into a range of possible future outcomes and thus highlight potentially useful avenues for technical development aimed at creating an environmentally sustainable railway industry.

Sustainable Rail Traction: Before ideas can be developed as to possible cost scenarios, it is necessary to define (as best as may be possible) what the term "sustainable rail traction" might cover. Two possible options spring immediately to mind - viz: (a) "environmentally sustainable", in terms of not releasing CO2 or other harmful substances, and (b) "energy sustainable" in terms of not relying on fossil or other "mined" fuel source. For instance, with 100% carbon capture, coal could be regarded as an "environmentally sustainable" fuel source whilst ever coal resources remain exploitable, whereas electricity supplied only from wind, water or geothermal sources could be regarded as "energy sustainable" in the longer term. Both require major advances in technology and/or capital investment which will inevitably result in substantial increases in the price of energy.

Energy is likely to represent the largest cost component of any rail traction system, however it should not be forgotten that a comprehensive analysis should include the environmental or energy costs of manufacture as well as those associated with fuels for operation. Such costs might be similar for each form of traction unit and may therefore not weigh significantly in comparative terms, but it is questionable whether the energy inputs required to build the infrastructure associated with electric traction would be insignificant in comparison with steam or diesel traction. Such considerations fall outside the limited scope of this article, but should not be ignored in a more detailed analysis.

This article uses a simple methodology for comparing costs of traction alternatives. Much further work is required to refine both the costing methods and data before firm conclusions can be drawn. For instance (as noted above) no attempt is made to assess the energy costs of equipment manufacture, and the figures used for future sustainable energy costs are no more than crude guesstimates.

Cost Analysis Assumptions: The methodology used to produce the cost comparisons for the CORE2008 paper was based around a conceptualized purpose-built single-use single-track coal haulage railway of specified length and configuration designed to deliver a predetermined annual throughput of coal. The costing model included detailed predictions of train size (based on the tractive capacity of each locomotive type) from which estimates of locomotive and rolling stock requirements could be made. An intensive 24 hour per day operating schedule for the line was also derived, which allowed detailed estimates to be made of locomotive utilization, annual mileages and maintenance requirements.

Fuel consumption estimates were made based on assumptions relating to thermal efficiency, calorific value of fuels etc, these estimates being calibrated with reasonable accuracy against known fuel consumption data. Capital costs and maintenance costs and frequencies were based on Chinese data for each type of traction excepting, of course, for the “modern steam” option for which no historic data exists. Costs for modern steam were therefore based on such information as was available from various sources, and where necessary through intelligent guesswork. Fuel (and electricity) costs were based on 2006 Chinese data.

The other cost items that were included in the calculations were labour costs (for operational purposes only) and water costs for steam traction only, including water treatment costs.

As stated above, both traditional and modern steam options produced the lowest overall costs by substantial margins, showing a 60% costs advantage over electric traction, and more surprisingly, a 200% cost advantage over diesel traction. These outcomes appeared to be robust insofar as large changes in input values changed only the magnitude of the cost differentials rather than their order.

Such dramatic cost advantages for steam traction arose from very low costs for both coal and labour available in a Third Word coal-producing country. As might be expected, diesel and electric traction costs become much more competitive in a Developed World scenario where much higher costs apply to these items. Notwithstanding, in looking forward to a fossil fuel-depleted future, in which renewable transport fuels will become a necessity instead of an option, and where fuel costs are likely to rise dramatically, it behoves us to consider all “sustainable” options that might serve to keep trains moving and preserve something of the mobility that mankind has enjoyed since railways were first created 200 years ago.

Analyzing traction costs for a non-specific general merchandize railway system is more problematical than for a specific single-purpose single-commodity railway of known length and throughput. A simplified analysis is therefore proposed, in which comparative costs are derived in "NZ dollars per million net-tonne-km", based on assumed values for average train weights, average length of journey, loco fleet size etc, in addition to a large number of cost assumptions.

For the purpose of the preliminary study that was prepared for this article, the following assumptions were made, based on estimates and (in some cases) assumptions of current costs.

Assumptions for Comparing Loco-Hauled Rail Operations based on 2009 Costs			
Item	**Modern Steam**	**Diesel**	**Electric**
Av distance travelled by each loco	200,000 km per year (approx 600 km per day)[1]		
Average train weight	1200 tonnes gross, 900 tonnes net[1]		
Locomotive fleet size	16 units[1]		
Average train journey length	200 km[1]		
Annual tonnage handled (assuming fully loaded journeys both ways	14.4 million tonnes net (2,880 million net tonne-km)		
Percentage of single-line track	50%[1]		
Refuelling and servicing infrastructure cost	NZD 10 million (including watering facilities)	NZD 2.5 million	NZD 2.5 million
Capital costs for locomotives	NZD 6.0 million[2]	NZD 4.0 million[3]	NZD 4.0 million[3]
Life expectancy (for depreciation)	25 years	25 years	25 years
Electrical infrastructure costs			NZD 1.5 million per km per track[4]
Operating shifts per day	2	2	2
Loco crew per shift	2	1	1
Servicing crew per shift	0.5 per loco[5]	0.3 per loco[6]	0.5 per loco inc. lines-men[7]
Labour costs including overheads etc	NZD 60,000 per annum[8]	NZD 60,000 per annum[8]	NZD 60,000 per annum[8]
Water costs	NZD3.00 per tonne[9]	n/a	n/a
Water treatment costs	NZD 1.25 per tonne[10]	n/a	n/a
Net Calorific Value (NCV) of fuel	wood pellets: 18 MJ/kg = 4300 kcal/kg[11]	light fuel oil: 42.9 MJ/kg = 10,250 kcal/kg[12]	
Fuel costs	wood pellets NZD 300 per tonne	light fuel oil: NZD 1000/tonne	electricity NZD 0.10 per kWh
Carbon tax or sequestration costs applied to electrical supply costs	NZD 0 per tonne of CO_2	NZD 0 per tonne of CO_2	NZD 0 per tonne of CO_2
Assumed thermal efficiency	12%[13]	25%[14]	73% (from point of supply)[15]

"Load Factor" to estimate average day-to-day thermal efficiency	55%[16]	55%[16]	55%[16]
Major Overhaul costs[17]	NZD 250,000 each 500,000km	NZD 400,000 each 700,000 km	NZD 500,000 each 1.2 million km
Minor Overhaul costs [17]	NZD 50,000 each 167,000 km	NZD 75,000 each 233,000 km	NZD 100,000 each 400,000 km
Regular Maintenance costs[17]	NZD 7,500 each 30 days	NZD 12,000 each 30,000 km	NZD 15,000 each 40,000 km
Maintenance cost of Electrical Infrastructure	n/a	n/a	4% of capital cost per annum
Spare locos needed to cover maintenance and breakdowns (calculated numbers)	15.8% over nominal requirement	12.1% over nominal requirement	9.8% over nominal requirement

Notes:

[1] These values are based on the assumption of a medium length freight haulage railway;

[2] Steam loco capital cost based on studies by 5AT Group – see www.5at.co.uk;

[3] Diesel and electric loco capital costs based on price of UK Class 66 diesel freight loco;

[4] Electrical infrastructure cost extrapolated from 2001 Chinese cost data, viz: RMB 3.4 million per km. The assumed value of NZD 1.5 million per km is probably on the low side;

[5] A figure of 0.5 men per loco per shift is adopted for steam locomotive servicing – i.e. refuelling, watering, firebox and smokebox cleaning, mechanical checks etc.

[6] A figure of 0.3 men per loco per shift is adopted for diesel locomotive servicing – i.e. refuelling, mechanical checks etc.

[7] A figure of 0.5 men per loco per shift is adopted for electric locomotive servicing, including teams of lines-men looking after the electric power transmission system.

[8] Assumed labour costs (no firm data available)

[9] Assumed water costs (no firm data available)

[10] Estimated water treatment costs are based on information from Martyn Bane – see http://www.portatreatment.com/;

[11] The net calorific value for wood pellets (18 MJ/kg) is taken from "Review of Carbon Neutral Fuels with Potential Use in Modern Steam Locomotives" is as given by B. McCammon;

[12] The net calorific value for diesel and light fuel oil (42.9 MJ/kg) is as given by B. McCammon (23 Jul 09);

[13] The maximum drawbar thermal efficiency of modern steam traction is assumed to be 12%;

[14] The maximum drawbar thermal efficiency of diesel traction is assumed to be 25% based on a maximum crankshaft thermal efficiency of 35% (estimated by J. Keyte 23 Jul 09);

[15] The maximum drawbar efficiency of electric traction is assumed to be 73% (recommended by J. Keyte 22 Jul 2009) comparing output at the drawbar to energy input at the point of supply. This figure excludes power station and transmission losses;

[16] The "load factor" is applied to allow for locos operating at sub-optimal conditions. A 55% load factor has been selected to generate fuel consumption rates that are consistent with 1995 Chinese data (with allowance for improved efficiencies likely to be achieved by more modern designs).

[17] Maintenance costs and frequencies are based on Chinese data for diesel and electrical traction. Modern steam maintenance costs extrapolated from Chinese steam maintenance data.

Space does not permit a detailed description of the relatively simple methodology used to analyze these cost assumptions. For the purposes of this article it is sufficient to summarize the outputs of the analysis and to look briefly at their sensitivities to changes in input values.

Looking first at the outputs generated from the above-listed assumptions:

Cost Comparisons for Loco-Hauled Rail Operations based on 2009 Costs			
Item	**Modern Steam**	**Diesel**	**Electric**
Capital Costs per loco per km	NZD 1.31	NZD 0.83	NZD 8.33
Labour Costs per loco per km	NZD 1.50	NZD 0.78	NZD 0.90
Water Costs per loco per km	NZD 0.58	-	-
Fuel Costs per loco per km	NZD 3.88	NZD 2.60	NZD 1.06
Maintenance Costs per loco per km	NZD 1.20	NZD 1.29	NZD 3.54
Total Cost per Loco per km	**NZD 8.46**	**NZD 5.50**	**NZD 13.83**
Total Cost per Loco per million net-tonne km	**NZD 9,404**	**NZD 6,116**	**NZD 15,369**

The outputs confirm what should be expected – that the diesel option is the most cost-effective for this scenario. In a more heavily trafficked (suburban) scenario with (say) 100 locomotives operating over average distances of 50 km, the model confirms that (as might be expected) electric traction becomes the most cost-effective option.

Looking to the future however, perhaps to 2029 when “light fuel oil” (fossil diesel) may have been replaced by bio-diesel having a calorific value of only 8840 kcal/kg[1]; where liquid diesel and electricity prices have doubled (based on 2009 prices) but where wood products have risen only 50% (reflecting the much higher rate of energy return that wood products offer[1]); where electric power is further penalized with a $50 per tonne carbon tax (or carbon sequestration cost); and where steam technology has advanced far enough to allow single-man crewing and capital costs similar to diesel and electric traction: the cost comparisons change significantly:

Cost Comparisons for Loco-Hauled Rail Operations based on Hypothetical 2029 Costs			
Item	**Modern Steam**	**Diesel**	**Electric**
Capital Costs per loco per km	NZD 0.83	NZD 0.83	NZD 8.33
Labour Costs per loco per km	NZD 0.90	NZD 0.78	NZD 0.90
Water Costs per loco per km	NZD 0.58	-	-
Fuel Costs per loco per km	NZD 5.82	NZD 6.04	NZD 2.13
Maintenance Costs per loco per km	NZD 1.20	NZD 1.29	NZD 3.54
Total Cost per Loco per km	**NZD 9.32**	**NZD 8.94**	**NZD 14.89**
Total Cost per Loco per million net-tonne km	**NZD 10,360**	**NZD 9,933**	**NZD 16,550**

[1] Figure taken from “Review of Carbon Neutral Fuels with Potential Use in Modern Steam Locomotives” - an unpublished paper by Brian McCammon.

In this scenario, wood-fired “modern steam” presents a potentially cost-competitive alternative to bio-diesel traction. Whilst the cost assumptions and methodology used in this study are somewhat crude, they do suggest that when looking forward to a world that will be searching for alternatives, the steam option should not be dismissed as summarily it was in the mid-20^{th} century, and that more detailed costing studies may be warranted.

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About the Author:

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