Traction Cost Comparisons

for an

Indonesian Coal Haulage Railway

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1. Introduction

Following up an enquiry about the availability of the 5AT locomotive[1] for hauling coal trains in Indonesia, the author (whose engineering career centred on bulk materials handling) was invited to adopt the role of technical adviser for planning a new rail and barge transportation system for the haulage of 20 million tonnes of coal per year from mine-site to a new port off the coast of Indonesia.

The 5AT enquiry arose because the project planners, unusually, favoured the use of steam traction for their proposed new railway to take advantage of the low-cost coal available from the mine. The author therefore took the opportunity to prepare a detailed proposal for the operation of the rail system using reconditioned QJ locomotives from China, since at the time, such locomotives were readily available and purchasable at very low cost[2]. The proposal was based on QJ performance data supplied to him by a senior engineer from China National Railways.

In April 2006, the author travelled to Indonesia to present to potential partners in this $500 million transportation project a detailed cost comparison between four traction alternatives. This paper summarizes his findings which, based on cost data from China National Railways, conclude that the cost of QJ traction (per tonne-km of coal hauled) should be about half that of diesel traction at current diesel fuel costs, and perhaps 60% that of electric traction. The comparison goes on to suggest that the cost of (new) "modern steam" traction should be lower than that of reconditioned QJ locomotives despite its much higher capital cost.

Whilst the cost comparisons reflect the availability of low-cost of coal and low-cost labour for this project, they confirm that steam still has a role to play in the 21st century where circumstances favour its use. That role will be enhanced as diesel fuel prices continue to rise.

2. Outline of Operating Plan for Railway

The proposed railway will run from an inland mine-site approximately 90km to a riverside transfer station where coal will be transhipped from train to barge. The planned route traverses a coastal plain and drops just 23 metres over its 90km length at a near uniform grade of around 0.06%.

No connections are planned to link the planned railway with other railways lines, hence it is feasible to consider the use of Chinese rolling stock operating on "standard" 1435mm gauge for this heavy-haul railway instead of the normal Indonesian gauge of 1076mm.

Haulage of 20 million tonnes is planned to take place over 320 days per year – i.e. at an average rate of 62,500 tonnes per 24 hour day (or 2,600 tonnes per hour). If we assume an operating efficiency of 75%, the target coal delivery rate for the railway becomes 83,300 tonnes per day (or 3,500 tonnes per hour).

Whilst it is not the purpose of this paper to discuss details the railway operation, some understanding of it is necessary to estimate the appropriate size of loco fleet. The main assumptions are as follows:

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[1] The 5AT advanced technology steam locomotive is a brainchild of David Wardale conceived for hauling high speed passenger trains. The author is a founder member of the 5AT Project group and acts as its Webmaster. Details of the 5AT Project can be found at www.5at.co.uk.

[2] See "End Note" on page 15.

- The railway is assumed, for the purpose of this exercise[3], to have twin-tracks with trains running at 50kph (average speed) between loading and unloading stations.
- Trains operate on a merry-go round system, with locos and trains remaining coupled together for at least one circuit of the railway;
- Each train loco hauls its wagons under a loading hopper (or hoppers) at slow speed (aided by gradient in the case of steam, to prevent stalling) at an average loading rate of 6000 tonnes per hour;
- Each train loco hauls its wagons over the unloading hopper at slow speed (aided by a gradient) at an average unloading rate of 3000 tonnes per hour. Thus two consecutive trains will be unloading at the same time over two separate hoppers;
- Additional spare locos will be required according to the anticipated servicing and maintenance requirements and to take account of breakdowns.

3. Estimate of Locomotive Fleet Requirements

The following table summarises the calculations for estimating the fleet size required for each type of traction. A (subjectively chosen) "haulage capacity factor" has been added for the purpose of estimating appropriate train sizes for each traction type, starting with a factor of 1.00 for the QJ locomotives.

A nominated net capacity of 3000 tonnes for a QJ-hauled train is based on separate calculations outlined below. If the coal is hauled in Chinese C70 wagons (70 tonnes net weight, 93 tonnes gross) then the gross train weight becomes 4,000 tonnes, a comfortable load for a QJ on level track (see Table 2).

Table 1 – Estimates of Loco Fleet Requirements for 62,500 tonne per day 90 km haulage operation

Traction Type	Electric (New)	Diesel (New)	Modern Steam	QJ Steam Reconditiond
Haulage Capacity Factor (QJ=1)	1.75	1.50	1.00	1.00
Net Train Capacity (tonnes)	5.250	4,500	3,000	3,000
Return Journeys per day	16	19	28	28
Average Train Speed both ways (kph)	50	50	50	50
Train Travel Time (mins)	108	108	108	108
Train Load Time at 6000 tph (mins)	53	45	30	30
Train Unload Time at 3000 tph (mins)	105	90	60	60
Minimum Train Cycle Time (mins)	373	351	306	306
Assumed Train Cycle Time (hours)	7.0	6.5	6.0	6.0
Locos required to haul trains	5	6	7	7
Number of Locos being serviced	0	0	1	1
Table continued overleaf				

[3] In fact studies carried out so far favour a single line track with passing loops (see next page). A twin track arrangement is more likely if the throughput is raised to 40 million tonnes per annum.

Table 1 continued				
Traction Type	**Electric (New)**	**Diesel (New)**	**Modern Steam**	**QJ Steam Reconditiond**
Number of Locos under Maintenance	1	1	1	1
Standby Loco Requirements	1	1	1	2
Total Loco Requirement	**7**	**8**	**10**	**11**
Total Locos in Cost Estimate (below)	7	8	11	12

In actual fact, if the annual tonnage remains at 20 million tonnes per annum, the track arrangement is likely to be single line with passing loops. In this situation, the time interval between trains will be governed by the spacing of passing loops, with the likelihood that the full traction capability of the diesel and electric units may not be usable.

Whilst there remains a degree of uncertainty as to the exact number of locos required to operate the railway, it will be found that the loco fleet size is not as important in this cost comparison exercise as one might assume. To demonstrate this and especially to demonstrate an absence of bias towards steam, we will add one extra of each type of steam locomotive to the above estimates, giving a final assumption of loco requirements as: 7 electrics, 8 diesels, 11 modern steam, and 12 QJs (per bottom line of Table 1).

4. Loco and Train Rolling Resistance

China National Railways provide the following equations for estimating the starting and rolling resistances of QJ locomotives (with 4 axle tenders)[4] and of a train of wagons running on roller bearings:

QJ Starting Resistance = 8N/kN[5]

Wagon Starting Resistance = 3.5N/kN

QJ Rolling Resistance = $W \times [(0.70 + 0.0243\ V + 0.000673\ V^2) + 1/\text{grade} + 600/\text{Rad}]$

Wagon Rolling Resistance = $W \times [(0.92 + 0.0048\ V + 0.000125\ V^2) + 1/\text{grade} + 600/\text{Rad} \times \text{Train Length}/\text{Curve Length})]$

Where:
R = rolling resistance in Newtons
W = weight in kN
V = speed in kph
Rad = Track curvature radius in metres
Grade = Gradient in %.

These formulae have been incorporated into a spreadsheet that calculates rolling resistances for any chosen set of parameter values and which compares them with the available tractive force from a QJ locomotive.

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[4] The equation for rolling resistance of QJ locomotives with 6 axle tenders is similar to, but inconsistent with the equation for the locos fitted with 4 axle tenders.

[5] The original Chinese formulae use kN (kilo-Newtons) as a unit of weight.

Note: These formulae give lower resistance values than those used in some other countries.

5. QJ Performance Characteristics

QJ performance characteristics are set out in the following diagram supplied by China National Railways. The diagram presents a range of curves that define the tractive effort in relation to a range of speeds up to the maximum design speed of 80 kph, each curve representing a specific steaming rate (measured in kg/hr/m^2. The adhesion limit of the locomotives is also shown, as are the cut-off percentages that are required to deliver a selected steaming rate over the speed range (see Fig 1).

Tractive force and steam consumption rates can thus be inserted into the same spreadsheet with the rolling resistance calculations to determine the locomotives performance limits and the steam consumption rates for any performance demand (see Table 2).

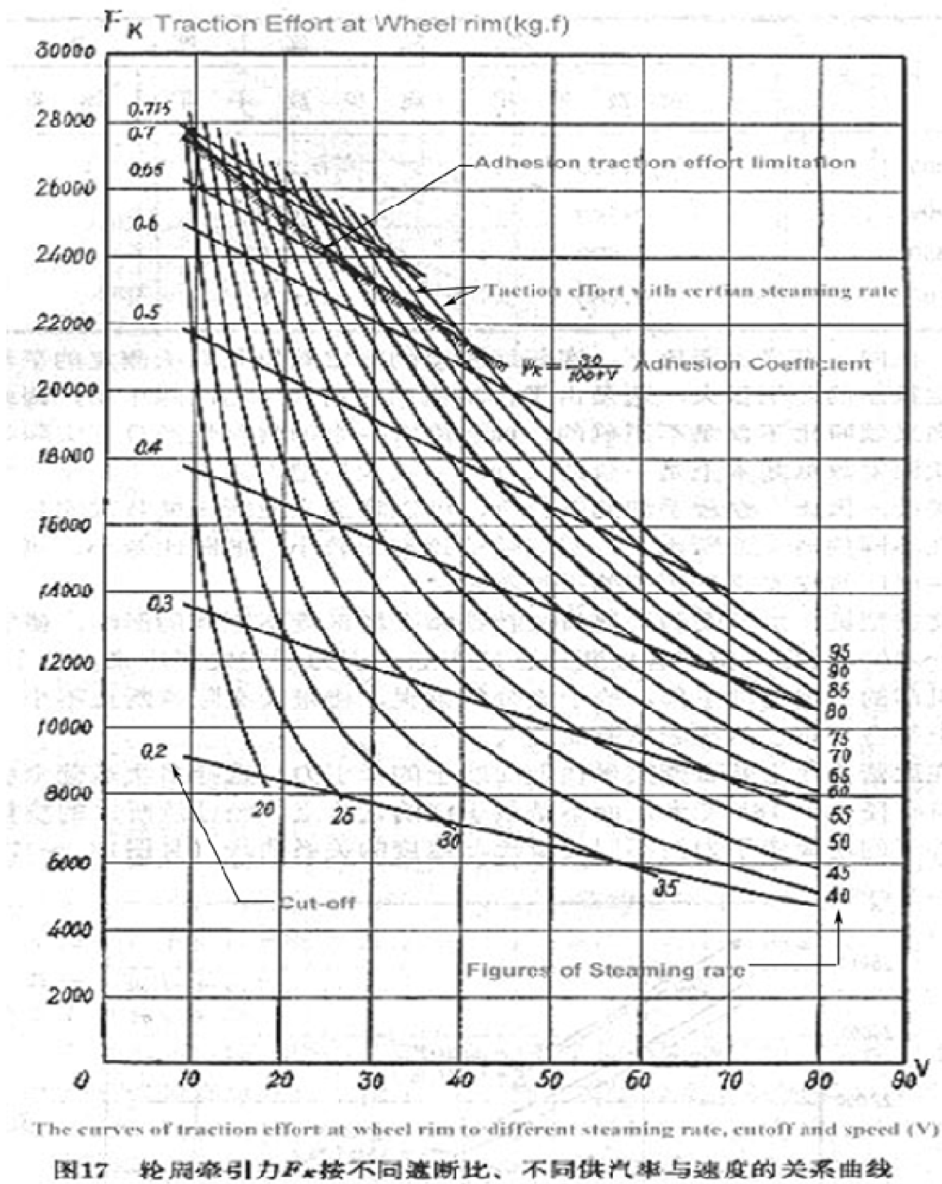

Figure 1 - Performance Curves for QJ Class Steam Locos
from China National Railways

Table 2
Typical spreadsheet calculation to assess QJ haulage limits and water consumption rates, in this case based on 4000 tonne train on 1000m radius curved track on horizontal grade.

Track Data						
Gradient	**Grade**	**Grade**	**Curve**	**Curvature**	**Curve**	**Length**
%	**1 in …**	**Angle**	**Radius**		**Length m**	**Factor**
0.00	Flat	0	1000	0.001	1000	1.000

Wagon Data								Loco Mass	Train Mass
Individual Wagons (Tonnes Mass)				**Train (Tonnes Mass)**					
Tare	**Gross**	**Length**	**No**	**Tare**	**Gross**	**Net**	**Length**	**Tonne**	**Tonne**
23	**93**	14.7m	**43**	989	3999	3010	633m	200	4199

	QJ Traction and Power Limits*		**QJ + 4 axle tender + Wagons with Roller Bearings**					
Speed			**Roller Bearings**			**Empties**		
Kph	Power kW	Traction kN	Power kW	Traction kN	Check	Power kW	Traction kN	Check
0	**0**	**295**	**0**	**178**	OK	0	71	OK
10	750	270	181	65	OK	88	32	OK
20	1389	250	385	69	OK	195	35	OK
30	1875	225	623	75	OK	334	40	OK
40	2333	210	906	81	OK	517	47	OK
50	2500	180	1242	89	OK	758	55	OK
60	2583	155	1644	99	OK	1070	64	OK
70	2625	135	2121	109	OK	1467	75	OK
80	2667	120	2684	121	**Overload**	1960	88	OK

Wagons Full or Empty	**Train Weight Tonnes**	**Train Speed Kph**	**Tractive Force**		**Steaming Rate** from Graph	**Heating Surface** M^2	**Steam Usage Kg/hr**	**Journey Time Hrs**	**Total Water Tonnes**
			kN	**kg**					
Full	3999	80	86	8,767	73	255.3	18637	1.1	21
Full	3999	70	84	8,563	60	255.3	15318	1.3	20
Full	3999	60	74	7,543	43	255.3	10978	1.5	16
Full	**3999**	**50**	**65**	**6,626**	**36**	**255.3**	**9191**	**1.8**	**17**
Empty	**989**	**50**	**55**	**5,607**	**30**	**255.3**	**7659**	**1.8**	**14**
Empty	989	70	75	7,645	50	255.3	12765	1.3	16
Empty	989	80	88	8,970	65	255.3	16595	1.1	19

Notes – 1: the full spreadsheet includes estimates of acceleration rates. These are not shown in the above table.

2: As might be expected, these CNR calculations appear to produce conservative results. For instance, by adjusting the parameters one can produce results that indicate that a QJ would be unable to haul a 4000 tonne train up a 0.5% (1 in 200) grade. However in his book "Red Devil and Other Tales from the Age of Steam" (page 467), Wardale cites an instance where a GPCS-fitted QJ locomotive hauled 4100 tonnes up a 0.7% grade at a steady 25 kph.

6. QJ Coal Consumption Estimates

Whilst the performance curves for QJ locomotives can be used to estimate the rate of water consumption, they provide no basis for estimating coal consumption since this is dependent on outside factors such as the coal's calorific value, lump size etc. However some data on local (Indonesian) coal quality is available. So too are China National Railways' statistics for average steam loco coal consumption rates in China.

The coal mine that will supply coal to the railway produces a variety of grades that vary significantly in quality. Their range of properties are summarised in Table 3, however it is believed that low (reject) quality coal type will be made available for locomotives.

Table 3 – Coal Quality Data

Parameter	Worst Value	Best Value
Total Moisture % a.r.	26	12
Inherent Moisture % a.d.	16	6.5
Ash Content % a.d.	9	6.7
Volatile Matter % a.d.	40	38
Fixed Carbon % a.d.	35	48.8
Sulphur % a.d.	1	0.7
Calorific Value kCal/kg GAR[6]	5021	6541

Table 4 provides a set of data which compares the fuel consumption and failure rates for steam and diesel traction over the period that Chinese rail traction was converted from steam to diesel (and electric). It may be noted that both fuel costs and failure rates for diesel were consistently higher throughout the period, though "failure rate" cannot necessarily be regarded as an accurate measure of reliability[7].

Table 4
Data from Official Statistics of the Operation Department of China's National Railway.
Note: The figures do not include contemporary fuel costs;
2003 costs have therefore been adopted for comparative purposes only.

Year	Available Locos Per Day (sets)		Gross Train Movements 10^6 Tonne-kilometres		Loco Failures per 10^6 ton-km		Average fuel consumption Tonnes per 10^6 t-km		Unit Price of fuel (RMB)		Unit Price of traction (RMB/ 10^6 t-km)	
	Steam	Diesel	Steam	Diesel	Steam	Diesel	Steam	Diesel	Steam	Diesel	Steam	Diesel
1987	5317	3282	770,009	750,090	3.0	11.0	11.09	2.59	200	3050	2218	7900
1995	3061	6224.2	268,998	1,495,365	3.4	16.8	13.74	2.43	200	3050	2748	7412
1999	1013	7825.6	32,475	1,682,046	0	13.1	***20.66***	2.62	200	3050	4132	7991
2003	-	8585.5	-	1,384,996	-	7.0	-	***2.54***	200	3050	-	7747

Note: Figures in ***bold italics*** are used in subsequent calculations.

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[6] GAR = Gross as received. NAR (see over) = Net as received; GAD = Gross Air Dried.

[7] See "The Red Devil and Other Tales from the Age of Steam", page 494.

It may noted on Table 4 that the fuel consumption of the steam loco fleet increased substantially over the 15 year period (from 11 tonnes per million tonne-km to over 20 tonnes per million tonne-km), and it may be assumed that this increase was the result changing circumstances that almost certainly included:

- Lower steam-hauled train mileages;
- Lower steam-hauled train weights;
- Lower steam loco coal quality;
- Lower steam loco maintenance standards.

It may thus be assumed that the figure of 20.66 tonnes per million tonne-km is a worst case scenario at the death of steam, and that the figure of 11.09 tonnes per million tonne-km represents the normal scenario in the late heyday of Chinese steam.

An alternative method of estimating coal consumption can be made by assuming a steam loco's thermal efficiency, quantifying the work that has to be done, and applying the calorific value of coal that is to be burned. In this case, we might assume a thermal efficiency of 7% and a coal calorific value of 4000 kcal/kg (NAR).

Assuming an equivalence of 860 kcal/kWh, then at an efficiency of 7%, a locomotive will require 860/7% = 12,285 kcal of fuel to generate 1 kWh of useful work. This implies a coal consumption of 12,285/4,000 = 3.071 kg of coal/kWh of work (based on the use of 4000 kCal per kg coal).

Chinese rolling resistance formulae indicate that hauling a 4000 tonnes (gross) train at an average of 50kph on level track requires approx 1250 kW of power. Hauling an empty train of 1000 tonnes (tare) on the level requires a power output of about 400 kW. At 50 kph the 90km journey will take 1.8 hours, from which it can be deduced that on the loaded journey the loco will consume approx 7.0 tonnes of coal, while on the empty journey it will consume 2.2 tonnes, or 9.1 tonnes for the round trip. The tonne-km travelled is (4000+1000) x 90 = 0.45 million tonne-km, indicating an average coal consumption of 20 tonnes per million tonne-km, or 19.2 tonnes per million tonne-km for the loaded journey and 24.6 tonnes per million tonne-km for the empty journey.

Of course the above consumption figures would need to be increased a little to allow for coal consumption during standing periods, but they indicate that the Chinese statistical data is realistic. Indeed, if a coal calorific value of 6500 kcal/kg is used, then the above calculation produces a coal consumption rate of 11.8 tonnes per million tonne-km for loaded trains, which is consistent with the Chinese figure for 1987. [Note: in the author's experience in the early 1990s, Chinese freight trains almost always ran loaded.]

7. Maintenance Costs for Alternative Traction Types

The following data for Electric, Diesel come not from China National Railways, but from a commercial supplier of Chinese railway equipment (including reconditioned steam locos). The QJ maintenance cost figures are based on commercial quotations for the reconditioning of locomotives except for the "routine maintenance cost" which is the author's "guestimate". The modern steam figures are the author's and represent no more than "guestimates".

Table 5 – Comparative Maintenance Costs (US$ values)				
Traction Type	**Electric (New)**	**Diesel (New)**	**Mod'n Steam**	**QJ Steam**
Major Overhaul Cost	$250,000	$200,000	$100,000	$100,000
Major Overhaul Intervals	1.2 m km	700,000 km	400,000 km	250,000 km
Light Overhauls per Major Overhaul	3	3	2	2
Cost per Light Overhaul	$65,000	$50,000	$50,000	$50,000
Routine Maintenance Period	40,000 km	30,000 km	40,000 km	30,000 km
Routine Maintenance Cost	$12,000	$10,000	$5,000	$5,000
Assumed Train Capacity (net tonnes)	5,250	4,500	3,000	3,000
Number of Train Kilometres per year	685,714	800,000	1,200,000	1,200,000
Av. Travel per year per loco (km)	97,959	100,000	109,091	100,000
Annual Major Maint Cost per loco	$20,408	$28,571	$27,273	$40,000
Annual Intermdt Maint Costs per loco	$10,612	$14,286	$13,636	$20,000
Annual Regular Maint Costs per loco	$29,388	$33,333	$13,636	$16,667
Annual Maintenance Costs	**$422,857**	**$609,524**	**$600,000**	**$920,000**

8. Water Costs Estimates (Steam Only)

QJ water consumption has been calculated in Table 2 to be 17 tonnes for loaded trains from mine to port and 14 tonnes for the empty reverse journey, giving a total of 31 tonnes per round trip. For the purpose of this costing exercise, a consumption of 36 tonnes has been assumed to allow for standing and other losses. A lower consumption figure of 30 tonnes is assumed for the "modern steam" alternative. Water cost of $0.5 per tonne has been assumed plus $1.90 per tonne for water treatment (both figures likely to be conservative) giving cost estimates as follows:

Table 6 – Water Cost Estimates - Steam only (US$ values)				
Traction Type	**Electric**	**Diesel**	**Mod Steam**	**QJ Steam**
Water consumption – tonnes per round trip			30	36
Number of round trips			6,667	6,667
Total water consumed			200,000	240,000
Water Cost - assumed per tonne[8]			$0.5	$0.5
Water Treatment Cost – per tonne[9]			$1.9	$1.9
Total Water Costs			$480,000	$576,000

[8] Cost figures shown are almost certainly conservative.

[9] Based on estimates for Porta's Water Treatment supplied by Martyn Bane.

9. Labour Cost Estimates

Because labour costs are low in Indonesia, they represent a relatively small component of these cost estimates. The following observations are offered:

- The servicing crew numbers used are no more than a crude estimate of the manning requirements to keep the locomotives running 24 hours per day;
- In the case of electric traction, the servicing crew number includes an even cruder estimate of the number of men that might be required to keep the electrical supply connected.
- The assumed wage rate of $5000 per annum is believed to be high for rural Indonesia. Use of a lower rate would increase steam's cost competitiveness.

Table 7 – Labour Cost Estimates (US$ values)

Traction Type	Electric (New)	Diesel (New)	Modern Steam	QJ Steam Reconditiond
Shifts per day	3	3	3	3
Loco Crew per loco	1	1	2	2
Total Loco Crew	21	24	60	72
Servicing Crew per shift	6	2	5	5
Total Servicing Crew	18	6	15	15
Wage Rate per year	$5,000	$5,000	$5,000	$5,000
Wages per Year	**$195,000**	**$150,000**	**$405,000**	**$435,000**

10. Fuel Cost Estimates for Alternative Traction Types

As noted earlier, in order to avoid accusations of bias, the estimates presented in this paper give no preference to steam. In this instance, a coal consumption figure of 21 tonnes per million tonne-km is assumed is adopted for the QJ haulage option (being slightly higher than the highest Chinese coal consumption figure of 20.66 t/mt-km), and a figure of 14 t/mt-km is adopted for the "modern steam" option (conservatively assuming it to be 50% more fuel-efficient than a QJ).

In the case of diesel traction, the fuel consumption rates are much more consistent, and a low-average figure of 2.50 t/mt-km has been adopted.

Additional cost data was supplied by China National Railways as shown in Table 8. Once again cost data that is used in the comparative costings that follow are highlighted in ***bold italics***.

Table 8 – Supplementary Cost Data supplied by China National Railways		
Average cost for normal electric railway construction, including infrastructure, contact wire, signalling system, stations and marshalling yards	>30 m RMB per km	>$3.75 m per km
2001 Average Cost for Main Line Electrification	>3.4 m RMB per km	***>$425,000 per km***[10]
2001 Fuel Consumption – Steam	19.5 tonnes per 10^6 t-km	
2001 Fuel Consumption – Diesel	2.57 tonnes per 10^6 t-km	
2001 Power Consumption – Electric	***11310 kW-h per 10^6 t-km***	
2005 Cost – Diesel Fuel	3970 RMB / tonne	$496 per tonne[11]
2005 Cost – Electric Power	0.65 RMB/kW-h	***$0.081 cents per kW-h***

It may be noted that the fuel consumption rates quoted for steam and diesel in 2001 are consistent with the figures given in the previous table.

Using the above data, it is now possible to estimate the fuel/power costs for four alternative traction types, each hauling 20 million tonnes of coal per year (one way) and returning empty trains over a 90 km railway. Figures in bold italics are transferred to Table 10.

Table 9 – Comparative Estimates of Fuel/Power Costs (US$ values)				
Traction Type	**Electric (New Build)**	**Diesel (New Build)**	**Modern Steam (New Build)**	**Reconditiond QJ Steam**
Total Gross Tonne-km ($x10^6$)	2,391	2,391	2,391	2,391
Total Tare Tonne-km ($x10^6$)	591	591	591	591
Total Tonne-km ($x10^6$)	2,982	2,982	2,982	2,982
Consumption t or kWh per 10^6t-km	11310	2.5	14	21
Total Consumption t or kWh/year	33.7m	7,457	41,760	62,640
Fuel/Power Cost per tonne or kWh	$0.08	$700[11]	$20[12]	$20[12]
Total Fuel Cost per Year	***$2.699m***	***$5.220m***	***$0.835m***	***$1.253m***

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[10] The stated cost of electrification applies to single tracks (including stations, yards etc). Thus the cost should be doubled for a two-track railway. However because this particular railway is likely to be a single track railway, the single track cost is used. Double tracks have been assumed only to facilitate estimation of locomotive requirements.

[11] The 2006 cost of diesel fuel in Indonesia is approx $700 per tonne, which is the figure adopted in Table 7 for this cost comparison. The value of coal at the mine site is given as $20 per tonne but it may in fact be as low as $16.

[12] It might be argued that the export price (rather than cost) of the coal should be used for fair comparison, however it is understood that only reject coal (near lignite quality) will be used for the locomotives, and that its actual cost/value may in fact be less than $20 per tonne.

11. Final Cost Comparisons

The above data and deductions can now be entered into another spreadsheet (reproduced in Table 10) in which cost estimates for each traction type are compared. Purchase cost estimates for electric, diesel and QJ locomotives come from a commercial supplier of railway equipment. Modern steam development and purchase costs are intelligent estimates by the author, based on studies (by others) for the 5AT project.

Table 10 – Cost Comparison between locomotive types for hauling 20 million tonnes of coal per year over a 90 km coal-haulage railway (US$ values)

Traction Type	Electric (New Build)	Diesel (New Build)	Modern Steam (New Build)	Reconditiond QJ Steam
Electrification (Table 8)	90km x $425,000 = $38.25 m		Assumed $6.0m development	
Purchase Cost (Table 5)	$1.0 m	$1.0 m	$2.0 m	$0.4 m
No Locos Needed (Table 1)	7	8	11	12
Total Investment	**$45.25 m**	**$8.0 m**	**$28.0 m**	**$4.8 m**
Life Expectancy (assumed)	25 years	25 years	25 years	10 years
Annualized Cap Cost[13]	$1.81 m	$0.32 m	$1.12 m	$0.48 m
Maintenance Cost (Table 5)	$0.42 m	$0.61 m	$0.60 m	$0.92 m
Fuel/Power Cost (Table 9)	$2.70 m	$5.22 m	$0.84 m	$1.25 m
Water Cost (Table 6)	-	-	$0.48 m	$0.58 m
Labour Cost (Table 7)	$0.20 m	$0.15 m	$0.41 m	$0.44 m
Total Cost per Year	**$5.13 m**	**$6.30 m**	**$3.44m**	**$3.66 m**
Cost per Tonne hauled	**$0.26**	**$0.31**	**$0.17**	**$0.18**
Cost per Million Tonne-km	**$2,848**	**$3,500**	**$1,911**	**$2,035**

The following observations should be made about the above figures:

- Maintenance of the electrical power supply and cabling systems have not been included in the cost estimates for the electric traction alternative. These costs are likely to be significant in hot and humid climatic conditions.
- The operation of shorter trains using steam traction reduces the rolling stock requirement by virtue of the fact that wagons spend less time waiting to be loaded and unloaded. The author has calculated that operation of 4000 (net) tonne trains will require at least 27 more wagons in the fleet than operating 3000 (net) tonne trains. At $70,000 per wagon (ex-China price) this represents a capital saving of around $2 million. Furthermore, the lower traction forces required to pull shorter trains should reduce rail, wagon wheel and drawgear wear.

[13] A straight-line depreciation rate is assumed to estimate annualized capital costs.

- Whilst the cost differential favouring steam appears to be significant, it should be recognised that traction costs represent only a small part of the overall costs of building and operating a railway. This may be judged by the fact that in this particular case the total capital cost estimate for the railway is over $150 million of which less than $5 million represents the purchase cost of the (QJ steam) loco fleet. Furthermore the total cost of moving the coal from mine to ship (including barging costs and port costs) is expected to be over $5 per tonne, compared to the $0.15 to $0.30 estimated range of costs for locomotive haulage.
- The amortization cost of developing a new “modern steam” design could be reduced by spreading it over more production locomotives for use on other railways. This could happen if “modern steam” were able to gain a foothold on this project or a similar one.
- There is no certainty at the time of writing that this particular project will go ahead.

12. Alternative Cost Scenarios

It is acknowledged that there is a degree of uncertainty in many of the assumptions made in the above calculations. It is therefore valuable to look at alternative cost scenarios to judge how sensitive the outputs are to changes in inputs.

Three alternative scenarios are therefore taken:

1. where the deliberate anti-steam bias is removed from the cost estimates;
2. where costs are increased to levels where electric and diesel become cost-competitive.
3. where coal throughput is doubled to 40 million tonnes per year, to reduce the electrical infrastructure costs per tonne hauled.

Looking first at the removal of anti-steam bias, this requires the following changes to the inputs:

- reducing the estimated number of steam locos to the actual estimated requirements as calculated in Table 1;
- increasing the life expectancy of modern steam locos to 30 years and reconditioned QJ locos to 15 years;
- Assume modern steam’s coal consumption is half that of the QJ;
- reducing the cost of water plus water treatment from $2.40 per tonne to $1.80;
- reducing labour costs from $5000 per annum to $3500;

These changes produce the following “bottom line” figures in Table 10:

Traction Type	Electric	Diesel	Modern Steam	QJ Steam
Cost per Tonne hauled	**$0.25**	**$0.31**	**$0.14**	**$0.16**
Cost per Million Tonne-km	**$2,816**	**$3,474**	**$1,508**	**$1,676**

Looking next at cost increases that might make the diesel or electric attractive alternatives, the following further input changes are made (otherwise leaving the above changes in place):

- increasing the cost of coal to $50 per tonne;
- increasing the cost of steam overhauls to $150,000 at the previously assumed intervals, and $75,000 (half the amount) for intermediate overhauls;
- putting water + treatment cost back to $2.40 per tonne;
- setting labour costs at $10,000 per annum;
- putting depreciation periods back to original values

These changes produce the following "bottom line" figures in Table 10:

Traction Type	Electric	Diesel	Modern Steam	QJ Steam
Cost per Tonne hauled	**$0.27**	**$0.31**	**$0.27**	**$0.33**
Cost per Million Tonne-km	**$2,957**	**$3,583**	**$2,995**	**$3,639**

It is interesting to note that coal costs have to increase to $55 per tonne before the modern steam cost reaches $0.26 per tonne of coal hauled. Of course in that circumstance, the cost of electric traction would also have to rise with the price of coal, and inevitably diesel fuel costs would rise too – and probably by a greater percentage.

Finally, looking at higher coal throughput, one would expect that a scenario where coal throughput was increased, that electric traction would come into its own in that the higher infrastructure costs per tonne of coal would be reduced. However even if the throughput is doubled to 40 million tonnes per year, steam still appears to offer the best:

Traction Type	Electric	Diesel	Modern Steam	QJ Steam
Cost per Tonne hauled	**$0.21**	**$0.31**	**$0.15**	**$0.17**
Cost per Million Tonne-km	**$2,368**	**$3,446**	**$1,701**	**$1,936**

Note: A throughput to 40 million tonnes per years would almost certainly require twin track operation, which would double the electrical infrastructure cost. This extra cost increases the electric cost to 25 cents per million tonne-km.

13. Environmental Considerations

It is inevitable that coal burning steam locos will generate more CO_2 than diesels, both because coal has a higher carbon content than diesel oil and because of steam's lower thermal efficiency. Notwithstanding, it is possible that the total carbon emissions produced from burning locally available coal may be less than those emitted from drilling, extracting, transporting, processing and burning of oil for diesel locomotives.

In any case, since Indonesia is not a party to Kyoto accord, it is not possible to include environmental costs as "real" costs since they cannot be estimated and will not be incurred by the railway.

Notwithstanding, it might be argued that it is important to re-establish steam traction technology so that it can be developed in future to burn greener fuels such as bio-mass and other “waste” products.

14. Conclusions

The cost figures derived for this paper suggest that there should be a substantial cost advantage in the use of steam traction for this particular railway. Indeed, there appears to be a large margin within which cost assumptions can be adjusted before the steam option becomes unattractive.

It may be easy for the rail industry to dismiss this conclusion as representing only a “special case” in which unusual circumstances favour the use of steam – namely the availability of low-cost coal and low-cost labour. However, these circumstances are not so unusual in the developing world and similar situations must exist in many other places. Furthermore, the “unusual” circumstance will become less unusual as the price of oil climbs higher in relation to that of coal.

The figures presented in this paper serve to confirm the off-hand response given to the author by an operations manager on China’s famous Jitong Railway who, when asked if steam was cheaper to run than diesel, replied: “Of course it’s cheaper. But we still have to get rid of it in order to conform to the Ministry of Railways’ steam ban policy[14]”.

The conclusions drawn in this paper also serve to confirm the conclusions of other similar studies, most notably Dave Wardale’s much more sophisticated studies for SAR in the 1980s[15] which found that in favourable circumstances (when operating low-to-medium density traffic in the vicinity of adequate coal and water supplies) steam offers a significant cost advantage over rival forms of traction. The main difference in this instance is the existence of a railway planner that has a positive preference for steam traction.

It may thus be concluded that even “old’ steam may have a place in the 21st century where circumstances favour it, and where planners and financiers can be persuaded to accept it. The case for “modern steam” appears to be even more compelling.

CJEN
15th Dec 2006

[14] China National Railways is a substantial shareholder in the “privately” run Jitong Railway.

[15] Refer to David Wardale’s “The Red Devil and Other Tales from the Age of Steam” Chapter 5.