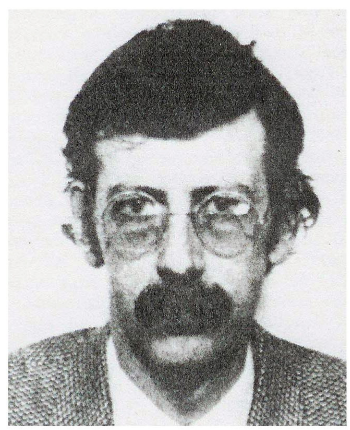
MODERN STEAM LOCOMOTIVES - TRACTION FOR THE FUTURE?

Developing Railways 1985

In the rush to dieselise during the 1950s and 1960s, all but a handful of railways dispensed with the motive power that had served them well for a century. Then oil prices rose, and the diesel locomotive was not quite the panacea it had seemed. Administrations that maintained their steam loco fleets are increasingly seen as having exercised good judgment. But time has not stood still for steam. Refinements made to existing fleets in various parts of the world, and research carried out in the USA, have brought technology to the point where steam might again be a serious traction option under certain circumstances.



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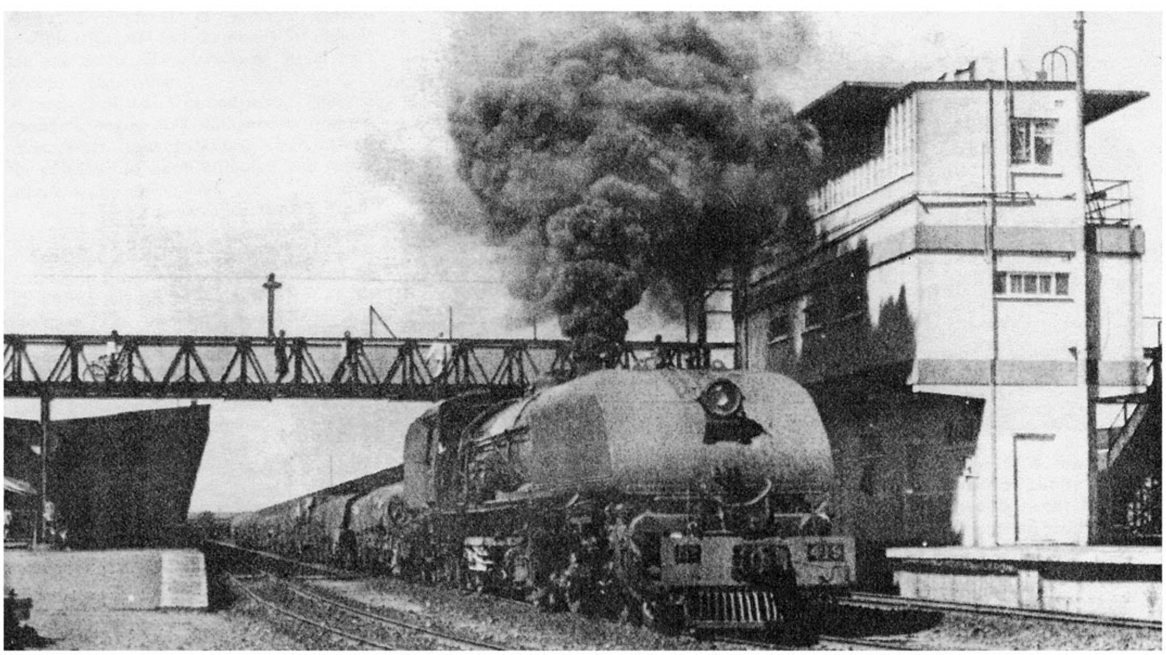
There is a growing awareness that modern coal fired steam locomotives can be the most economical type of traction under certain conditions, especially on railways located in regions with cheap coal supplies. Development work in countries where steam traction had never ceased to be important has assured the continuance of steam operations at least onto the turn of the century. China is still building some 250 units a year, while India, South Africa and Zimbabwe all have comparatively modern steam fleets.

Recent South African trials have shown that overall costs can be lower for steam than any other form of traction in many circumstances, and have produced much other important data on the relative economies of steam, diesel and electric traction. But a major breakthrough would be translation into hardware of the conceptual design for a high technology steam locomotive produced by American Coal Enterprises Inc (ACE), and aimed at the North American market[1].

Before looking at locomotive developments, it is worth mentioning that in the shipping field the Australian National Line commissioned an 80,000 tonne coal fired bauxite carrier in 1983, some 30 years since the last coal-filed ocean-going ship was built. Other ships are being built or converted in several countries, including Japan, Italy, Spain and the USA. There are two main reasons for a return to coal-fired steamships. First, oil price rises in the 1970s have resulted in the cost per unit of energy of coal being significantly less than for oil, especially in coal-producing regions. Secondly, there have been major technological advances in coal-fired steam power generation equipment. These same factors apply to steam railway locomotives.



[1] Paul B, 'New Steam Locomotives – a Solution to Imported Fuel'. Modern Railroads, Volume 37 No 9, Des Plaines, Illinois, September 1982.

ACE 3000

In the American Coal Enterprises project, termed ACE 3000, the proposal would be equivalent to a 3,000 hp (2,240 kW) diesel locomotive at low speed; it would be compatible with existing North American operating procedures and infrastructure, for instance in respect to one-man operation and the ability to run in multiple with other locomotives (either diesels or ACE steam locomotives). The concept retains many service-proven features of the Stephensonian locomotive. A firetube boiler with a cyclonic gas-producer firebox developed by the Argentinean locomotive engineer L.D. Porta, who is now with the ACE team, would feed steam at 2,070 kPa and 425°C to a four-cylinder compound engine with horizontally opposed cylinders. This eliminates the need for the traditional reciprocating balance that produces hammer blow. Power transmission would be by direct rod drive to coupled wheels.

Several departures from normal practice are proposed to comply with North American requirements. The exhaust steam would be fed via a turbine for driving the boiler draft fan to an eduction condenser in the service module coupled to the power unit, allowing an estimated 800 km between water stops which could then coincide with mandatory train inspections. Operation of the boiler, engine unit, condenser and other equipment, would be fully automated using microprocessor control, allowing one-man multiple-unit operation.

Formidable development work will be necessary to bring this proposal from the conceptual stage to a successful commercial locomotive. Recognising this, ACE is steadily building up a team of engineering specialists with expertise in various fields which are important for the success of ACE 3000 (combustion, microprocessor controls, heat transfer etc). Equally important is the development funding. Two prototypes are required to prove conclusively that multiple unit operation can be achieved, and the price tag for these has been set at $US 45 million. Obtaining full funding has proved elusive, but ACE is convinced that potential operating savings for North American railways by switching over to coal-burning traction are so great that the research and development capital will be obtained.

Although ACE 3000 is tailored for the North American market, its success is important for developing railways in two ways. First, scaled-down ACE locomotives could be of interest to railways that may be able to handle such sophisticated technology, which have similar operating practices to North America in respect of long trains requiring multiple-unit consists, and where coal is cheaply available. Examples are the railways of Australia and South Africa. Secondly, much of the technology developed for ACE 3000 could be applied to the classic steam locomotives that would be the most appropriate technology for other developing railways

A similar approach to that of ACE has been made by Dr John Sharpe of London University in his `Yeoman' proposal for heavy haulage work. This also features a cyclonic gas-producer firebox, reciprocating compound engine and full exhaust steam condensing. There are however a number of differences. In the Yeoman the exhaust from each low pressure cylinder is would expand to sub-atmospheric pressure through a turbine driving a compressor for compressing the steam between the high pressure cylinder exhaust and the low pressure cylinder intake. By this means the Rankine Cycle efficiency could be increased at the expense of additional complexity in the form of the turbo-compressors, and the problem of maintaining the necessary condenser vacuum. The Yeoman must therefore be considered at this stage as a largely theoretical proposal showing what the ultimate thermal efficiency of the steam loco might be, and by what means this efficiency might be achieved, rather than a practical proposition.

Porta's work

Of more immediate interest to practical railway engineers and operating staff on railways where steam traction is still being used, or where it may with advantage be reintroduced, are the developments in the classic Stephensonian locomotive which have taken place in Argentina and South Africa. In Argentina, important advances in locomotive design were made by Porta before he joined the ACE team, many of which have been well documented[1]. The most significant were:

- the gas producer firebox which reduces coal particle carryover and smoke emission by admitting a large part of the combustion secondary air over a gas-producer firebed which has clinker-control steam mixed with its sub-stoichiometric primary air;
- the development of superior exhaust systems ('Kylpor' and 'Lempor') for improving the boiler draught/exhaust steam back pressure relationship;
- mechanical and thermodynamic improvements to engine unit components (pistons, valves, rings, liners, packings), which increase the efficiency of steam utilisation and reduce maintenance requirements.

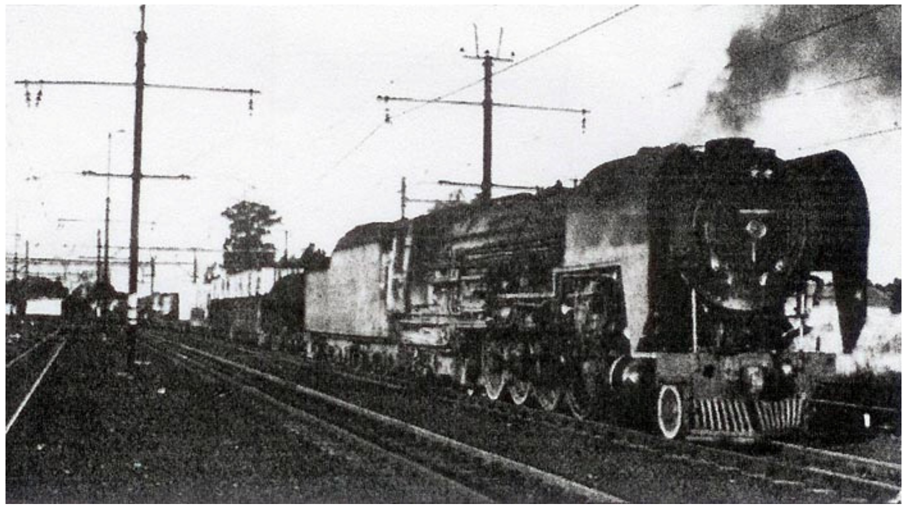
Twenty 2-10-2 two-cylinder simple expansion locomotives featuring these developments are working on the 750 mm gauge Rio Turbio Railway in Patagonia conveying coal from the El Turbio mines 250 km to the port of Rio Gallegos. The performance of these locomotives is impressive. Although weighing only 48 tonnes without tender, of which 35 tonnes is adhesive, they haul 1,700-tonne loaded trains and burn the 15% to 20% ash, clinker-forming, sub-bituminous, El Turbio coal without fire-cleaning stops.

As water stops are coincident with stops to pass trains and for crew changes, there are effectively no stoppages for locomotive purposes. These locomotives are good examples of what is required in steam traction for most developing railways. They are cheap to build, simple, robust, easy to maintain and therefore reliable, economical in coal and water consumption, of high power capacity for their size, and fully able to satisfy the requirements of the operating department.

On South African Transport Services, several locomotives were modified by D. Wardale to Porta's principles. Some alterations were quite minor, such as draughting changes. A 19D class 4-8-2 was fitted with the gas producer combustion system, double Lempor exhaust and other modifications. Subsequently, a 25NC class 4-8-4, representative of the best steam locomotive design practice hitherto available, was thoroughly rebuilt to determine to what extent the performance of these locomotives could be improved by incorporating the latest technology, and what the financial implications of such improvements would be. These modifications involved fitting the gas-producer combustion system (the

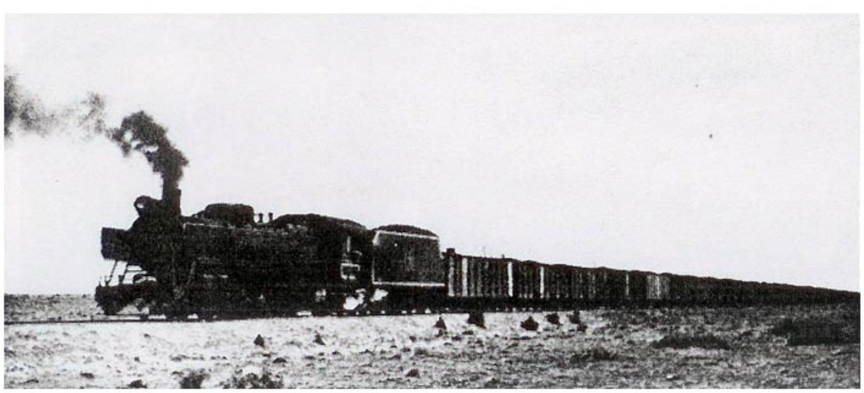
[1] Porta L.D., 'Steam Locomotive Development in Argentina – its Contribution to the Future of Railway Technology in the Underdeveloped Countries'. Journal of the Institution of Locomotive Engineers 59, Volume 59, Paper No 721, London, 1969.

first such application to a large mechanically-fired locomotive), a double Lempor exhaust, an internally aerodynamic spark-arresting and self-cleaning smokebox developed from the Master Mechanics type, a larger superheater, a surface type feedwater heater, larger steamchests, new multi-ring long-lap piston valves incorporating several design refinements, special valve liners cooled by saturated steam, modified piston and valve rod packings, improved valve and cylinder lubrication, and many other detail modifications.



The modified locomotive, reclassified as Class 26, was first steamed early in 1981 and was subjected to intensive trials both on special test trains and on regular passenger and freight trains over a three-year period, during which the overall performance of the locomotive and that of individual components was measured and evaluated. This period was also used for continuous tuning-up, components being altered wherever possible when necessary to further improve performance. Some significant test results were achieved in comparison to the unmodified 25NC class:

- Coal consumption in identical freight service reduced by 28%;
- Water consumption in identical freight service reduced by 30%;
- Measured increase in maximum equivalent drawbar power of 43%;
- Maximum recorded indicated power of 3,350 kW (4,492 hp) at 75.5 km/h. Extrapolating the power-speed curve to speeds higher than those tested gives a probable absolute maximum of 3,750 kW (5,030 hp) at 100 km/h, very high figures for a 1 067 mm gauge simple expansion locomotive weighing 123 tonnes without tender.



Rio Turbio 2-10-2 with its 1700 tonne coal train heads for Rio Gallegos

The financial evaluation of this project was incorporated in the work of a Traction Policy Committee set up to assess the three available types of locomotive (steam, diesel and electric) and to formulate a sound traction policy. A sub-committee was formed to determine an accurate means of establishing locomotive costs. This committee rejected the use of overall statistics and decided that factors such as traffic density, ruling gradient and distance from the coalfield varied so much from line to line that locomotive costs for each section would have to be determined individually to ascertain the most cost-effective type of traction for the section concerned (no universal locomotive being the cheapest in all situations). An equation was evolved identifying all costs of owning and operating locomotives to meet any traffic requirements on any given section, and was applied to a study of the 231 km Kimberley (Beaconsfield)-De Aar section of the Johannesburg-Cape Town line, which currently has mixed steam and diesel working. The major costs involved were capital, maintenance (including maintenance of electric power transmission equipment), running sheds, locomotive crews, fuel (including its transport), and water.

The sub-committee's report was presented during 1983 and showed that under the prevailing conditions, with a freight traffic density totalling 20 million gross tonnes per annum, steam was the most economic type of traction for this service. The estimated annual locomotive costs were:

- Modified steam (Class 26) - 11.932m Rand
- Standard steam (Class 25NC) - 12.897m Rand
- Diesel (Class 34D) - 13.141m Rand
- AC electric (Class 7E) - 17- 590m Rand.

Three graphs are shown, illustrating the results of this study:

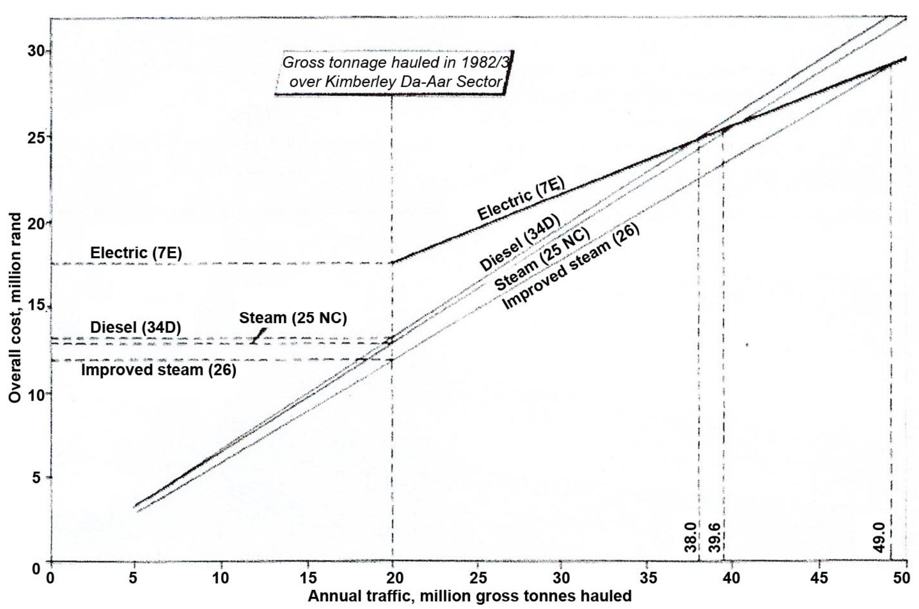


Fig 1. Annual cost at 1982-83 prices of working the Kimberley Da-Aar section by electric steam and diesel traction. Use of improved steam locomotives would raise the economic threshold for electrification from 39 to 49million gross tonnes per year.

Fig 1 shows the annual total locomotive costs for the Kimberley (Beaconsfield)-De Aar section at 1982-83 prices for the different types of traction related to traffic density.

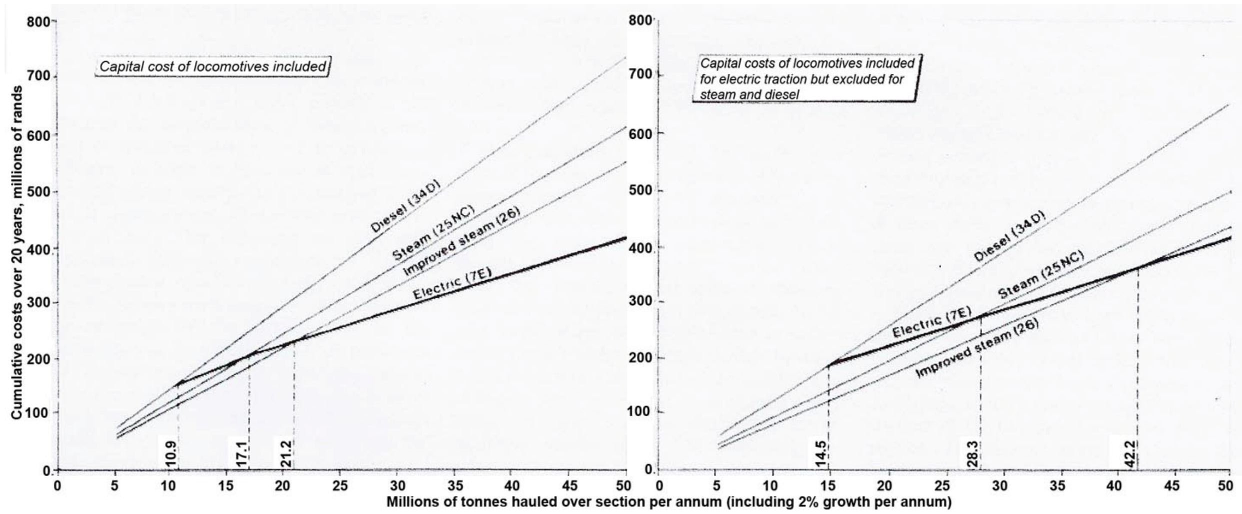


Fig 2. The graph on the left shows the breakeven tonnages for electric traction if the capital cost of all types of locomotive is included. If steam and diesel are deemed to be readily available (right), the breakeven point for electrification is much higher.

Fig 2 (left) shows the cumulative costs over 20 years for the same parameters, including the effects of traffic growth and inflation. This graph includes the current capital costs for each type of traction and therefore indicates which type of traction should be used if new locomotives need to be purchased in each case. Modified steam is additionally debited with the cost of the modifications, which would be about 10 per cent of the cost of a new steam locomotive.

In the real situation, the steam and diesel locomotives already exist and do not have to be purchased. Fig 2 (right) therefore gives the same data but excludes the capital costs of steam and diesel traction except for the rebuilding cost of modified steam. This graph shows the respective traffic levels which would justify electrification of this section if it was already being operated by the other types of locomotive. Fuel costs, inclusive of transportation costs, were stated in the study as being 30.17 Rand per tonne for coal and 0.4483 Rand per litre for diesel oil. The line concerned is some 700 km from the coalfields and coal transport cost as the largest single item debitable to standard steam traction.

There are some interesting conclusions to be made from this study:

- Steam traction as cheaper than diesel irrespective of the traffic volume.
- Electrification cannot be justified until the traffic volume increases from its present level, which is already high by the standards of developing railways.
- Modifications to standard steam locomotives do result in significant cost savings.
- By modifying standard steam locomotives the traffic level at which electrification can be justified is greatly increased. This is important because it shows that if traffic grew to the point where electric traction had the same overall cost as the existing steam, the relatively insignificant investment in

modifying the steam locomotives would not only produce savings at that traffic level but would render the high investment in electrification unnecessary until still larger traffic volumes occurred. Predicted traffic growths are not always achieved, especially in the uncertain economic times now prevailing. In consequence, large investments giving high fixed costs irrespective of the number of trains run, can turn sour when the equipment is not fully utilised, whereas a policy of keeping investment to a minimum and having overall costs more proportional to actual traffic levels may be more sound.

- Fuel costs represent 63% of the annual cost of owning and operating diesel locomotives in this service; for standard steam the corresponding figure is 39% and for modified steam 31%. There is therefore every incentive to introduce fuel-saving technology provided that it does not adversely affect service reliability.

Although this study was for a specific section of route, and separate studies are required for other sections since relative traction costs will vary with the particular factors unique to each, the outcome was significant in that this thorough analysis did not confirm the hitherto widespread belief that steam traction is uneconomic. Indeed, it showed that for this section steam traction is the most economic, when all factors are taken into account.

The engineering and operating data gathered on the performance of the prototype Class 26 4-8-4 gave a clear picture of the potential for improvement of steam locomotives of the type most suited to developing railways, of what is required of such locomotives, and of what is likely to succeed in the hostile environment of railway service and what is not. The following are important conclusions from this experience:

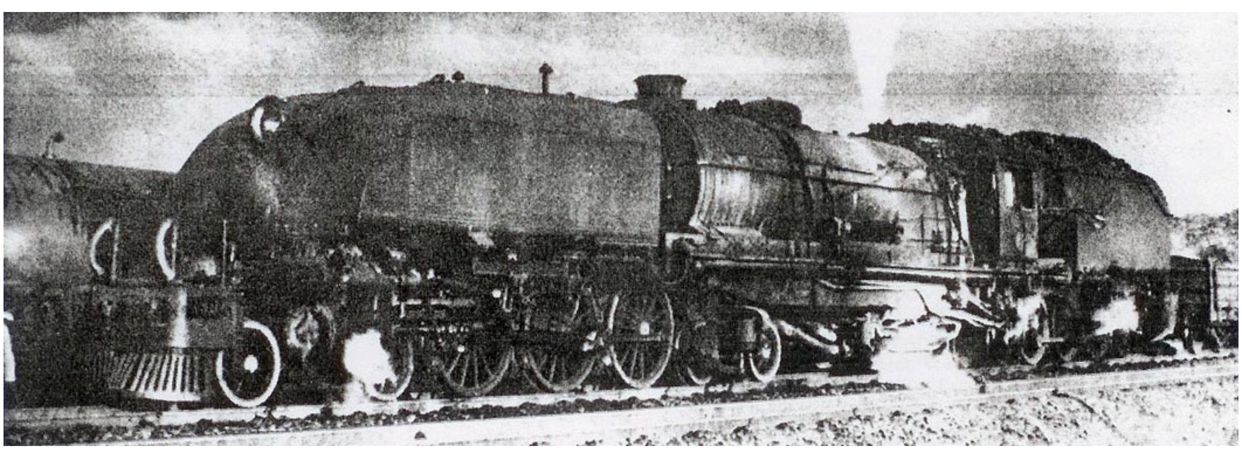
- The utmost reliability is required. In practice this equates with simplicity which dictates the retention of the classic form of the Stephensonian locomotive and in particular the two-cylinder simple expansion piston valve locomotive. This has been the form in which steam traction has proved the most successful for producing drawbar work and for many years has been the standard type.
- The performance of steam traction in this form can be considerably improved in respect of coal and water consumption, power capacity, reliability and operational convenience, by the use of improved design and materials with no increase in complexity. This can be achieved by modifying existing locomotives at low cost, although the best results would be achieved with new locomotives in which existing structural constraints do not apply.
- Improvements to locomotive front ends (engine units and exhaust systems), especially in conjunction with higher steam temperatures, can significantly reduce coal and water consumption and increase power capacity. Simultaneously, component wear rates and hence maintenance requirements can be reduced. This is important because the technology concerned is well-defined and proven, and is independent of the type and quality of fuel which the locomotives have to burn.
- Steam locomotives must be made more attractive to operating departments. Operating inconveniences traditionally associated with steam traction, which are unpopular with staff, must be reduced or eliminated. These include the need for frequent stops for taking water, fire cleaning

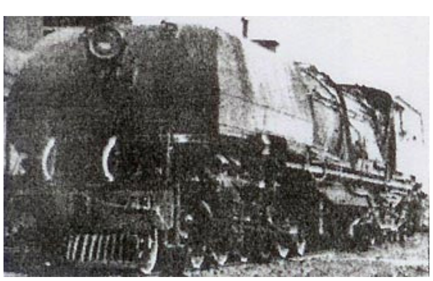
and ash disposal; steaming problems due to inadequate draughting; boiler tube bird-nesting; clinker formation; superheater element leaks; and short periods between boiler washouts. Component unreliability and excessive wear rates reduce availability and require a large staff to deal with trivial recurrent maintenance. The technology to achieve this exists.

- The locomotives must be popular with crews and running shed staff. If they are not popular, for whatever reason, they will not be successful.
- Prior to introduction of new steam locomotive technology, a careful study must be made of the environment within which the locomotives must work, of all problems and limitations which the railway may currently be experiencing or might expect to experience with steam traction, and of the specific operating requirements which the locomotives must fulfill. Only in this way can the most appropriate technological solution be applied. Even minor problems, such as difficulty in maintaining packings steam-tight, can be solved individually if so desired by the railway concerned.

As a result of the developments described above, modern steam traction has much to commend itself to the developing country with indigenous fuel reserves or seeking to become more self-reliant in keeping its locomotive fleet operational. Its advantages may be summarised as:

- lowest overall ownership and operating costs in many circumstances;
- minimum capital investment required, especially where a steam locomotive infrastructure and locomotives suitable for modernising already exist;
- long economic life;
- indigenous fuel supplies can be used, reducing foreign currency spent on imported fuel;
- spare parts, generally of simple construction, can mostly be manufactured locally, reducing foreign currency required for expensive imported spares for diesel locomotives.





Zimbabwe's rehabilitated Garratts: Class 20A (left) and Class 15A (above) on a Hawange-Bulawayo coal train.

These advantages have been implicitly recognised in countries such as China where steam traction has never ceased to be important, or where it has recently made a comeback, as in Zimbabwe which a few years ago rehabilitated its fleet of Garratt locomotives for main tine service. The Garratt principle enables locomotives of high tractive capacity to be built for any gauge, and together with modern component design and combustion techniques, would provide very effective and economical heavy freight locomotives.

Recognising the demand which renewed interest in steam traction suitable for developing railways can create, American Coal Enterprises has established a section specifically to develop and market this technology, whilst Steam Locomotive Designs Ltd, based in London, has been formed for the same purpose. Both groups firmly believe that modern steam traction has a potentially important future role to play on railways where circumstances favour its use.

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