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RAIL WORKING GROUP

RAIL GAUGE STUDY REPORT

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RAIL GAUGE STUDY REPORT

Contents

1 The Brief

There is a need for long term forward thinking that will produce the best eventual results for South Africa regarding the alternative options surrounding the choice of a railway track gauge. A document is required that could inform a suitable strategic framework for freight and intercity passenger rail gauge technologies.

It is to be based on an analysis and discussion of the relevant issues around current and possible future rail developments in the world at large and with specific reference to Africa and of course South Africa.

2 Executive Summary

More than 60% of the world's 1 144 000km of railway lines operate on standard gauge (SG) (1 435mm between the rails). North America, Europe and China account for more than 90% of this. A further 24% of the world's railways operate on even wider gauges termed broad gauge (BG). These range from 1 520mm to 1 676mm. India and what was previously known as Soviet Russia, account for some 80% of the broad gauge railways. The remaining 16% are narrow gauge (914 to 1 067mm). The dominant narrow gauge (NG) countries are South Africa, Japan, Australia (all on 1 067mm) and Brazil (1 000mm). More than 85% of the railways in Africa operate on narrow gauge.

South Africa dominates the railway scene in Africa and ranks about 14th in the world based on number of kilometres and freight conveyed per year.

Breaks-of-gauge are serious operational impediments whether internally or at international borders. Countries such as Australia, India and Spain have invested heavily (and not completed yet) to alleviate this problem.

The pace of railway development for the last four decades has been set by heavy haul, high speed intercity, and heavy intermodal. Of the applications that strongly exploit these technologies only heavy haul is present on narrow gauge. Railways that do not exploit at least one of these niches are generally insecure and struggling financially.

In 2007 the Africa Union resolved that standard gauge should be adopted for the construction of new railway lines in order to promote interoperability on the continent. Member countries were encouraged to keep the proposed standard gauge corridors and radials in mind whenever new lines are considered.

The underlying fabric of Transnet's masterplan points towards increasing use of heavy haul type technologies on its narrow gauge lines. Its general freight network will however remain at axle loads below the proven capabilities of narrow gauge. The plan makes no mention of and takes no position regarding the AU resolution.

The report presents a number of case studies in order to provide a "feel" for financial and operational numbers associated with projects such as a new high speed standard gauge line from Johannesburg to Durban, conversion of Transnet's existing core network to standard gauge as well as a comparing a new narrow gauge heavy haul line with one in standard gauge.

The main findings of the report indicate that standard gauge generally holds all the trump cards compared to narrow gauge in terms of better, faster, more economic, economy of scale, quality of R&D etc. Only with respect to the cost of the track infrastructure does narrow gauge hold an advantage over standard gauge (about 5 to 7%).

Conversion of the existing Transnet core network to standard gauge is discussed in some detail with the conclusion that it is not economically justifiable.

The report concludes with recommendations that South Africa should gradually move towards standard gauge via the route of a new standard gauge network. Such a network must be based on a masterplan that will have to be the result of a separate study.

It is also recommended that the existing network should not be converted to standard gauge as this cannot be justified economically. Investment should continue in the existing network whilst keeping the to-be-developed masterplan in mind.

Lastly it is recommended that South Africa fit in reactively (rather than pro-actively) with whatever happens across our borders in terms of the AU guidelines.

3 Document Structure

The full document comprises the following components:

- Rail Gauge Report (26 pages)
- Annexure 1 - Literature Review - World Focus (36 pages)
- Annexure 2 - Literature Review - Africa Focus (6 pages)
- Annexure 3 - Some influences of Track Gauge on Rolling Stock (13 pages)
- Annexure 4 - Analysis of a Notional Heavy Haul Coal Line (8 pages)
- Annexure 5 - A Passenger line from Johannesburg to Durban (13 pages)
- Annexure 6 - Moloto Corridor (8 pages)
- Annexure 7 - Converting SA's rail network to standard gauge (9 pages)

References in this report to an annexure (e.g. Annexure 6) are indicated as xxx[A6].

4 Background

The rapidly changing international environment is characterised by economic integration. One of the challenges facing Africa is how to adapt its rail infrastructure systems in order to respond to and integrate with the emerging trading systems[1].

The existing track gauge in South Africa is 1 067mm between rails and is commonly known as Cape Gauge. It is classified as part of the ***narrow gauge*** (NG) or meter gauge group which accounts for less than 17% of the world's railways. The dominant gauge in the world is 1 435mm (> 60%). It is classified as ***standard gauge*** (SG) and has various advantages over narrow gauge. Stability is better and may permit higher speeds as well as higher and wider rolling stock. Sheer economy of scale provides advantages in research and development and availability of rolling stock.

Railways in Africa are mostly of the narrow gauge variety (85%) and account for less than 7% of the world' railways by kilometres. Excluding South Africa and some countries in the extreme north of Africa, these railways are generally in a very poor condition with no cross border networks worth mentioning, apart from the SADC network. In 2007 the African Union together with the Union of African Railways resolved that standard gauge should be adopted for the construction of new railway lines on the continent.

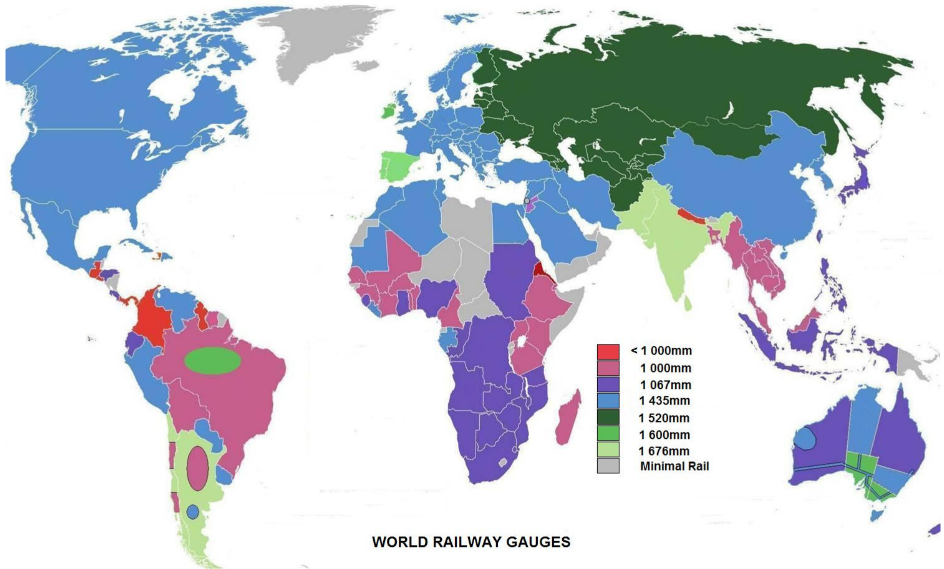
Against the background of the AU resolution, the perception that South Africa's railways are in need of major improvements in efficiency and performance and the perceived advantages of standard gauge, it is essential to investigate the value and the pros and cons of a change of gauge.

In a lengthy discussion document on its website[A1(45)] the Department of Transport presented a change of South Africa's gauge to the world's dominant 1 435 mm standard gauge as a visionary 50-year forward looking catalyst that will solve rail problems in South Africa and redress imbalances of the past as far back as the colonial era. Although somewhat tongue-in-cheek, it nevertheless lays a heavy finger on the fact that all is not well in the railways of South Africa.

It emanated from the Minister of Transport's challenge to the rail industry in 2005 to think 50 years ahead considering whether the advantages of the Cape Gauge outweigh moving towards the standard gauge system.

5 Disposition of rail gauges in the world[A1]

The world's existing railway track inventory comprises 1 144 000 route kilometres, of which narrow or meter gauge (914 to1 067mm) accounts for 16,6%, standard gauge (1 435mm) for 60.2%, and broad gauge (1 520 to 1 676mm) for 23.2%.



In many parts of the world diversity in gauge arose and, often, persists to this day. Although this is recognized as a costly hindrance to national and international commerce, several countries each make extensive use of two or even three track gauges.

"*Breaks-of-gauge*" hinder through-service across numerous international borders.

In recent decades, Australia and India have made substantial progress in reducing their diversity of gauge.

Among the common elements to different regional histories was the mix of incentives governing the choice of gauge.

Firstly, railway builders, operators, and in some cases regulators have had preferences for specific gauges, based on perceptions of the technical performance characteristics of different gauges.

Secondly, agents have nearly always valued compatibility with neighbouring railways, adopting established gauges where they existed.

Early choices of gauge were generally made by individual local railway companies or governments, with little regard for the effects of their choices on others. Later, cooperation and the formation of interregional railway systems led to increased coordination of choices, often facilitating the resolution of earlier diversity.

The gauge that happened to be chosen by the first line built tended, on average, to be adopted by nearly two-thirds of all the lines built thereafter in that region.

Historically, newly preferred gauges have been able to get a foothold only where previous railways were sparse.

The conversion cost relative to network integration benefits has a substantial effect on the likelihood that early diversity will be resolved.

Experience has shown broader gauges to be generally better than narrower, causing regret in regions where narrow gauges emerged as standards.

More often, experience has caused regret over the emergence of diversity, which has generated costs first of coping with breaks-of-gauge and then, sometimes, of converting whole regions.

South Africa ranks about 14th in the world based on number of kilometres and 12th in terms of tons of freight conveyed per annum. It is nevertheless a relatively small operation compared to the USA, Russia, China, and Europe, who are the world's railway heavyweights. Around 60% of South Africa's freight tons are conveyed over its two heavy haul lines that comprise less than 10% of its network.

As far as narrow gauge railways are concerned, South Africa together with Australia, Japan, and Brazil are the heavyweights of the world with almost 50% of the kilometres and more than 70% of the freight tons.

6 Break-of-Gauge issue[A1]

The multitude of gauges becomes an operational impediment at various international border crossings as well as internally in many countries. To name a few of the more important ones:

- The contiguous networks of the Commonwealth of Independent States[1] and the Baltic States[2] (all 1 520mm) to Western Europe, China, the Korean Peninsula, and the Middle East (all 1 435mm);
- The Iberian Peninsula (Spain and Portugal) (1 668mm) to Western Europe (1 435mm);
- China (1 435mm) to Vietnam (1 000mm);
- Internally in India, Australia, South America and Africa (the SADC 1 067mm network joins the East African 1 000mm network in Tanzania);

Break-of-gauge can be a major operational impediment. There are a number ways this is handled around the world notably[A1]:

- Transhipment,
- Bogie changing,
- Variable gauge wheel sets (notably for smaller differences, such as Western Europe to the Iberian Peninsula to the west, and the Commonwealth of Independent states and the Baltic States to the east), and
- Dual gauge track.

All of these add to operational costs and origin to destination transit times.

7 Pro's and Con's of SG vs. NG[A1]

The standard gauge technology has one disadvantage compared to its narrow gauge counterpart, and that is the additional capex needed for initial construction due to the longer sleeper, wider formation and additional ballast requirements. This premium is however fairly small and would generally be around 5 to 7% for a new railway line.

[1] Azerbaijan, Armenia, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Moldova, Russia, Tajikistan, Turkmenistan, Uzbekistan and Ukraine.
[2] Estonia, Finland, Latvia, and Lithuania.

For the rest, the standard gauge technology has a number of important advantages:

- Speed

  Having a ± 32% wider wheel base, it is only logic that SG will provide more stability enabling higher safe speeds on both straights and curves. Minimum curve radii on NG lines are seldom set above 1 000m as this will not restrict speeds around curves for the conventional NG speed range of up to 130 km/h. SG rolling stock can safely negotiate these curves at 15% ($\sqrt{1,32}$) higher speeds than similar NG rolling stock.

  Best practices in advanced NG lines, such as the JR Freight (Japan), QR (Australia) and Transnet Freight Rail (TFR), operate or have operated specially equipped light to medium freight traffic at speeds of 100 – 120 km/h. QR and TFR operate their world class heavy haul trains at speeds of up to 80 km/h (similar to SG heavy haul).

  The current maximum speeds on NG for passenger traffic is 160 km/h on QR (tilt trains), 130 km/h on the networks of the six Japanese passenger railway companies, and 100 km/h on TFR. During the nineteen-eighties Spoornet operated a regular 150 km/h service between Pretoria and Johannesburg (known as the Metroblitz).

  Both Spoornet and QR had undertaken regular test runs at 200 km/h and up to a maximum of 256 km/h. Hearsch[A1] projected regular 200 km/h operations on NG railways as likely in the foreseeable future but to date nothing has materialized.

  Best practices in SG operations employ speeds that are way ahead of the current NG technologies. Notable are Japan and Europe where intercity trains operate in the 200 to 300 km/h bracket and beyond. Most of these lines are very modern and beautifully engineered with extremely flat curves (4 000 to 7 000m radii compared to NG where 800 to 1 000m radii are considered flat).

  Freight traffic operations are much more dependent on price and service delivery (predictability of time of arrival at the destination) than on actual speed between stations. The extra speed capabilities of SG therefore provide limited advantage over a NG operation except in double stack container train operations where the norm is generally to operate up to about 120 km/h.

- Stability (Double stacking of containers)

  As discussed above, the higher stability of SG also enables the option of double stacking containers to enable heavy intermodal freight train traffic. This is extensively used in the USA and Canada where electrification is sparsely used. Most lines in Europe are electrified. Double stacking is therefore a lot less common than in the USA. It is nevertheless used on some lines where the electrification wires have been raised.

  The 32% wider wheel base permits a 32% higher centre of gravity for a wagon travelling around curves of the same radius on SG compared to NG.

- Vehicle profiles

  SG operations allow wider and higher vehicle profiles than NG. This is also a result of the better stability. SG profiles are 200mm wider and at least 600mm higher than NG profiles[A1]. NG standards can arguably be widened to similar dimensions as for

SG, but on existing lines such endeavours will more often than not be thwarted by a multitude of existing structures along the lines that were built to the original permissible structure profiles.

- Availability of research and development (R&D)[A3]

  Globalisation changed the railway industry. R&D became concentrated in a number of centres of excellence which are generally based in the standard and broad gauge countries. No new developments which fundamentally raised the competitiveness of NG have emerged for a long time.

- Wagons and coaching stock[A3]

  With manufacturing capacity and R&D primarily residing in the SG and BG countries, global sourcing is likely to gain momentum as the most competitive way to acquire trailing stock.

  Volumetric size of wagons is important as far as light density commodities such as coal are concerned. Pursuing world's best practice in axle load terms, SG has an important advantage in dramatically reducing the wagon fleet size required for a large coal transportation operation[A4]. This comes with associated capex and opex savings.

- Locomotives[A3]

  The power and tractive effort of NG locomotives are limited by the back-to-back wheel-set dimensions of a motored bogie. SG locomotives are way ahead of their NG counterparts in terms of cost per kN tractive effort. It would be fair to say that there is no indication that NG will be able to catch up or overcome this handicap[A3 & A4].

  The capital costs of SG and NG locomotives are best compared on a cost per tractive effort basis. Inspection of available offerings point at R60 000 to R80 000 per kN for NG locomotives and R25 000 to R60 000 for SG locomotives[A3 & A4]. So even if there is limited difference in total price per locomotive, the fleet size is substantially decreased with associated capex and opex savings.

  The lower cost of standard gauge rolling stock (wagons and locomotives) as well as the lower cost of operations (less rolling stock to maintain and fewer trains to operate) can generate substantial savings compared to a narrow gauge operation. Depending on the traffic volume, this should normally be sufficient to offset the higher cost of standard gauge track and to provide real economic gain.

- Formation stresses

  Although the longer sleeper of the SG should reduce formation stresses due to the larger footprint, the actual gain is judged to be limited to omissible. Due to the nature of ballast tamping machines the centre portion of the sleeper does not contribute much to bearing[A4]. The wider base does however reduce the effect of differential settlement on cross levels. This is advantageous for riding quality and reduces track maintenance.

- Track maintenance (and tolerances)

  As a composite beam the SG track structure provides better resistance to lateral displacement compared to the NG track structure. In terms of riding quality the SG track is also more tolerant to errors of twist in the running top (a 5mm error in twist on SG will have the same effect as a 3,7mm error on NG). The cost of track maintenance should therefore be marginally in favour of SG.

Modern day track maintenance machines restore errors in alignment and running top to the same absolute limits with equal ease on NG and SG.

The literature revealed no reports comparing the actual maintenance costs of NG and SG track operations. For similar axle loads and traffic volumes it would be realistic to expect similar levels of life cycle costs for rails and sleepers. Standard gauge operations would have some advantage regarding ballast life cycle costs and a substantial advantage regarding track geometric maintenance (running top and alignment)

SG thus has a maintenance cost advantages over NG. Although it is difficult to quantify, it is not expected to be substantial.

8 Country strategic choices holding possible lessons for RSA

Various railways in a number of notable countries have gone through important repositioning in modern times. It is wise to take note of their developments and decisions as background information for South Africa's own future strategic framework.

- Japan[A1]

  Japan is an example of a uni-gauge country (20 000km of 1 067mm NG) **adding** an additional separate passenger network of a wider gauge (SG). The initial decision was triggered by the need to overcome serious capacity problems. The wider gauge was chosen to provide a more stable platform for the high speeds envisaged for passenger transport.

  In the sixties, Japan had 20 000 km of NG railways only. Their capacity problem was purely passenger driven. Their response was to open the 515 km standard gauge Tokaido Shinkansen high-speed railway between Tokyo and Osaka just prior to the 1964 Olympic Games in Tokyo. This opened a new era in transport that triggered a global boom in high-speed rail. Today the Shinkansen network has grown to more than 3 000 km whilst speeds have increased from the initial 200 km/h to more than 300 km/h.

  Their NG network remains the backbone of its railway operation and carries even more passengers than the SG Shinkansen. It has grown to 23 000 route km. Together with Queensland Rail and Transnet Freight Rail, Japan remains one of the prominent NG operators in the world.

- Spain[A1]

  Spain operates some 15 000 km of railways, of which about 85% are constructed to the broad "Iberian" gauge of 1 668 mm. There is a serious break-of-gauge problem with neighbouring Europe's SG. They decided (initially) to add a separate network of the narrower standard gauge in order to integrate with the rest of Europe. Subsequently Spain decided to convert most of their BG network to SG over a 40 year period.

  They have also made good progress with a new dedicated, standard gauge, high-speed (350 km/h maximum) passenger network, which will link the main centres of

Spain as well as linking Spain with France and the rest of Europe.

The main driver was the need to eliminate the break-of-gauge with the rest of Europe for freight and especially to become part of the European high-speed passenger network. Their strategy is to convert the BG to dual gauge (1 668/1 435mm) and eventually back to standard gauge (1 435mm SG)

Massive investments of the order €125 billion are being reported in the press.

Spain's change to standard gauge will increase the threat of isolation to neighbouring Portugal's national railway. Except for the few standard gauge links that are planned to be built, more than 90% of Portugal's small network of about 2 600km is on BG.

It will be worth studying what influence Spain's gauge change has on Portugal. The answer could be relevant for South Africa's influence on its neighbours.

- Australia[A1]

Australia is a country with three different gauges (1 067mm NG in West Australia and Queensland, 1 435mm SG in New South Wales and 1 600 mm BG in South Australia and Victoria).

The multiple gauges were always a major impediment to the flow of freight between States. Australia decided to create an interstate standard gauge network. The SG network of the NSW state was extended to connect all the state capitals. This required converting the Melbourne-Adelaide broad gauge line to SG, some dual gauging (especially on the West Australian NG network, and also around Brisbane). The interstate standard gauge network was completed in 1995.

Apart from the national SG network the rest remained largely as before. West Australia and Queensland (jointly 19 000km of NG) have no plans to convert their networks to SG. Queensland's capital Brisbane, sits at the southern tip of the state. It has a SG connection to NSW and on to Sydney but nothing further. It has continued to expand its 10 000km of NG network and also employs a 160 km/h tilting train operation between Brisbane and Cairns some 1 680 km to the north.

South Australia and Victoria (jointly 4 300km of BG with the bulk of it in Victoria) also remained unchanged. Victoria has gone through various investigations over the last 10 years to find economic justification to convert its BG to SG in order to eliminate the inefficiencies caused by breaks-of-gauge. To date there has been no physical progress.

- India[A1]

India is predominantly a BG country (47 000km of 1 676 mm). It also has some 16 000 km NG lines (1 000 mm) as well as an assortment of routes on 610mm (2 feet) and 762mm (2 feet 6 inches) track gauges. India is steadily converting most of its 1 000mm lines to BG under its "uni-gauge" policy which envisages the eventual elimination of all non-broad gauge lines. The aim is to reduce the inefficiencies of operating across breaks-of-gauge. However, some of the 1 000mm lines have been abandoned, and the sub-1 000mm lines have generally been left to their own devices.

- Russia[A1]

  Russia together with the Commonwealth of Independent states have a very large railway network of about 150 000km of 1 520 mm BG. Their international operations are hampered by many cross border breaks-of-gauge with the 1 435mm SG networks of Europe, Scandinavia, China, Korea and the middle East. After speculation regarding gauge conversion, the Russian President in 2006 ruled out any possibility of a conversion. This put an end to Kazakhstan's aspiration to position itself as a key railway transit country between East and West.

- There are a number of other examples of countries adding some SG lines to their networks such as Taiwan and Argentina but these are relatively small compared to the examples mentioned above and they are dedicated high speed lines.

9 Macro trends in the role of railways in the world[A1]

The pace of railway development for the last four decades has been set by heavy haul, high speed intercity and heavy intermodal. Of the applications that strongly exploit these technologies only heavy haul is present on NG with South Africa, Queensland and Brazil, as examples.

Introducing high-speed intercity services and double-stack container trains into NG countries will, as a minimum, require overcoming the constraints of their narrow track-gauge technologies.

Successful railways differentiate themselves from competing transport modes. They compete in three niches, so distinct that they are virtually separate transport modes:

- Heavy haul competes against sources in *other countries*, with <1 000km hauls and aggressive cost reduction.
- High-speed intercity competes against road and air in the 300-1 000km mobility niche.
- Heavy intermodal competes against *other modes* in the 3 000-12 000km niche between road- and maritime

Double-stack container trains are an extension of the heavy haul application to general traffic routes, rather than raising the axle-load bar. Narrow- and diverse track gauges do however not support the high centre of gravity that associates with double stacking.

Railways operating in one or more of these three categories are flourishing to various degrees. Those who are not also major players in at least one of these three categories are more often than not merely in survival mode or in some stage of demise.

10 The Africa Railway picture[A2]

Railways in Africa are mostly of the narrow gauge variety (85%) and account for less than 7% of the world' railways by kilometres and much less by tonnage.

Excluding South Africa and some in the extreme north of Africa, these railways are generally in a very poor condition with no cross border networks worth mentioning apart from the SADC network.

In Africa, South Africa dominates the railway scene with almost 30% of the continent's kilometres and more than 60% of its rail freight. Only 10 countries in Africa move between 3 and 30 Mt/a of freight with South Africa overshadowing the rail freight activities with some 180 Mt/a.

Intercity passenger traffic is currently fairly insignificant in the Sub-Saharan countries. South Africa has almost 50% of the rail kilometres in this area and transport more than 90% of the rail freight tonnages[A2].

There is a fairly extensive 1 067mm NG rail network covering the SADC countries. There is a break-of-gauge at Kidatu in Tanzania from where the network continues in 1 000mm NG into Kenya and Uganda.

Apart from a one small network in the extreme north, there are no other cross border rail networks in Africa. Outside SADC the general picture is currently of country bound hinterland to coastal railways predominantly in poor condition and of the 1 000mm and 1 067mm gauge variety.

11 *Africa Union rail development guidelines and the 2007 gauge Resolution*[A2]

In 2007 the Africa Union together with the Union of African Railways resolved that standard gauge should be adopted for the construction of new railway lines on the continent[A2].

It was worded:

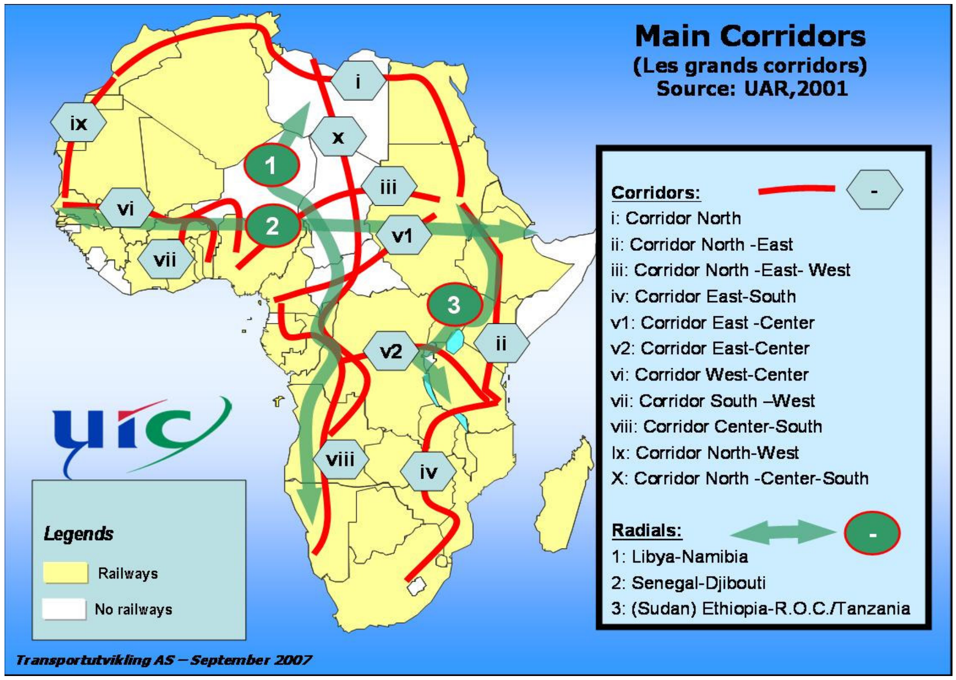
> "***To this end and to facilitate interoperability of rail transport networks in Africa, standard 1 435mm gauges should be adopted and retained for construction of new rail lines in the Continent***"

and concluded that:

> "***The conversion to standard gauge (1 435mm) for new railway lines should enable African railways to benefit further from the wide range of material and equipment at global level, and will contribute significantly to resolving the problem of interoperability in the future Pan-African railway network***."

Ten **Corridors** and three **Radials** feature in the vision of the Union of African railways and member states are encouraged to keep these in mind for future integration whenever new lines are considered.

Viewed from the background of general poor rail conditions and lack of rail networks in Africa, this resolution makes eminent sense.



Apart from construction in Libya, actual activities on the ground do not as yet provide any support to this resolution. There are nevertheless a fair number of positive intentions under consideration in a number of countries. Notable ones are:

- As far back as 2003, Nigeria decided to rebuild and remodel its total 1 067mm NG network to SG specifications. Progress to date remains zero due to contractual and presumably funding difficulties.

- Algeria and Morocco who are already predominantly SG countries are both planning substantial extensions to their networks inclusive of a SG high-speed line in Morocco to European standards.

- In 2008 both Kenya and Uganda announced their intentions at ministerial level to replace their current 1 000mm NG networks with SG technologies.

- Burundi and Rwanda, also at ministerial level, announced their intention to build a 700 km line to connect their landlocked countries to Tanzania. This will obviously be influenced by the Tanzanian intention to rebuild in SG.

Extensive portions of the rail network in South Africa totalling almost 10 000km are currently classified by TFR as branch lines and lines with no train service. In May 2008 the minister of Transport announced plans to transfer these lines from TFR to the Department of Transport[2]. Most of these lines can only continue to exist with substantial subsidies or under dramatically revised management structures. For many of them this will probably be an interim step towards final demise.

In a competitive business sense the remaining core network of about 15 000 km has probably also not seen the end of its pruning process.

The AU resolution is sometimes loosely used in South Africa as a demonstration of political will to go the route of converting existing railway lines from NG to SG. From careful reading of the resolution and its supporting documentation it is however quite clear that the AU was careful to stress that this was a guideline for newly constructed lines only. Conversion would be way down the time scale when this was required for operational, economic and/or strategic reasons.

12 Transnet long term Masterplan[3]

Transnet states that their strategy is focused on the development of a world class bulk freight transport system which will provide domestically based firms with a competitive advantage in the global market[3].

The masterplan identifies the current core system and shows how this core will develop over time to meet future demand for freight transport in the economy.

Amongst others the strategy emphasises integrated planning and operations in order to:

- Implement a high performance rail corridor backbone to recapture corridor market share from road and provide the capacity to meet the long term demand.
- Enhance the connectivity of the South African freight system with others in Africa.

Future demand for freight transportation is forecast by means of a freight demand model. The total demand for freight transport in the economy is estimated to more than double in 20 years under a likely growth scenario and almost treble under a high growth scenario.

The demand for surface transport of freight is expected to continue to consolidate along the existing national freight corridors. Long term forecasts of corridor demand show that it will be practically impossible to provide the infrastructure that the economy will need in the same rail/road configuration that is currently the case. Even the doubling of the current rail supply means that road volumes will have to increase by 60 percent on average to meet demand in 2019 and almost double by 2025. The bulk of Transnet's future investment is therefore to be concentrated on these corridors.

The extent of the challenge is illustrated through an examination of the Gauteng-Durban corridor. The current freight demand on this corridor is 42 million tons (2004), of which approximately 75% is road based. If the road freight volumes were to remain at this level in future to prevent further corridor congestion, rail freight volumes will have to grow from 10 million tons to 50 million tons over the next two decades. This level of growth cannot be achieved through efficiency improvements alone and the corridor and associated rail infrastructure will require significant investment in new capacity.

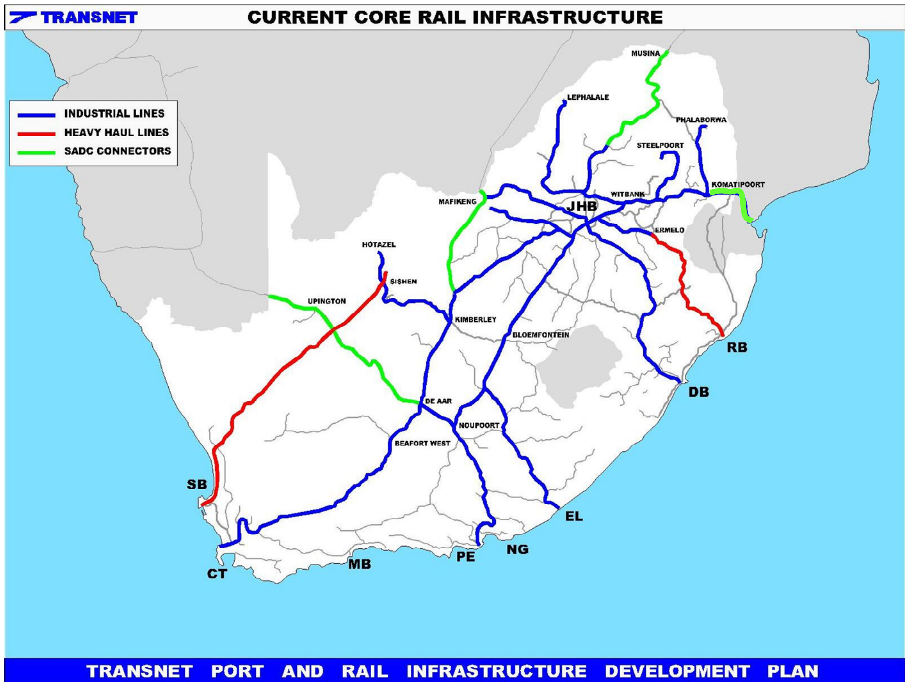
The export of dry bulk products, dominated by coal and iron ore, is forecast to increase by between 2.5 and 3 times between 2004 and 2025 while containers are also expected to exhibit strong growth over the long term.

Whereas the requirement for efficient transport has largely been realised for the bulk export of coal and iron ore, allowing local deposits to be internationally competitive, Transnet recognizes that the transport of general freight is seen as being too slow, too expensive and too unreliable.

Factors such as poor operational practices and inefficiencies and inadequate use of technology are acknowledged as contributing to poor system performance.)

Transnet classifies its rail network of 30 000 km (22 300 route kilometres) into heavy haul export lines, the core network, two classes of non core lines and closed lines. The core network (inclusive of the two heavy haul export lines) represents 43% of the network, with low and light density lines (non core network) being 42%. The balance of 15% represent closed and no service lines.

Based on the figure of 43% plus Masterplan indications of some extensions and some planned upgrading of non core lines, the total of core and heavy haul lines can be placed at about 15 000 km of track.



The following enhancements are envisaged to the core network:

- A Freight Ring around Gauteng, separate from the PRASA network.
- A Western Bypass to connect the Waterberg region to the SW corridors.
- An additional Industrial line along the alignment of the Coal line to Richards Bay.
- A connection from the Gauteng SW corridor to the Saldanha Heavy Haul Line.
- Demand driven capacity increases on the Coal and Iron Ore Export lines.
- Extend the heavy haul Coal line towards Gauteng and connect to Waterberg region
- Provide heavy haul extensions from the Waterberg across the Botswana border.
- Upgrade the Hotazel – Ngqura line to heavy haul standards.

All the main corridors will require some capacity enhancements. Some key developments will include:

- Improving the links between neighbouring ports on the east, south and west coasts
- Develop the Maputo Corridor
- Re-align the Eastern Corridor

Upgrading and expanding in line with the masterplan is estimated to require about R40 billion over the next 5 years.

Comments on Transnet's Masterplan

Three aspects of the Transnet Masterplan are worthy of comment in this document that strives to make a contribution towards South Africa's rail gauge debate.

The first is an apparent omission in the plan to comment on rail's competitiveness (or uncompetitiveness) vis-à-vis other modes (particularly road) and to develop strategies with that in mind. (see paragraph 7). Some of this is partly implied by the envisaged extensions to the heavy haul lines as well as the upgrading of the Hotazel-Ngqura line to heavy haul standards. Rail's competitors are improving continuously and that will best be addressed through strategies striving to exploit rail's competitive strengths.

The second aspect is that of intercity passenger services, which admittedly no longer features in Transnet's vision or mandate. The future of intercity passenger traffic is bleak in its current form in South Africa. It is unlikely to progress beyond a nice-to-have tourist cum social service requiring regular subsidies. High speed passenger services will require substantial investments (see paragraph 13) and feasibility will depend on sufficient demand for such a service.

A high speed passenger line (200 km/h plus) require very flat curvature (radii of 4 000m plus) but can live with steep gradients of 1 in 35 or even steeper. A heavy haul or heavy intermodal line can operate adequately at speeds of 80 – 100 km/h on relatively sharp curves of 600m radius. Gradients however need to be fairly flat like 1 in 100 or flatter. In principle both types of traffic could operate well on a line with flat curves and flat gradients. In practice such examples are hard to come by.

The responsibility for intercity passengers has moved to DOT's PRASA. In the light of the huge freight transport demands projected by Transnet, cooperation with PRASA on new joint ventures might be advantageous to both.

Thirdly the plan makes no mention of the AU's standard gauge resolution and how it might possibly impact on the Transnet network at our borders. Being a 20-year plan it is possible that Transnet expects no impact in that period of time. Time will tell.

13 Case studies to provide a "feel" for cost of rail lines etc

A number of case studies were conducted in order to develop a "feel" for the costs associated with rail projects. The details are captured in fair detail in annexures attached to this report. Only the salient facts are repeated here.

- **Johannesburg – Durban (cost of a new high speed passenger line)[A5]**

  The infrastructure cost of a new 640km high speed standard gauge double line for this route is estimated to be of the order of R80bn. As a rough approximation about 100 km (x2) is expected to be in tunnels and 50km (x2) on viaducts. High geometric standards and sections of difficult topography contribute to the high costs.

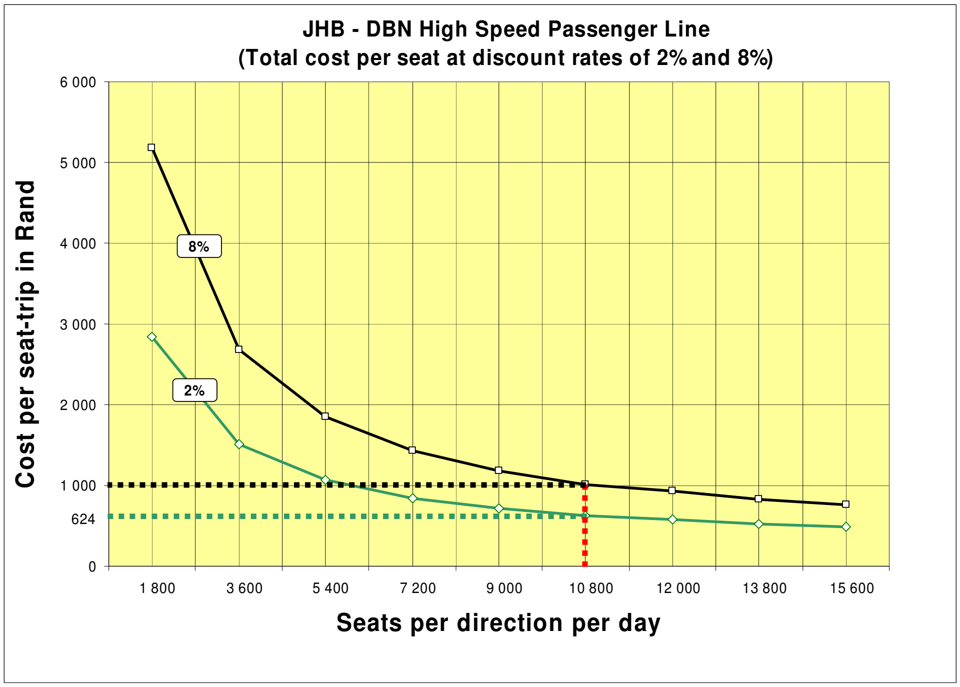
  Trip time including 5 stops of 40 minutes total could be about 4½ hours compared to the current trip of about 14 hours with 40 minutes of stops.

  Useful perspective is gained by comparing this with the 700km Paris-Marseille high speed TGV operation. The TGV non-stop time is 3 hours, while schedules with two stops are 3 hours 16 minutes (i.e. the station dwell time is the same as this Johannesburg-Durban proposal). For a distance of 640km, this proposal is around one hour slower than a TGV would be.

  The cost per seat-trip will be a function of the financing model, patronage and the extent to which spare line capacity could be utilized by freight traffic.

  Sharing the line with freight trains (container traffic perhaps) will bring the unit costs down for passengers but will complicate the operation. For safety and operational reasons freight traffic should only run during the night when high speed passenger trains are stationary. Operating container trains at up to about 120 km/h will also limit super-elevation (cant) around curves. This will be sub-optimal for passenger trains and will limit speeds around such curves.

The capacity of the night time window for container trains will diminish with increasing passenger traffic. At about 11 000 seats per direction per day this window will become too small for the operation of container trains (see Annexure 5).



The figure above projects a cost per seat-trip of R1 000 at a volume of about 11 000 per direction per day (for a discount rate of 8% p.a.) With sufficient freight trains to contribute to the revenue this rate could be stable at R1 000 per seat-trip for all volumes down to 1 800 per direction per day.

For a discount rate of 2% p.a the cost could come down to just above R600 per seat-trip at a volume of about 11 000 per day per direction (and with sufficient freight trains, remain at that level for the lower volumes as well).

The current volumes for air travel between Johannesburg and Durban is about 5 000 per day per direction with tickets selling between R750 and R1 000. Volumes are projected to escalate to about 11 000 per direction per day by 2020 (see Annexure 5).

According to current projections there could be merit in such a new line in the distant future (or sooner depending on the financing model and the demand for freight traffic).

- **Moloto Corridor choice between NG and SG[A6]**

This project proposes a new 124km double railway line to replace the current inadequate bus service for passengers between Siyabuswa in Mpumalanga and the Belle Ombré station close to the CBD in Pretoria.

In 2006 some 642 busses moved 46 000 passengers per direction per day.

The detailed feasibility study by the Moloto Corridor Consortium concluded that a rail solution would provide the most beneficial and economic solution to replace the current inadequate bus service.

The financial feasibility allowing for inflation demonstrated a NPV of R10 356 million for a conventional PRASA 10M5 Metrorail technology solution on narrow gauge tracks in comparison to the current bus service.

Further analysis using double deck coaches on standard gauge rail technology, improved the NPV by 14% to R11 769 million.

These coaches have a seating capacity of 278 and can achieve speeds of up to 160 km/h compared to 118 seats per coach on PRASA's 10M5 technology running at maximum 100 km/h. There are currently no examples in the world of double deck narrow gauge coaches running at 160 km/h.

The report anticipates various advantages for the standard gauge double deck train option over the conventional PRASA narrow gauge technology option. Some of these are a 28% saving in capital cost required for rolling stock, an 8% saving in annual operating cost and an additional 14 minutes trip saving time.

The Moloto Corridor is interesting from a gauge point of view. It illustrates the standard gauge rolling stock advantages over narrow gauge in a similar way as for freight railways (refer to the analysis of a heavy haul line in the next paragraph). Being a commuter line, further interpretation is best left to a separate study dealing with passenger rail technologies.

- **A Notional Heavy Haul Coal Line[A5]**

A number of new railway lines are currently being planned in Southern Africa. As yet none of these has advanced far enough to enter the public domain. Knowledge of the feasibility studies however make it possible to distil sufficient elements of these projects into a realistic notional picture to demonstrate some of the thinking currently going into the choice of track gauge for these projects.

Existing networks in the vicinity of these projects are of the narrow gauge variety but connectivity is generally considered to be a fairly minor issue. The project(s) are therefore classified as being quite close to a green field scenario(s).

A notional example was developed for a new 1 000km line required to move 30Mt/a coal. Realistic infrastructure and rolling stock capital costs as well as operating costs were used to determine a unit transportation cost in cent/ton.km. This was done for both NG and SG using current world's best practice heavy haul parameters for both options.

The sensitivity of the model was tested for factors such as discount period, discount rate and required annual throughput.

The results from Annexure 4 are summarised in the table below for 30 Mt/a. It is based on discounting the full capital costs over 25 years at 15% p.a.

The estimated premium to be paid for standard gauge track in this example is about R0,7m per km. This is handsomely offset by the rolling stock and operational cost advantages. Only at a theoretical premium of R2,25m per km will the advantages disappear in this example.

The economics favour standard gauge over narrow gauge provided the traffic volume is more than 10 Mt/a. Below that level the R0,7m premium required for each km of track will start to exceed the advantages of standard gauge.

Advantages of moving 30 Mt/a of coal with standard gauge (as opposed to narrow gauge)	
Reduction in capex for rolling stock	42%
Reduction in capex for the total project	6%
Reduction in number of wagons required	32%
Reduction in number of locomotives required	40%
Reduction in size of train crew required	41%
Reduction in annual operating cost	13%
Reduction in unit transportation cost	8%

Premium this project can afford to pay for standard gauge track and still break even with a narrow gauge option	10 Mt/a	R0,75m per km
	30 Mt/a	R2,25m per km
	50 Mt/a	R3,75m per km
Actual premium required		R0,70m per km

This provides some perspective on the decision of the then Cape- and Natal governments some 130 years ago when they decided to go the narrow gauge route (even after the first 110 km of railway line in South Africa was built in standard gauge). At that time speed along with all the other modern day SG advantages was not a factor. Traffic volumes of 10 Mt/a probably also seemed far fetched.

It took more than 100 years before the wisdom of the 1871 gauge decision came into question.

14 Cost of a full RSA rail freight net-work conversion to SG[A7]

Before venturing into an approach to convert South Africa's NG railways to standard gauge and what it might cost, it is wise to examine plausible scenarios that could call for such a strategy.

The existing network is most probably not an optimal reflection of what rail can do best for South Africa. This is borne out by a recent announcement of the Minister of Transport that a memorandum of understanding is being finalised between the national departments of transport and public enterprises and Transnet Freight Rail that will see tourism rail lines, branch lines and "no service" lines transferred to the Department of Transport[2].

It is a debatable point whether the remaining ± 15 000km of core lines in the TFR network represents an optimal network. It is however not the purpose of this report to debate the matter of an optimal network.

TFR's 15 000km core network was therefore used as a departure point to develop a "feel" for the cost order of magnitude for a gauge conversion. In as much as the globular figures appear to be of staggering proportions, it was found that even more valuable insights could be gleaned from an integration of the conversion cost per kilometre with economics that transpired from annexure 4. More about this in paragraph 15.

Converting the gauge of such an extensive network will be an operational challenge of monumental proportions. The most practical and least disruptive operational methodology would be to convert everything to dual gauge. Adding a third rail will require replacement of all the sleepers and the provision of extra ballast.

Dual Gauge 1 435/1 067 mm WestRail Ausralia

Illustration: Railway Corporate Strategy cc

Operations can then continue as before and SG rolling stock can be introduced as and when NG stock has to be retired. This will also prevent the head ache of a break-of-gauge problem with our SADC neighbours.

Converting the 15 000 km core infrastructure to dual gauge is estimated to cost around R100 billion[A7]. About 25% of this amount will have to be used to improve vertical clearances and to widen formations.

Replacing the NG rolling stock would cost an additional R100 billion but this could be left out of the equation in a dual gauge situation if rolling stock is only replaced when they reach the end of their economic life.

This infrastructure conversion cost will place a premium of more than R6m on every kilometre of track so converted. About 60% or R4m per km is solely for the sleeper replacement, third rail and extra ballast.

The assumptions on which the estimate of R100 billion is based are explained in Annexure 7. To simplify matters the key assumption was that no upgrading is included whereby axle loads and speeds could be increased.

The validity of this could of course be challenged. In particular that such a conversion to a standard gauge would result in a railway inheriting most of the key parameters of a narrow gauge railway. This of course largely nullifies the benefits of conversion. A real life conversion of gauge from NG to SG would obviously aim at realising the full potential of SG and would therefore go much further and require an investment of much larger proportions.

Other technicalities such as how to deal with stumbling-blocks such as the 3kV DC electrification, rail connectivity to South Africa's neighbouring countries and to local branch lines were also disregarded.

The main purpose was to arrive at a cost per km of track to do a very basic conversion. This figure is of the order of R6m per km. If anything this figure is much lower than what a real life conversion would require if it goes hand in hand with suitable upgrading in order to realise the full potential of SG.

15 Affordability of a gauge conversion in South Africa

The premium mentioned in paragraph 13 must be recovered over time by the advantages of standard gauge as elucidated in paragraph 7. A model was developed to quantify the advantages of standard gauge in a heavy haul type of operation[A4]. From this model it is clear that SG can afford a premium on the infrastructure costs ranging from R1m to R4m per kilometre for traffic volumes ranging from 10 Mt/a to 50 Mt/a.

This “affordable premium” ranging from R1m to R4m per km was extracted from a best case green field heavy haul scenario. Brown field heavy haul and general freight operations would at the very best be able to afford similar premiums. Lesser “affordable premiums” would be more likely.

Even without reduction, the affordable range of R1m to R4m is already way below the conservative expected premium of about R6m per km. to convert a kilometre of track to SG.

It is important to note that the affordable range of R1m to R4m per km is based on realising the full potential of standard gauge. On the other hand the premium of a straight forward conversion at R6m per km excludes upgrading. Thus the real cost of repositioning a narrow gauge railway for competitiveness is likely to be higher than the premium calculated here, and gauge conversion all the more economically unjustifiable.

The conclusion is obvious – conversion costs of R6m/km or even R4m/km are not economically justifiable in South Africa.

It is important to note that the premium to pay for standard gauge infrastructure is quite small in a green field project. The example worked in Annexure 4 placed this premium at about R0,7m per km. This figure is easily offset by the rolling stock and operational advantages of standard gauge for traffic volumes above 10 Mt/a.

For some railway applications like high speed passenger and double stack container operations the answer is even simpler as narrow gauge cannot deliver services of that kind.

16 Discussion and Views

It is clear that South Africa should not convert its rail network to standard gauge based on the perceived advantages of standard gauge or the resolution of the Africa Union. The AU has concentrated on the need for moving towards a network for the continent and has in fact steered away from recommending ad hoc conversions.

Breaks-of-gauge are operational impediments and countries such as Australia, Spain and India made changes to their gauge to rid themselves of this problem.

A study of railways world wide indicates that only one country came close to converting their network from a narrow gauge to standard gauge and that is Nigeria. Compared to South Africa, their railways are small with no cross border connections and in very poor condition. This places them virtually in a green field situation. Their decision makes sense and fits in with the AU resolution. The decision was announced some years ago but to date there is still minimal progress.

South Africa has already opted for one stand-alone SG line (Gautrain[A1]) and a further potential one (Moloto[A6]) has progressed beyond the pre-feasibility stage. Both these SG green field projects make strategic and economic sense with their abilities to deliver something that NG cannot do with similar levels of success or cannot do at all.

The way to go appears to be a situational evaluation of each transportation need by pro actively including the standard gauge technology in the analysis.

Strategic and economic reasons should govern a conversion or change to SG. The following are a few examples of scenarios that could justify employing the SG technology in South Africa:

- If a need develops to provide intercity passenger services at speeds beyond the probable or proven abilities of NG – provide a new line in SG.
- If a need develops for the higher capacity and the lower unit costs that can be provided by double stack intermodal services – provide a new line in SG.
- If a need develops for a new relatively stand alone heavy haul line (especially for light density commodities such as coal) – provide a new SG line in order to make use of its lower unit transportation cost capability[A4].
- If and when the resolution of the Africa Union (paragraph11) starts to show signs of nearing our borders – consider dual gauging or new SG lines from our economic hubs towards our borders as a strategic imperative.
- If and when it becomes clear that the above four scenarios will be taking on critical mass proportions – dual gauging of some lines might become strategic imperatives.

In 2007 the Rail*Road* Association developed a position paper on the choice of gauge for South Africa. Their position in as far as it is applicable to this study is as follows[4]:

- **Whatever decisions are taken should be economically viable** - the authorities should prescribe neither that all new track should be standard gauge**,** nor that all existing track should be changed to standard gauge.
- **It is unlikely that it will be found economic or realistic to change all existing track to standard gauge**.
- **Existing narrow gauge track should be operated as a going concern**, as long as it can economically serve its intended purpose.
- **Major new railway projects in South Africa should use the dominant applicable technology**. For example, application of double-stack container trains, and/or high-speed intercity trains to new corridors should use standard gauge.
- As and if such projects gain momentum, it will then be **up to future generations to convert appropriate portions** of the existing rail network to standard and/or dual gauge lines.

This current study has expanded on, illuminated and quantified several of the parameters addressed by the Rail*Road* Association's position paper. It has uncovered nothing to fault the RRA's position and provides extensive backing even to the point of quantified economic numbers.

In the 1870's the Natal and Cape Governments decided[A1] to go the narrow gauge route. Today we regret that decision but should spare a thought for the logic that probably guided it 130 years ago.

At that time speed along with all the other modern day SG advantages was not part of the equation. They probably also came to the conclusion that standard gauge track would require a premium of 5 to 7% over narrow gauge as determined in Annexure 4. Traffic volumes of 10 Mt/a probably also seemed far fetched.

It took more than 100 years before the wisdom of that gauge decision came into question!

17 Findings

1. Standard gauge has a number of substantial advantages over narrow gauge such as speed, stability, volumetric vehicle size, volume and quality of R&D, mass production of rolling stock and sheer economy of scale.(§7)

2. Standard gauge locomotives can fit stronger motors, produce better tractive effort and as a result can be two to three times less expensive based on a cost per kN tractive effort basis.(Annexure 3)

3. Standard gauge railways can perform certain functions that narrow gauge cannot do at all (e.g. high speed and double stacking). For such functions standard gauge railway lines would be the only logic solution, provided the economics favour such an option above other alternatives.(§7 and Annexure 1)

4. Apart from high speed and double stacking, standard gauge railways can also do most other things more economically than narrow gauge. The economic advantage measured in unit transportation cost is dependent on traffic volumes. Based on world best heavy haul practices, break even is achieved at about 10 Mt/a. From there the advantage moves up to 10% at about 37 Mt/a and 20% by about 120 Mt/a. (§13 and Annexure 4)

5. Where adequate freight traffic volumes are on offer (> 10 Mt/a), a new line will easily justify the use of standard gauge. Connectivity and break-of-gauge will be the issues to analyse. (Annexure 4)

6. Standard gauge operations have only one negative compared to narrow gauge and that is the cost of the track infrastructure. This premium is of the order of 5 to 7% of the total cost of the infrastructure. Provided traffic volumes are adequate this is normally easily offset by the rolling stock and operational cost advantages of standard gauge. (§13 and Annexure 4)

7. The pace of railway development over the last four decades has been set in three distinct niches where rail managed to dominate other transportation modes. These niches are heavy haul, high speed and heavy intermodal (double stack container trains). (Annexure 1)

8. Heavy haul is the only one of these three niches that is been exploited by narrow gauge railways. The other two are beyond the proven capability of narrow gauge. Railways not exploiting at least one of these three niches are generally insecure and are struggling financially. (Annexure 1)

9. Breaks-of-gauge are major impediments in the networking ability of railways. Various countries across the world invested heavily to rid themselves of this. (§6 and Annexure 1)

10. A number of countries invested in separate networks with a gauge differing from their normal gauge in order to achieve specific objectives. Invariably the choice for such an extra network has fallen on standard gauge because of the sheer economy of scale and technological advantages offered by standard gauge.(§8 and Annexure 1)

11. A standard gauge high speed line between Johannesburg and Durban capable of a journey time of about four hours, will cost about R80 billion. That is to provide the

track infrastructure and excludes the rolling stock. The right combination of patronage, financing model plus a contribution from medium speed freight trains could see such a line become a reality somewhere in the future.(§13 and Annexure 5).

12. The Africa Union passed a resolution calling on their members to adopt standard gauge for the construction of new lines on the continent. It is a sound resolution and is in line with global reality. It also makes eminent sense when viewed from the background of Africa's diverse gauges, lack of rail networks and the general poor condition of the majority of existing lines.(§11 and Annexure 2)

13. The Africa Union also indicated that interoperability of a future Pan-African network was one of the main drivers for this resolution.(§11 and Annexure 2)

14. Converting the gauge of the whole or portion of the existing Transnet narrow gauge network to standard gauge is not economically justifiable in South Africa. It will cost at least R4m to R6m per km without provision for upgrading to fully realise the advantages of standard gauge. This will far exceed the advantages to be gained from standard gauge rolling stock and operations (§14 & 15 and Annexures 4 and 7).

15. Dual gauging at R4m to R6m per km is nevertheless less expensive than a complete new SG line and would be the way to go where interoperability such as with the rest of Africa becomes a necessity or a strategic objective by the time standard gauge railway lines would be migrating towards our borders in line with the AU resolution.

18 Recommendations

1. Regarding the use of standard gauge, South Africa should

a. Develop a long term masterplan based on what an optimum standard gauge freight and intercity passenger network should look like (using the analogy of desirable corridors and radials as per the Africa Union plan).

b. Expect this masterplan network to be much smaller and quite different to the existing Transnet core network.

c. Use every logical opportunity to tap into the advantages presented by this technology whilst keeping the masterplan network in mind.

d. Evaluate each such opportunity on its individual merits and then build it in standard gauge if economically viable (as was already done for the Gautrain and Moloto projects)

e. See this as its long term plan to gradually migrate to a standard gauge network via the step by step introduction of new standard gauge lines on a masterplan basis.

2. Regarding the existing Transnet core freight and intercity narrow gauge network, South Africa should

a. Accept that a large scale conversion to standard gauge is not economically justifiable and should therefore not be attempted.

b. Continue to invest in, operate and maintain this network whilst keeping a constant lookout for opportunities to rather migrate to portions of the master plan standard gauge network.

c. Understand and accept that the existing network will continue to shrink where it is not competitive with other modes of transport and/or with the growing new standard gauge network.

d. See gauge conversion and/or dual gauging of portions of the existing network as justifiable only for strategic reasons.

e. View the creation of dual gauge overlaps with the envisaged new standard gauge network or for the purpose of interim connections to neighbouring countries as examples of such strategic reasons.

3. Regarding the Africa Union's standard gauge resolution, South Africa should

a. Apply the resolution solely from the point of view of what makes economic sense for the country itself.

b. As the southern most country on the continent, be a follower rather than a pace setter when it comes to implementing standard gauge on corridors with cross border break-of-gauge implications.

c. Thus only progress towards our boundaries with standard gauge when it makes economic sense for the country. In all other situations the procedure should be to wait for new standard gauge lines to approach from the north before taking strategic action to meet them.

19 References

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NATMAP RAILWAY WORKING GROUP (RWG)

RAILWAY GAUGE

ANNEXURE 1

LITERATURE REVIEW – WORLD FOCUS

(version 4 - 200904)

SYNOPSIS

This report reviews what has and is happening in the world of railways in so far as it is related to the gauge of the railway.

In many parts of the world diversity in gauge arose and, often, persists to this day. Although this is recognized as a costly hindrance to national commerce, several countries each make extensive use of two or more gauges

"*Breaks of gauge*" hinder through-service across numerous international borders.

In recent decades, Australia and India have made substantial progress in reducing their diversity of gauge

Among the common elements to different regional histories was the mix of incentives governing the choice of gauge.

Firstly, railway builders, operators, and in some cases regulators have had preferences for specific gauges, based on perceptions of the technical performance characteristics of different gauges.

Secondly, agents have nearly always valued compatibility with neighbouring railways, adopting established gauges where they existed.

Early choices of gauge were generally made by individual local railway companies or governments, with little regard for the effects of their choices on others. Later, cooperation and the formation of interregional railway systems led to increased coordination of choices, often facilitating the resolution of early diversity.

The gauge that happens to be chosen by the first line built tended, on average, to be adopted by nearly two-thirds of all the lines built thereafter in that region.

The conversion cost relative to network integration benefits has a substantial effect on the likelihood that early diversity is resolved.

Experience has shown broader gauges to be generally better than narrower, causing regret in regions where narrow gauges emerged as standards.

More often, experience has caused regret over the emergence of diversity, which has generated costs first of coping with breaks of gauge and then, sometimes, of converting whole regions.

The world's existing railway track inventory comprises 1 144 000 route kilometres, of which narrow or meter gauge (914 to1 067mm) accounts for 16,6%, standard gauge (1 435mm) for 60.2%, and broad gauge (1 520 to 1 676mm) for 23.2%.

The lack of interest in international standardization is clearly evident in the adoption of broad gauges during the late 1830s and 1840s by the Netherlands (1 945 mm), the German grand duchy of Baden (1 600 mm.), Russia (1 524 mm), and Spain (1 672 mm). Sooner or later, most of these countries came to regret their choices.

Spain's (and Portugal's) choice mattered relatively little until the recent integration of Spain and Portugal into the economy of the European Union.

In 1862, Norway pioneered the development of narrow-gauge railways. There was an unrealistic belief that narrow gauges had the ability of to make sharper curves and follow the contours of rugged or mountainous landscape thereby reducing the need for costly tunnels, cuttings, bridges, and embankments. Beginning in the 1870s, narrow gauges were widely used for lines in the Alps and other mountains as well as for extensive systems of light railways used to bring agricultural produce to market in several parts of Europe. (Cap Gauge and Cape Gauge)

In North America a “narrow-gauge fever,” based largely on the same unrealistic expectations of cost savings, led to the construction of over 20,000 miles of 3'0” (914 mm.) and 3'6” track. The costs of breaks of gauge, together with the financial failure of a “National Narrow-Gauge Trunk” in 1883, led to a sharp decline in new construction.

Puffert[1] found that regions where railways were introduced by the 1860's adopted either standard gauge or broader gauges. Regions where railways were introduced after the 1860's adopted standard gauge or narrower. Because railway builders differed in their preferred gauges, diversity emerged as local common-gauge networks of different gauges came into contact.

Japan is noteworthy for introducing new diversity in recent times. Finding its 3'6” gauge unsuitable for high-speed service, Japan introduced standard gauge in 1964 for its Shinkansen “bullet”-train system.

The origin of the 3'6” gauge is ascribed to the Norwegian civil engineer Carl Abraham Pihl. This gave rise to the term “CAP-gauge” and also “Kapspur” in German. Later on it became more widely known as “Cape-gauge”.

The first four railway lines completed in South Africa between 1860 and 1867, totalling 110km, were all built to standard gauge.

The Cape- and Natal governments then adopted the 3'-6” gauge (1 067mm) between 1871 and 1875, because they thought it to be more economical to construct through mountainous terrain. By 1881, they had converted the existing lines to 3'-6”, and subsequent railway construction proceeded accordingly.

The report provides an account of the use of the different gauges throughout the world and describes the important break of gauge problems that exist inside a number of countries as well as at cross border operations.

The abilities of different gauges are compared focusing on narrow gauge and standard gauge and evaluates aspects such as land requirements, curving, speeds, vehicle and structure profiles and maintenance requirements.

Various countries made important decisions in recent history to add new systems of a different gauge to their system. Others grappled with the decision to change or not to change their gauge. These are discussed with the various reasons behind such decisions.

The role of rail in the market place together with current macro trends is summarized.

Facts about railways in South Africa are followed by the divergent views on the gauge issue of the more important role players in the country

CONTENTS

1. HISTORICAL DEVELOPMENT OF RAIL GAUGE

1.1. Background

In many parts of the world diversity in gauge arose and, often, persists to this day. Australia and Argentina each have three different regional-standard gauges, although this is recognized as a costly hindrance to national commerce. India, Japan, Chile, and several other countries each make extensive use of two gauges. “Breaks of gauge” hinder through-service across numerous international borders, including that of France with Spain and most external borders of the former Russian and Soviet empires.

The United States and Canada had six gauges in widespread use until the 1880s. Now only a few relic tourist lines use variant gauges. Britain’s extensive Great Western Railway system used a variant gauge for over 50 years before completing its conversion to the gauge of neighbouring systems in 1892.

Similarly, the original gauges of the Netherlands, the earlier German state of Baden, and much of Norway gave way to the common standard that emerged in most of western and central Europe. In recent decades, Australia and India have made substantial progress in reducing their diversity of gauge.

The engineer George Stephenson transferred the gauge from a primitive mining tramway to the Liverpool and Manchester Railway.

Nevertheless, there appear to be systematic reasons why regional standards have given way to larger-scale standardization in some countries and continents but not in others.

The article investigates how regional standard gauges have arisen, persisted, and in some cases been superseded. The chief economic issue at stake has been the extent of standardization and diversity, not the selection of suboptimal gauges. At least some gauges in use are suboptimal, as most railway engineers hold that the optimal gauge for most applications is somewhat broader than the common Stephenson gauge of 4 feet 8.5 inches.

Puffert[1] investigated the historical emergence of regional standard railway track gauges.

He found that a path-dependent economic process in which specific contingent events - and not just fundamental determinative factors like technology, preferences, institutions etc - have a persistent effect on the subsequent course of allocation. Such contingent events, reinforced by positive feedbacks, determined both particular standards and the geographic extent of standardization in Britain, Continental Europe, North America, and Australia.

Most of the information under §’s 1.1 and 1.2 was obtained from Puffert’s paper and is often repeated verbatim.

In reviewing the history of gauge, he concludes that contingent events and positive feedbacks played a major role in deciding which particular gauges became the local standards of particular regions.

As the costs of diversity increased, systematic incentives and optimizing behaviour greatly reduced this diversity, but in some cases early contingent diversity persists to the present.

Common Elements to the History

Among the common elements to different regional histories was the mix of incentives governing choice of gauge.

Firstly, railway builders, operators, and in some cases regulators have had preferences over specific gauges, based on perceptions of the technical performance characteristics of different gauges.

Secondly, agents have nearly always valued compatibility with neighbouring railways, adopting established gauges where they existed.

The first incentive has been a source of variation in gauge practice; the second incentive a source of commonality of practice through positive feedbacks among the choices of different agents.

Historically, an interest in compatibility was often relatively weak in the early years of railways. Railway builders did not foresee the future value of long-distance railway transport, and thus they placed little value on compatibility with previous lines, except for those nearby.

Equipment supply - particularly of locomotives - seems to have affected only a few choices in Europe and one in North America, as suppliers offered equipment for all the usual gauges and also built to order.

Early choices of gauge were generally made by individual local railway companies or governments, with little regard for the effects of their choices on others. Later, cooperation and the formation of interregional railway systems led to increased coordination of choices, often facilitating the resolution of early diversity.

Puffert[1] seeked to capture these incentives in a modelling framework in order to shed further light on the underlying dynamic of the gauge selection process.

Some of his findings were:

- The gauge that happens to be chosen by the first line built tended, on average, to be adopted by nearly two-thirds of all the lines built thereafter.
- The impact of early gauge choices depended on the line's location within the lattice.
- Historically, newly preferred gauges have been able to get a foothold only where previous railways are sparse.
- Some railway builders had strong preferences for a specific gauge.
- The conversion cost relative to network integration benefits has a substantial effect on the likelihood that early diversity is resolved.

The gauge now used on nearly 60% of the world's railways, like other gauges, was not primarily the result of fundamental incentives, systematic optimization, or a market test but rather of a series of contingent events – even of historical accidents – reinforces by positive feedbacks.

Experience has several times refuted expectations that a new variant gauge would offer technical advantages outweighing the cost of diversity. Experience has also shown broader gauges to be generally better than narrower, causing regret in regions where narrow gauges emerged as standards.

More often, experience has caused regret over the emergence of diversity, which has generated costs first of coping with breaks of gauge and then, sometimes, of converting whole regions.

1.2. In The World

Principal Railway Track Gauges, 2000

Gauge		Major countries and regions	% of world total [1]	Gauge Grouping
English (ft.-in.)	Metric (mm.)			
2'6"	762	China* [2], India*	1.7	
3'0"	914	Colombia, Guatemala, Ireland*	0.6	NARROW (NG)
3'3.37"	1000	East Africa, Southeast Asia*, Argentina*, Brazil*, Chile*, India*, Pakistan*, Spain*, Switzerland*	8.8	
3'6"	1067	Southern Africa, Southeast Asia*, North Africa, Middle East* [3], Australia*, Japan*, New Zealand, Newfoundland	9	
4'8.5"	1435	Europe*, North America, North Africa & Middle East*, Argentina*, Australia*, Chile*, China*, Japan*	58.2	STANDARD (SG)
5'0"	1524	Former USSR, Finland, Mongolia	12.8	BROAD (BG)
5'3"	1600	Australia*, Brazil*, Ireland*	1.2	
5'6"	1676	Argentina*, Chile*, India*, Pakistan*, Portugal & Spain [4]	7	

Notes: *Countries or regions with more than one gauge.
[1] Percentages add to less than 100% due to additional, rare gauges
[2] 750 mm, [3] 1055 mm, [4] Originally 1672 mm; now 1668 mm
Sources: *Jane's World Railways*; *Railway Directory and Yearbook*

Emergence of continental networks in Europe and North America around the late nineteenth/early twentieth century encouraged differently gauged railways on those continents to convert to standard gauge to participate in the benefits of wide-area networking. Except for limited re-gauging to achieve- or extend networkability, no further continental-scale re-gauging took place until the Indian Railways embarked on its Unigauge (broad gauge) project in the 1990s.

Britain

Great Britain was the first country to develop modern railways, and events there had a world-wide impact. A large variety of gauges were used for the primitive railways that developed in mining districts, including 4'8" (1 422 mm.) on a small group of lines. The gifted mechanical engineer George Stephenson performed early experiments with steam locomotion during the 1810s. In recognition of his broad abilities, Stephenson was asked to build the two railways that together introduced a new era of construction and operating practice, the Stockton and Darlington Railway, opened in 1825, and the Liverpool and Manchester (L&M) Railway, opened in 1830. Stephenson used the same 4'8" gauge as before—except for adding half an inch (13 mm.) between the rails to allow for more space between rails and wheel flanges.

Stephenson gave no particular thought to the question of optimal gauge but rather simply followed precedent. Stephenson's friend and biographer Samuel Smiles (1868, p. 424) wrote that the gauge "was not fixed after any scientific theory, but adopted simply because its use had already been established."

The Stephenson gauge was adopted for the sake of traffic exchange by an expanding network of lines that soon branched out, because other engineers accepted it as representing best practice, and because specification of the gauge was briefly a standard feature of parliamentary acts to authorize new railways.

In the mid-1830s, however, some British locomotive builders found their ability to develop increasingly powerful, easily maintained engines constrained by the 4'8.5" gauge, while certain civil engineers expected that a broader gauge would promote improved stability, smoothness of ride, speed, and capacity. As a result, a few short lines adopted 5’0” (1 524 mm.) and 5’6” for what they initially expected to be isolated local networks. When the lines were reached by the expanding Stephenson-gauge network, they converted immediately.

Brunel, builder of the extensive Great Western Railway (GWR) system west of London, was convinced that a quite broad gauge of 7’0” (2134 mm.) was needed for the full development of railway technology. Brunel thought that his system would be independent but was soon proved wrong on the importance of breaks of gauge. GWR was able to manage the diversity in a relatively rational, efficient way, in part by using mixed gauges - three-rail track - on trunk routes serving both gauges. From 1868 to 1892, the GWR progressively converted to the Stephenson gauge.

Continental Europe

Belgium, France, Austria, and several of the then independent German and Italian states adopted the Stephenson gauge (later referred to as “standard” gauge) during the mid- to late 1830s. In other places local engineers either accepted the gauge as one element of current best practice or else simply fitted their track to British locomotives. Some of the German states apparently followed the prior choices of others, as an integrated German railway network was part of the pan-German economic program. Prussia was interested in a common-gauge link to France.

The lack of interest in international standardization is clearly evident in the adoption of broad gauges during the late 1830s and 1840s by the Netherlands (1 945 mm.), the German grand duchy of Baden (1 600 mm.), Russia (1 524 mm.), and Spain (1 672 mm.).

Sooner or later, all of these countries came to regret their choices. The Netherlands found itself losing trade to Belgium due to the latter country’s well-developed railway system and common-gauge connections to Germany. When Prussia expressed interest in a common-gauge connection to Amsterdam and Rotterdam in the early 1850s, the Netherlands converted.

Russia’s choice began to be costly during the 1860s, when the main Russian network advanced into Russian-ruled Poland, which had adopted the Stephenson gauge in 1839 in order to gain an outlet for international commerce through Austria to Trieste as an alternative to the Prussian-controlled mouth of the Vistula.

Spain’s (and Portugal’s) choice mattered relatively little until the recent integration of Spain and Portugal into the economy of the European Union. An estimated cost of (U.S.) $5 billion has prevented conversion, but Spain is reducing the cost of hoped-for future conversion by introducing dual-gauge prefabricated concrete cross-ties during routine track maintenance. Spain adopted the Stephenson (Standard) gauge for its high-speed train lines for the sake of a future connection to France’s TGV, at the cost of an awkward diversity of gauge within the country today.

In 1862, Norway pioneered the development of narrow-gauge railways. By this time the main difficulties in locomotive design that had previously favoured broad gauges had been resolved, and it became possible to take advantage of the ability of narrow gauges to make sharper curves, following the contours of rugged or mountainous landscape and reducing the need for costly tunnels, cuttings, bridges, and embankments. The narrow gauge was confined to lines north and west of Oslo that were expected to be used primarily for local traffic, but a new focus after 1900 on developing a nationally and internationally integrated network led to the gradual conversion and upgrading of these lines.

Beginning in the 1870s, narrow gauges were widely used for lines in the Alps and other mountains as well as for extensive systems of light railways used to bring agricultural produce to market in several parts of Europe.

North America

Builders of the earliest North American railways also regarded the Stephenson gauge as best practice, but they interpreted this practice loosely, introducing gauges of 4'10" (1473mm.) and 5'0", as well as 4'8.5", between 1830 and 1832. During these earliest years, railways were seen as inferior substitutes for waterways, used for routes where canal construction was impractical. They served strictly local purposes, and their builders did not foresee the later importance of a precise common standard. The gauge of 4'8.5" was introduced by far the most often in new regions, including by the great majority of the scattered early lines in the south-eastern United States. Nevertheless, the major network spanning that region happened to develop as a series of lines connecting to the original 5'0"- gauge railway, and this became the regional standard gauge. Similarly, the network of the eastern Midwest (chiefly Ohio) expanded from a single 4'10" line, forming a barrier between Stephenson-gauge regions to the east and west.

There is no clear case where equipment supply determined gauge in North America, as manufacturers supplied all major gauges and also built to order.

From 1838 to the early 1850s, builders also introduced broad gauges of 6'0" (1828 mm.) and 5'6" for what they thought would be self-contained systems. Indeed, in two cases, these gauges were chosen not only for their presumed technical superiority but also precisely because they differed, for the purpose of controlling regional traffic. However, as interregional traffic grew greatly in importance, the variant gauges served much more to keep traffic out of the systems than to keep traffic in.

As a result of these early events, nine different common-gauge regions emerged by the 1860s, including three separated regions using the Stephenson gauge. This diversity was resolved over the period 1866-1886 as a result of three developments: the strong growth in demand for interregional transport, including for the shipment of Midwestern grain to the seaboard; the growth of cooperation among separately owned lines; and the consolidation of interregional trunk line systems under common ownership.

Even as the early diversity was being resolved, a "narrow-gauge fever," based largely on unrealistic expectations of cost savings, led to the construction of over 20,000 miles of 3'0" (914 mm.) and 3'6" track. The costs of breaks of gauge, together with the financial failure of a "National Narrow-Gauge Trunk" in 1883, led to a sharp decline in new construction, but some local systems remained in service for several decades (Hilton, 1990).

Australia

Australia offers an example of institutional failure in the emergence and persistence of gauge diversity. In the early 1850s, the colony of New South Wales first chose 5'3" (1600 mm.) as its gauge and persuaded Victoria and South Australia to adopt the same measure. Then New South Wales changed its chief engineer and followed his recommendation to change the planned gauge to 4'8.5". Victoria, which had already ordered equipment from Britain for the broader gauge, appealed to the British colonial administration to intervene, but the latter applied the principle of *laissez faire* in refusing. The estimated cost of remedying the resulting diversity rose, as equipment was purchased and track was laid, from £15,000- £20,000 in 1853, when breaks of gauge were a distant prospect, to £2.4 million in 1897 and £12.1 million in 1913, when they were becoming costly. Efforts to resolve the diversity were long hindered by disputes over how the separate government-owned systems should divide the costs (Harding, 1958). From 1957 to 1982, the national government sponsored new standard gauge routes to form a nationwide system linking state capitals. During the 1990s, Victoria and South Australia converted their most major routes, and more conversions are expected to follow.

Rest of the World

The patterns of gauge selection in Latin America, Africa, and Asia are addressed here only in very broad strokes.

Regions where railways were introduced by the 1860s adopted either the Stephenson standard gauge or broader gauges; regions where railways were introduced after the 1860s adopted the standard Stephenson gauge or narrower. Because railway builders differed in their preferred gauges, diversity emerged as local common-gauge networks of different gauges came into contact.

Japan is noteworthy for introducing new diversity in recent times. Finding its 3’6” gauge unsuitable for high-speed service, Japan introduced standard gauge in 1964 for its Shinkansen “bullet”-train system. Since 1990, this diversity has hampered efforts to expand high-speed service and integrate the Shinkansen system into the rest of Japan’s network. Some short sections of track have been converted to standard gauge or to dual gauge.

1.3. In South Africa

Martin[3] extensively chronicled the origins and world-wide distribution of 3’6” railways. Like Stephensen is often honoured as the “father” of the 4’8½” gauge, Martin ascribes the origins of the 3’6” gauge to the Norwegian civil engineer Carl Abraham Pihl. This gave rise to the term “CAP-gauge” and also “Kapspur” in German. Later on it became more widely known as “Cape-gauge”.[8]

Zoutendyk[4] made an extensive study of the origin of railways in South Africa. He pointed out that the first four railway lines completed in South Africa between 1860 and 1867, totalling 110km, were all built to standard gauge (4’-8½”, or 1 435mm).

At that time 3’6” gauge railways were operating successfully in Norway, Queensland and Canada. Being aware of this fact[3], the then Cape- and Natal governments adopted the 3’-6” gauge (1 067mm) between 1871 and 1875, because they thought it to be more economical to construct through mountainous terrain. By 1881, they had converted the existing lines to 3’-6”, and subsequent railway construction proceeded accordingly[4].

Today South Africa has a total of 22 300 route km of mostly 1 067 mm NG track.

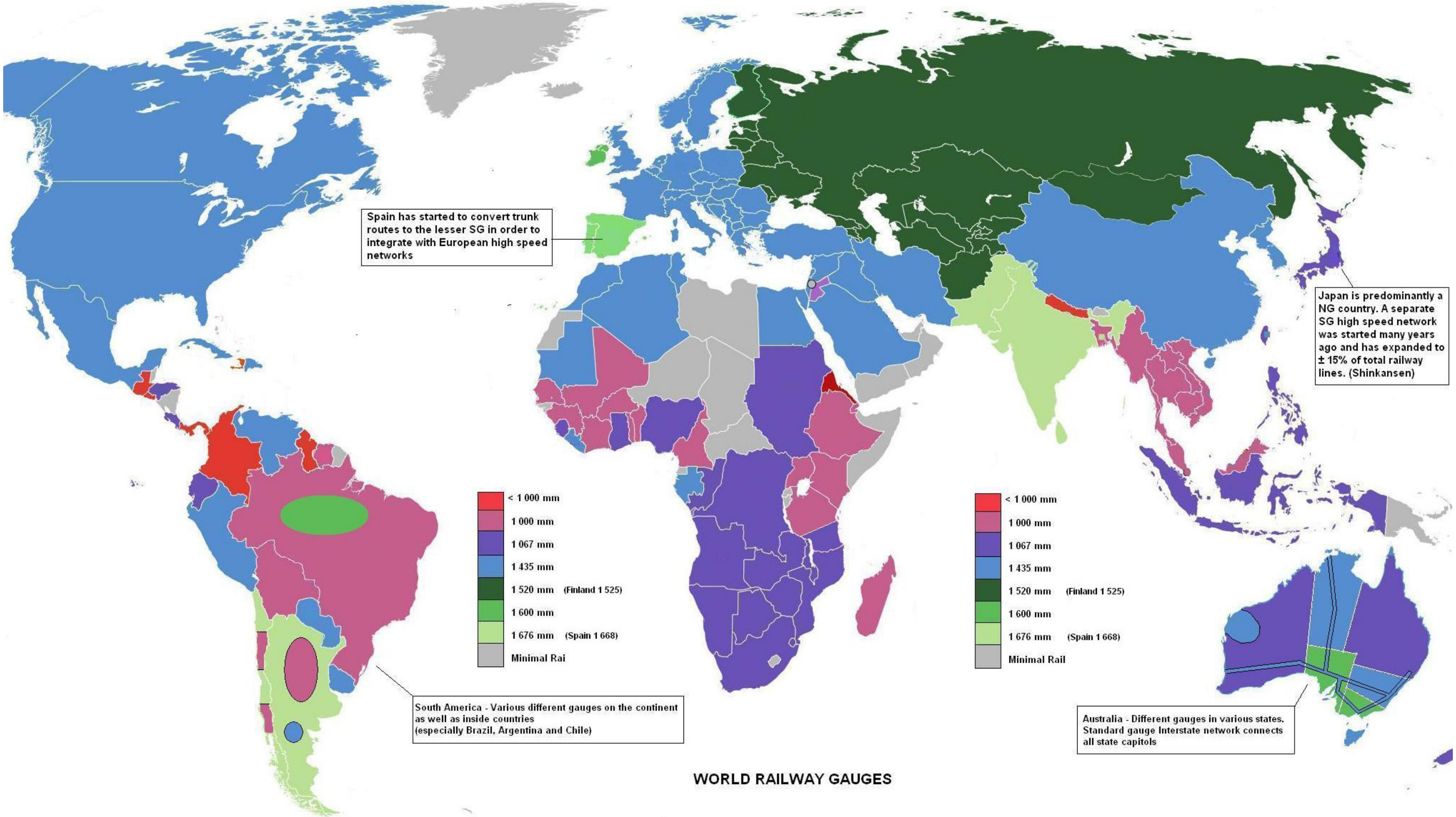
2. THE USE OF DIFFERENT GAUGES IN THE WORLD

2.1 General

The following table provides a list of route lengths in the more prominent gauges in use in the world[5,6]. Routes of less than 1 000 km are excluded from the list.

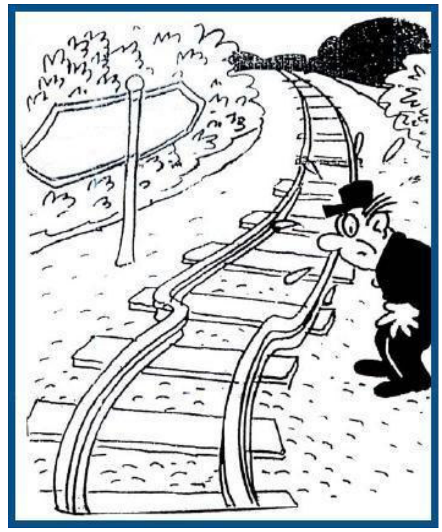
Gauge mm	1 000	1 067	1 435	1 520	1 600	1668/76
Country	NG		SG	BG		
(> ± 1 000 km only)	Kilometers					
Algeria		1 085	3 138			
Angola		3 000				
Argentina	7 600		2 739			24 028
Australia		18 988	16 042		4 301	
Austria			5 602			
Azerbaijan				2 116		
Bangladesh		1 822				883
Belarus				5 507		
Belgium			3 518			
Bolivia	2 743					
Bosnia			1 028			
Botswana		888				
Brazil	24 688		194		4 916	
Bulgaria			4 037			
Cameroon	1 016					
Canada			66 828			
Chile	3 339					3 870
China			72 404			
Colombia	1 470					
Congo, Dem.Rep.		3 641				
Cote D'Ivoire &	1 260					
Croatia			2 674			
Cuba			4 066			
Czech Rep			9 421			
Denmark			3 251			
Egypt			5 024			
Estonia				1 583		
Finland				5 861		
France			29 343			
Georgia				1 525		
Germany			45 991			
Ghana		953				
Greece			1 672			
Guinea	936		236			
Hungary			8 036			
India	14 024					47 193
Indonesia		4 552				
Iran			5 906			
Iraq			2 032			
Ireland					2 229	
Israel			679			
Italy			18 012			
Japan		23 030	3 459			
Kazakhstan				13 760		
Kenya	1 918					
Korea North			5 200			
Korea South			3 354			
Latvia				2 270		
Lithuania				1 753		
Malawi		797				
Malaysia	1 667					
Mexico			17 251			
Moldova				1 098		
Mongolia				1 815		
Morocco			1 907			
Mozambique		2 974				
Myanmar	4 677					
Namibia		2 382				
Netherlands			2 811			
New Zealand		3 898				
Nigeria		3 505				
Norway			4 183			
Pakistan						7 346
Peru			1 724			
Poland			19 568	395		
Portugal						2 630
Rumania			10 882			
Russia				86 660		
Saudi Arabia			1 394			
Senegal	905					
Slovakia			3 561	100		
Slovenia			1 229			
South Africa		22 300				
Spain	1 637		931			11 878
Sri Lanka						1 463
Sudan		4 578				
Sweden			10 537			
Switzerland			4 167			
Syria		347	1 801			
Taiwan		1 104				
Tanzania	3 000	1 581				
Thailand	4 071					
Tunisia	1 762		496			
Turkey			8 967			
Turkmenistan				2 313		
Uganda	1 241					
Ukraine				23 000		
United Kingdom			41 318			
Uruguay			1 629			
USA			218 554			
Uzbekistan				3 986		
Vietnam	2 237					
Zambia		2 232				
Zimbabwe		2 898				
Totals	80 191	106 555	676 796	153 742	11 446	99 291
Percentage	7%	9%	60%	14%	1%	9%
	1 128 021					

According to the RailRoad Association (RRA)[2], the world's existing railway track inventory comprises 1 144 000 route kilometres, of which narrow or meter gauge (914-1067mm) accounts for 16,6%, standard gauge (1435mm) for 60.2%, and broad gauge (1520-1676mm) for 23.2%. These figures differ slightly but not materially from the table above. The RRA figures are more recent.



The diagram of world rail gauges presents the position in graphic format

2.2 Break of Gauge



Gauge discontinuities are an issue in many regions[7].

Asia and Europe have an extensive rail network comprising more than 50% of the world's railways. There are many cross border rail connections and a significant number are plagued with this "***Break of Gauge***" issue

This is the case where China connects to Russia / Kazakhstan and South East Asia. Similar problems occur where Russia connects to Europe / China and the Middle East and where Europe connects to Spain and Portugal.

Australia with less than 5% of the world's railways has a mix of gauges ranging from the NG 1 067 mm to the 1 600 mm BG. They have unified their interstate network to 1 435 mm gauge but continue to operate with three different gauges in the country.

In Africa with about 6% of the world's railways, narrow gauge dominates the railway scene. There is an important break of gauge where the 1 067 mm SADC region railways join the 1 000 mm Tanzania/Kenya/Uganda- network in Tanzania.

North America has about 27% of the world's railways. The 1 435 mm standard gauge is dominant in Canada, USA and Mexico. Consequently there is no break of gauge problem in North America.

South America also has about 6% of the world's railways, in a variety of gauges. Both cross border- and national networks are limited by break of gauge problems.

3. NARROW, STANDARD AND BROAD GAUGES – FACTS AND CAPABILITIES

3.1 General

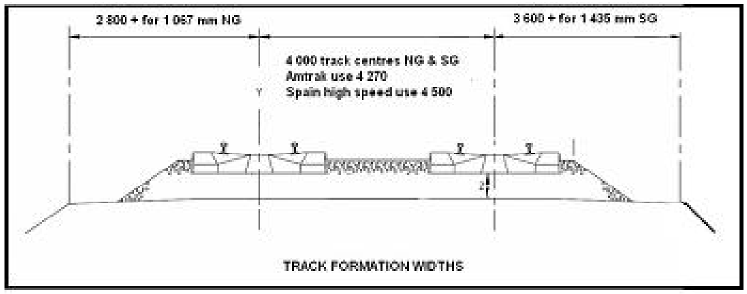
Low speeds and modest capacity were considered realistic and adequate for the railway needs of under developed countries in the late 19th century. The cost of heavy structures and rolling stock could not be justified. Conventional wisdom of that time was that such railways could be built cheaper in the narrower gauges than the Stephensen gauge that later became the world's "standard" gauge.

Lower standards in route location and track foundations (sharper curves, steeper grades and limited attention to material selection, compaction and drainage) as well as lighter track structures and rolling stock thus found their way into those first narrow gauge railway lines.[8]

Scientific and engineering analysis made by Zoutendyk[3] in 1978 indicated that the economic considerations that informed the 1871 decision to standardize on 1 067mm were fallacious. He called it an "unfortunate blunder" as the 4'-8½" gauge would have facilitated greater stability, passenger comfort, higher speeds, less restriction on locomotive design and easier availability of rolling stock.

3.2 Land Requirements

There is very little difference in land requirements for SG and NG. Track centres are similar at a nominal 4 000mm. Higher speed lines go to 4 500 mm as is the case in Spain. Amtrak in the USA use 4 270mm. The distance from the centreline to the edge of the formation is a function of the gauge difference (370mm), ballast shoulder and depth and standards chosen for width of the walkway between the toe of the ballast and the edge of the formation.

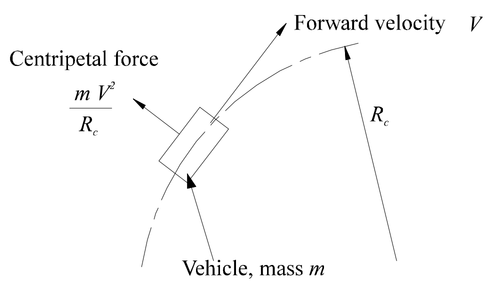


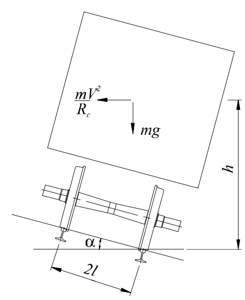
All of this adds up to a negligible percentage of normal railway reserve widths.

Formation widths can thus be about 400 to 1 000mm wider for SG of which 370mm can be attributed to the difference in gauge. . This will add some-what to the cost of construction.

3.3 Rolling Stock Stability

It's an elementary physical truth that similar railway vehicles are more stable on wider track gauges. This is best understood when analysing speeds around curves as per the following diagrams[9].





Overturning speed

$$V = \sqrt{gR_c\left(\frac{\ell}{h} + \tan\alpha\right)}$$

The formula provides the critical overturning speed for a rigid vehicle. The actual situation is complicated by the fact that vehicles are not rigid. The actual overturning speed for a sprung vehicle is generally about 20% below that provided by the above simplified formula.

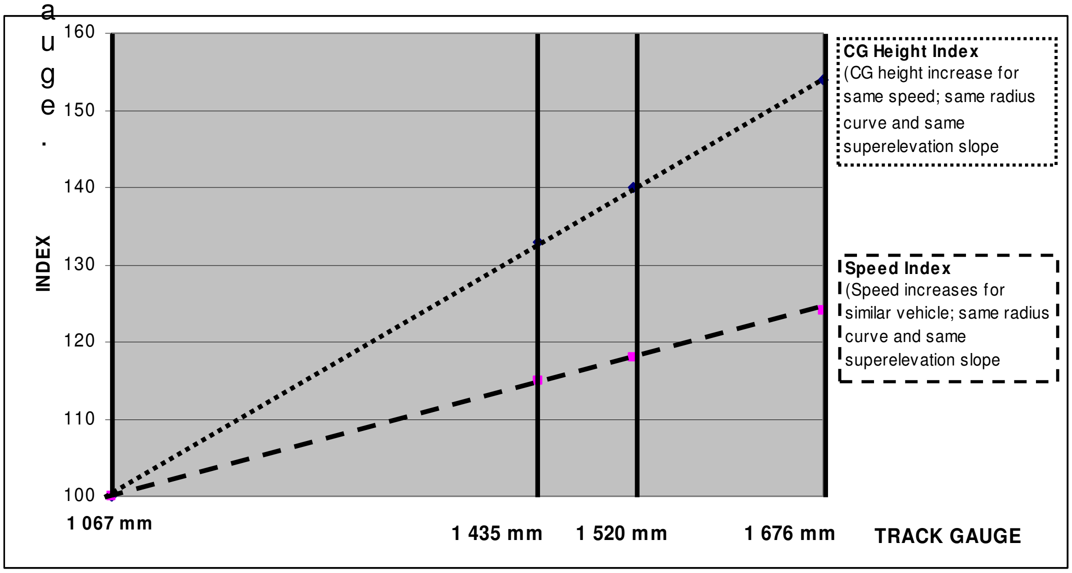
For reasons of safety and passenger comfort, maximum permissible speeds on curves are limited by a factor of safety to a level below the overturning speed[10]. This permissible value is generally about 50% of the theoretical rigid vehicle overturning speed. In practice this equates tot about 65% of the sprung vehicle overturning speed.

Inspection of the basic formula for overturning speed indicates that for similar vehicles (constant h), same radius curve (constant R) and same superelevation slope (constant α), overturning as well as safe speeds ***will increase roughly with the square root of the ratio by which the gauge is increased***.

Likewise for the same speed (constant V), same radius curve (constant R) and same superelevation slope (constant α), ***the acceptable height of the vehicle centre of gravity above rail height may be increased in direct proportion to the ratio by which the gauge is increased***.

The diagram below summarises some of these facts and indicates that:

- The same vehicle but with a wider wheel base can run about 15% faster around a same radius curve on 1 435 mm gauge (compared to 1 067 mm gauge). This value increases to around 23% when comparing 1 676 mm gauge with 1 067 mm gauge.
- The same speed can be achieved around a same radius curve on 1 435 mm gauge with 32% higher centre of gravity (compared to 1 067 mm gauge). This value increases to more than 50% when comparing 1 676 mm gauge with 1 067 mm gauge.



It would appear unlikely that double stacking of loaded containers on narrow gauge wagons will become feasible[6].

3.4 Track Structure

Track gauge does not influence the choice of rail section and except for length, sleeper design is also based on track gauge independent criteria.

Wider gauge railway lines do however have a larger foot print to assist with load distribution to the underlying foundation layers. This larger foot print should be taken into account conservatively because of the nature of ballast tamping machines. The centre portion of the sleeper provides minimal to zero vertical support but load distribution to subgrade layers is somewhat favoured by the wider placement of wheel loads in the SG situation.

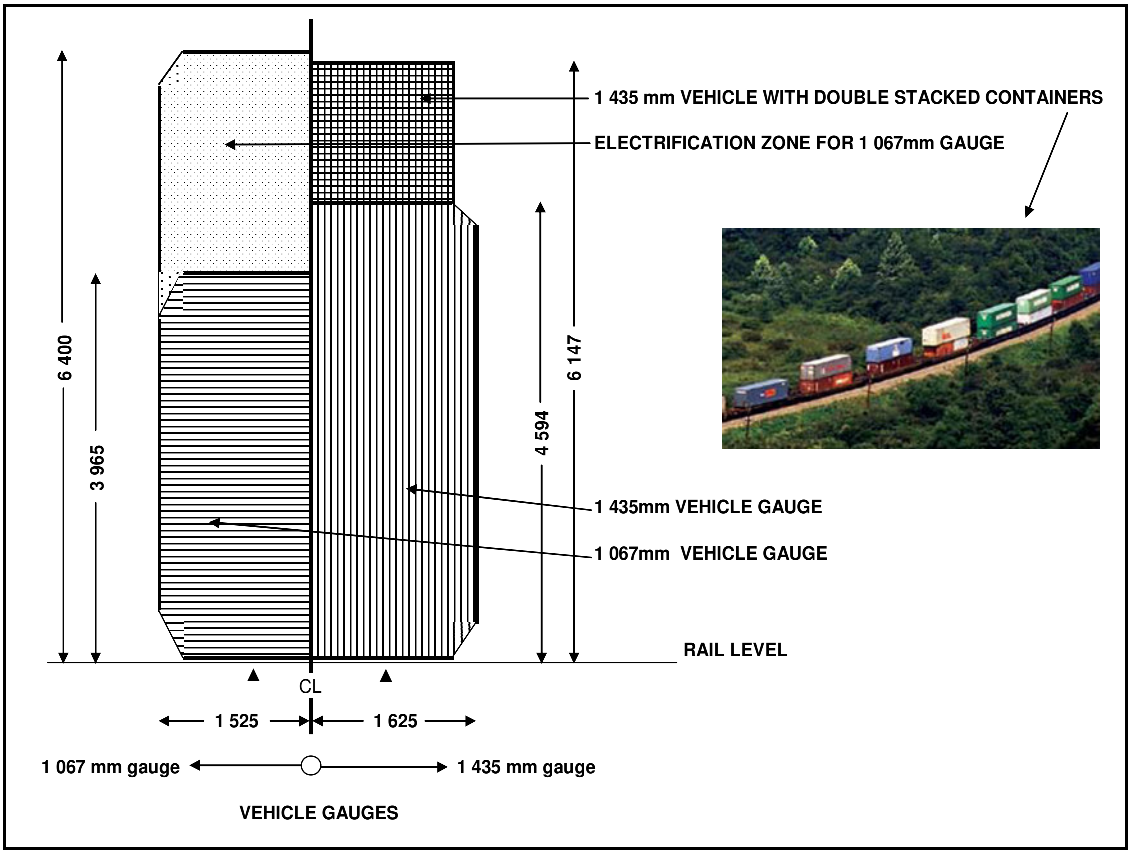
3.5 Vehicle Profiles

The vehicle width profile for SG vehicles is 200 mm (or 6,5%) wider than the standard on South Africa's NG[11,12] (3 250 vs. 3 050 mm wide). Japan Freight Rail allow 3 200 mm on their NG[6].

The North American Railways further operate box cars up to 629 mm (or 16%) higher above rail level than the maximum on South Africa's NG (4 594 vs. 3 965 mm). Japan Freight Rail allows 4 300 mm on their NG[6].

Whereas all core lines in South Africa use electrified traction, North America predominantly use diesel traction. This, together with the extra stability provided by their standard gauge, allows them the option of double stacking containers for increased line capacity and lower unit costs.

The following diagram is self explanatory.

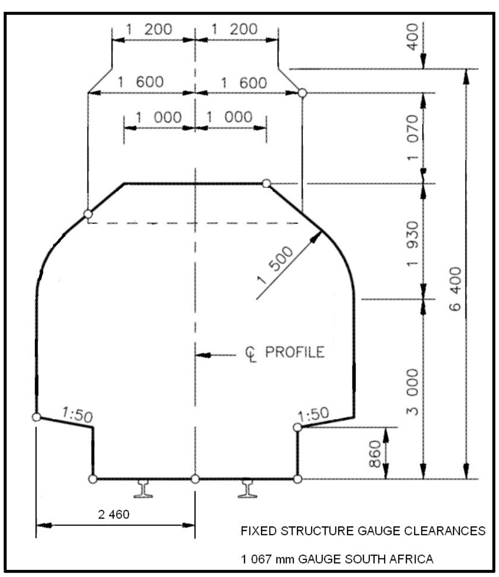


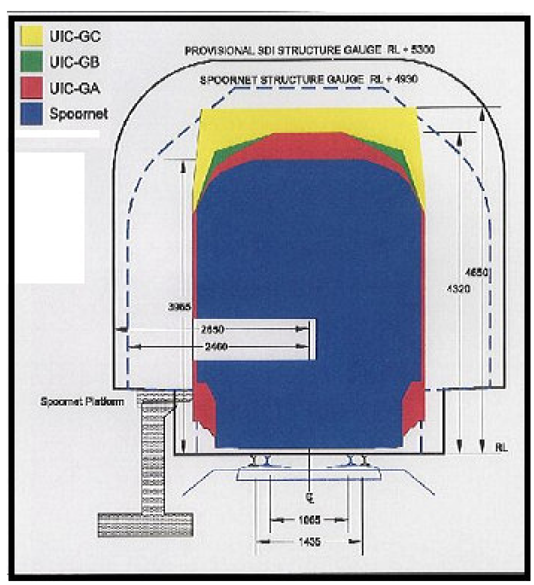
3.6 Structure Profiles

(i) Width of Formation & Structures (see §3.2)

(ii) Fixed Structure Clearances[11,14,22]

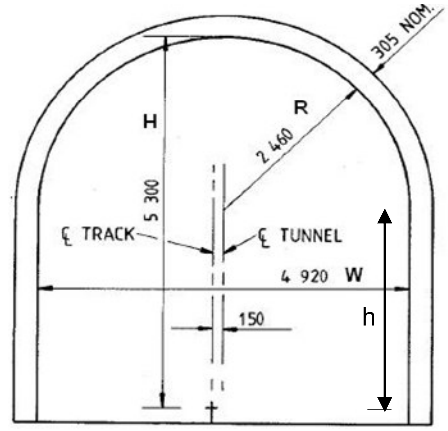
The diagrams below provide the fixed structure gauge clearance standards applied on NG in South Africa as well as the UIC standards used mainly in Europe. These are about 190 mm wider on each side of the track centre line and 390 mm higher.





(iii) Tunnels[28]

Dimensions of tunnels in South Africa vary according to date of construction. There are more than 160 tunnels with a total length of about 110 km of which 98% are on lines classified by Transnet as core lines.



STRAIGHT

Period	H	W	R	h	∆H	∆W
1982 -	5 300	4 920	2 460	2 840	0	0
1973 - 82	5 300	4 920	2 460	2 840	0	0
1968 - 73	5 181	4 825	2 996	3 200	- 119	- 95
1966 - 68	4 977	4 724	2 895	3 007	- 323	- 196
1947 - 66	4 928	4 572	2 286	2 642	- 372	- 348
1918 - 47	4 876	4 572	2 286	2 590	- 424	- 348
< 1918	4 876	4 267	2 134	2 742	- 424	- 653

(iv) Track Centres (see §3.2)

3.7 Design loading for Bridges & Structures

The design of bridges and structures are based on a moving line load. This is determined primarily by axle load and axle spacing. For a given axle load, the design load is independent of the gauge of the track. However, to the extent that standard gauge axle load could be higher than narrow gauge axle load, it would be necessary to examine the ability of existing bridges and structures to carry such higher axle load if a line were re-gauged to standard gauge with a view to simultaneously increasing axle load.

3.8 **Capacity**

The capacity of a line is a function of various aspects. A few more important ones are:

- Vehicle profile (of which vehicle height and vehicle width are subsets)
- Vehicle length
- Axle load (related to payload per wagon and load-to-tare ratio)
- Length of train
- Speed
- Operational efficiency in terminals and at crossing places
- The train authorisation system

Except for speed, none of these is gauge dependent. Heavy freight and suburban trains generally operate in the 80 to 100 km/h range whilst heavy intermodal trains in North America run at 120 km/h, other restrictions permitting.

The heaviest freight axle loads are currently operated on the standard gauge Australian iron ore lines (40t compared to 30t on the similar Transnet narrow gauge line). Train lengths are also gauge independent. In this case Transnet is currently operating the longest freight trains in the world on its Sishen-Saldanha line[13] (342 wagons and almost

4 km in length). This is however also purely a matter of investment in technology and suitable hardware and equally achievable on wider gauges.

The international standard container with a width of 2 400mm also fits comfortably on NG wagons.

Height wise SG has a 16% advantage and can therefore run bigger wagons with more payload whilst they can also employ container double stacking.

3.9 **Speed** (also refer to §3.3)

In terms of speed NG has a disadvantage compared to SG.

Railway development in undeveloped countries was mostly of a pioneering nature during the late 19th and early 20th Centuries. This resulted in relatively low geometric and formation design standards.

Faced with increasing demand, the normal response of railway operators is to invest in larger and heavier locomotives and wagons and to operate at higher speeds. In some countries, these demands, coupled with need for much improved operating efficiency, have resulted in ongoing programs of track and bridge strengthening, deviations to improve vertical and horizontal alignment, improved clearances, upgraded signalling and (in some cases) electrification. These developments have greatly increased the physical capability of some narrow gauge railways[6].

Today advanced NG lines such as JR Freight (Japan), QR (Australia) and Transnet Freight Rail (TFR) operate specially equipped light to medium freight traffic at speeds of 100 – 120 km/h. QR and TFR operate their world class heavy haul trains at speeds of up to 80 km/h (similar to SG heavy haul).

The current maximum speeds on NG for passenger traffic is 160 km/h on QR (tilt trains), 130 km/h on JFR and 100 km/h on TFR. During the eighties Spoornet operated a regular 150 km/h service between Pretoria and Johannesburg (known as the Metroblitz).

Both Spoornet and QR had undertaken regular test runs at 200 km/h and up to a maximum of 256 km/h. Hearsch[6] projected regular 200 km/h operations on NG railways as likely in the foreseeable future.

Curvature standards present major limitations for high passenger train speeds. Current standards for new railway lines on TFR are to limit the minimum radius of curves to 750m. At that radius of curvature there will be no speed restrictions on a 100 km/h line.

On SG the passenger speed profile in Europe currently hovers around 300 to 350 km/h. At that level minimum curve radii are specified between 4 000 to 7 000m[14]. Even at 4 000m radius, speeds are limited on the European high speed lines to below 300 km/h.

Lateral acceleration parallel to the floor of the coach determines passenger comfort. These curve limitations are governed by passenger comfort rather than any risk of overturning.

Given the reality that very high speed train operations generally require either new or substantially reconstructed infrastructure, most projects of this nature are likely to opt for standard gauge track[6].

3.10 Maintenance

There are no meaningful differences regarding rolling stock maintenance per vehicle that are gauge related. Narrow gauge fleet sizes are however generally significantly larger to perform a given task. This results in proportionately higher maintenance costs.

Narrow gauge track however requires stricter geometric twist standards and therefore a stricter maintenance regime than standard or broad gauge track for speeds of similar proportions. For example, given variations in track geometry (outside of normal tolerance) can have relatively more serious consequences than on wider gauge railways[6].

Lateral resistance of the track is also inherently weaker than for comparable standard and broad gauge track structures. Therefore, it can degrade more quickly and may require additional monitoring and maintenance input in some circumstances. It also therefore requires more intensive measures to prevent buckling in high ambient temperatures[6].

In terms of accuracy of lifting and aligning, track maintenance machines for different gauges have similar absolute capabilities.

One can therefore expect to find a nominal cost penalty in comparing track maintenance costs of NG with SG for similar operations.

4. COUNTRIES THAT ADDED NEW SYSTEMS WITH A DIFFERENT GAUGE

There are a number of examples of countries that became multi-gauge countries by adding an important new system with a different gauge. Some introduced a wider and others a narrower gauge. The five examples presented below all have one common denominator – their choice for the additional system fell on standard gauge.

In discussing and comparing various other countries with South Africa, some insight into key comparative parameters is useful. The table below is included to provide such perspective[5,15]

#	Country	Size	Population	GDP pp	Route distance	Rail pass journeys	Rail Freight	Rail Coverage	
								Area	Population
		Sq km (000)	(000 000)	US$	Km	(000 000)	(000 000)	km/10³ km²	km/m people
1	South Africa	1 000	50	3 897	23 000	4	176	23	460
2	Japan	380	100	37 647	26 489	14 763	42	70	265
3	Spain	505	40	23 450	14 446	567	40	29	361
4	India	3 000	1 000	673	61 217	5 217	502	20	61
5	Kazakhstan	3 000	10	2 563	13 760	15	228	5	1376
6	Australia	8 000	20	29 237	39 331	48	587	5	1967
7	Taiwan	36	20	5 000	1 104	191	15	31	55
8	Nigeria	924	100	420	3 505	3	3	4	35

Note
1 Main line intercity journeys in RSA = ± 4 million p.a
Commuter journeys per annum in RSA = ± 500 million p.a

4.1 Japan[16]

Up to the 1950s, railways in Japan consisted predominantly of a 1 067 mm NG network.

Serious and accelerating limitations developed in transport capacity along Japan's main arterial corridor between Tokyo and Osaka. At that stage this corridor was home to 40% of Japan's population, 70% of its industrial output and 60% of the national income.

Being a country with more than 20 000 km of 1 067 mm NG it was only natural to first consider a new but compatible NG line. In the end it was decided to build a totally separate and independent line. Out of this flowed the choice of standard gauge as it was considered necessary for stability at high speed. It also permitted complete modernisation without any limitations to fit existing equipment. This unleashed the development of a whole suite of new technologies.

In response to the capacity problems of the Tokaido corridor, Japan then opened the 515 km standard gauge Tokaido Shinkansen high-speed railway between Tokyo and Osaka just prior to the 1964 Olympic Games in Tokyo. This opened a new era in transport, that triggered a global boom in high-speed rail. Today the Shinkansen network has grown to more than 3 000 km whilst speeds have increased from the initial 200 km/h to more than 300 km/h.

The high-speed rail map of the world now also includes France, Germany, Spain, Belgium, Italy, Britain, Korea, US, and Taiwan, while Russia and Turkey have lines under construction, scheduled for completion in 2009.

About 35% of the original 515 km was on viaducts (93 km), bridges (19 km) and in tunnels (65 km) with a minimum curve radius of 2 500 m. This in itself was unique for that period in railway history.

The Tokyo Olympics boosted the Tokaido Shinkansen and it notched up 100 million passenger journeys within 3 years by 1967, and passed the billion mark after only 13 years in 1976.

The latest version of the train has active tilting. This will enable it to overcome the speed limitations of the original 2 500 m radius curves.

Today Japan operates about 300 trains per day on a Shinkansen network of more than 3 000 km and carries more than 120 million passengers per year – with legendary safety and punctuality. There are some minor extensions of the Shinkansen network onto the narrow gauge network, where dual gauge track is used.

Japan's 23 000 km of 1 067 mm NG network remains the backbone of its railway network and carries even more passengers than the SG Shinkansen. Together with QR (Australia), Vale (Brazil) and Transnet Freight Rail, Japan remains one of the prominent NG operators in the world.

Japan is thus an example of a country ***adding*** *an additional separate network of standard gauge. The initial decision was triggered by the need to overcome serious capacity problems. The wider gauge was chosen to provide a more stable platform for the high speeds envisaged.*

4.2 Spain[17,18,19,20,21,49]

Spain operates a 12 800 km broad gauge (1 668) national rail network as well as 1 022 km standard gauge (1 435mm) high-speed lines, which is fast expanding. Seven different organisations are also operating a total of 1 956 km of narrow gauge (1 000mm) lines.

Spain has a major break-of-gauge problem where it joins the rest of Europe on the French border. The whole of Europe operates on 1 435mm SG. It became obvious that the proliferation of high-speed train networks in Europe would marginalize Spain. Liberalization of open access to allow international freight train operators exacerbated the problem.

Spain decided that rail should play an important role in its future transport needs. In 1988 it decided to change the gauge of its broad gauge network from 1 668mm to 1 435mm, and to build a new dedicated, standard gauge, high-speed (350 km/h maximum) passenger network, which will link the main centres of Spain as well as linking Spain with France and the rest of Europe. Two high speed lines, with standard gauge, totalling 1 022 km are already completed while extensive expansion work is in progress. Trains will run at 350 km/h on dedicated high-speed corridors and, at 200 km/h on mixed use corridors.

A 15-year transport and infrastructure strategic plan for Spain (PEIT) was unveiled in July 2005. The plan calls for a massive investment of €250 billion of which half will go to rail. This will result in a 10-fold expansion of the high-speed rail network by 2020.

PEIT is designed to represent a change in transport policy, and to provide Spain with a more efficient and sustainable transport network. The plan seeks to convert the rail network into the central element of the passenger and freight inter-modal system. PEIT defines high-quality lines as high-speed, double-track, electrified, and standard-gauge lines.

High-speed lines totalling 9 000 km are planned over the next 15 years compared with the 1 000 km built over the past 15 years. By 2020 90% of the Spanish population will be less than 50 km from a high-speed station. The objective is to make rail more competitive with road for journeys of more than 300 km, and with air for trips below 700 km.

They decided to change their broad gauge (1 668mm) track of 12 800 km over a period of 40 years to standard gauge in order to be compatible with the high-speed system and the rest of Europe. So in the long run (40 years) Spain is aiming to move from uni-gauge (1 668) to multi-gauge and eventually back to uni-gauge (1 435mm).

Temporary axle and bogie change over facilities are provided and will be moved as the change of gauge on a line progresses.

To deal with the transition period they are building new and converting existing lines to dual gauge, and use gauge convertible locomotives and rolling stock.

The new lines are 25kV AC 50 Hz electrification, while the older lines use 3kV DC. To overcome the changing of locomotives they are purchasing dual voltage locomotives.

In 2005 the freight business unit operated 440 locomotives and 16 054 freight wagons.

Rolling stock operating beyond the French border passes through either a bogie-changing facility or a gauge-changing facility.

Portugal’s national railway (as distinct from urban rail systems) has become an insecure railway—it never was a star, and Spain’s change to standard gauge will further threaten it, except for the few standard gauge links that are planned to be built. It will be worth studying what influence Spain’s gauge change has on Portugal. The answer could be relevant for South Africa’s influence on its neighbours.

Spain is thus an example of a country deciding to (initially) add a separate network of a narrower gauge (SG) in order to integrate with the rest of Europe. In addition Spain decided to scale the gauge of their entire network ***down*** *from BG to SG over a 40 year period. This will obviously take place in various stages. The trigger was the need to eliminate the break-of-gauge with the rest of Europe for freight and especially to become part of the European high-speed passenger network.*

4.3 Gautrain[22]

The planners evaluated two possible track gauges for the Gautrain. The dominant South African narrow gauge of 1 067mm used by Transnet Freight Rail and the SA Rail Commuter Corporation was weighed up against the 1 435mm SG as used on 60% of the world’s railways.

Gautrain studies indicated that regular in-service speeds in excess of 130 km/h are very rare in the world on narrow gauge.

As all their technical evaluations pointed to the superiority of standard gauge, it was concluded that the SG (1 435) would be the best choice.

The only reason to consider NG (1 067) would have been compatibility with the existing rail commuter network. Technically compatibility was considered as a negative rather than a positive in the sense that linking to the existing rail commuter network was likely to have a negative influence on the performance of the Gautrain Rapid Rail Link.

Other considerations that also swung the decision in favour of using SG included the following:

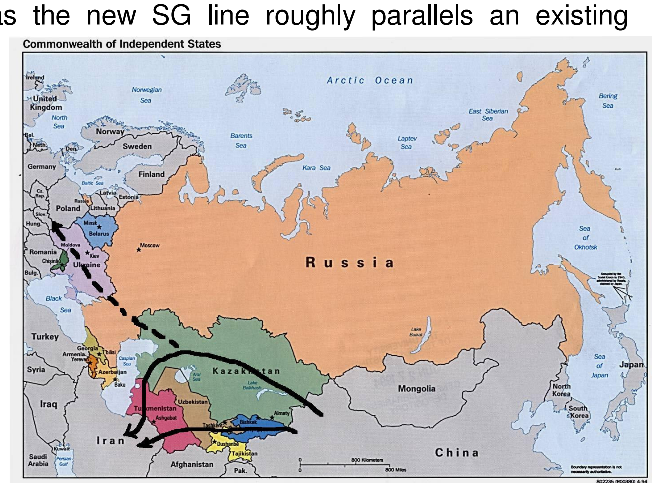
- The area to be served by the Rapid Rail Link is reasonably discrete and stands alone, generally remote from existing rail networks except at the termini.
- Standard gauge is well to the forefront in worldwide acceptability and usage.
- Other narrow gauge countries like Japan and Taiwan also chose SG for their high-speed lines.
- It was considered that the running of the old low performance trains on the new system would have a negative impact on the total Gautrain Rapid Rail Link system.
- As the SARCC network in the study areas was already running at almost full capacity, the Gautrain services would in any event have to operate independently on new tracks.
- Standard gauge is more tolerant of track imperfections, thus leading to reduced maintenance requirements.
- As there are a significant number of existing and successful train set concepts and designs in the world based on standard gauge, it was anticipated that train sets could therefore be purchased “off the shelf” at savings upward of 10%.
- The cost of standard gauge track was estimated at R1,8m per km (mid 2000) as compared to R1,6m per km for Cape gauge, a premium of 12,5%. This is due to the need for more ballast and for longer sleepers. The additional cost to the project of approximately R29m was considered relatively minor in the context of the overall project cost.

In many ways the Gautrain example mirrors the Japanese decision for their Tokaido corridor in the 1960’s. Like Tokaido, the Gauteng corridor also represents the hub of South Africa’s economic activities. And like Japan, South Africa is adding an additional separate network of a wider gauge (SG) and also with completion being pressured by an upcoming major world event.

4.4 **Taiwan**[22,23]

Taiwan has about 1 000km of NG railway. In 2007 they opened the new 346km long high-speed standard gauge line along the west coast between Taipei and Kaohsiung. Speeds will build up to 300km/h.

The Taiwan example is interesting as the new SG line roughly parallels an existing 1 067mm NG gauge line along its entire length. Taiwan like Japan, introduced standard gauge track to acquire the ability to run at high speed.



4.5 Kazakhstan[24,26]

Kazakhstan, in common with all the, former members of the Soviet Union, has a broad gauge (1 520mm) rail network oriented to Moscow.

The BG Trans-Siberian-Railway is currently a growing landbridge moving traffic from Japan and China to Europe. Such traffic still has to cope with breaks of gauge upon entering into the European SG network, and depending on origin, between China and Russia.

Russia has already ruled out changing the Russian BG to SG[25].

Sea routes between China's fast growing economy and European markets have serious drawbacks (Ship size and congestion limitations via Suez and up to 50 days to go via the Cape of Good Hope).

Kazakhstan saw a strategic opportunity to create a standard gauge landbridge from China (SG) to Europe (SG). Construction commenced in 2003 on the standard gauge Trans-Kazakhstan Railway. The first section started from the Chinese border for a distance of 320 km. The shortest route would have been to connect to Iran's SG network via Turkmenistan. This would nevertheless have exceeded 3 000 km! The strategic 1 520mm gauge partnership formed late in 2006 has effectively aborted this proposal for now[40].

An alternative and shorter option would be to connect China to Iran via Kyrgyzstan, Tajikistan, Uzbekistan and Turkmenistan. The political problems are likely to be even greater whilst the very mountainous topography will severely increase the cost. Nevertheless, construction has commenced on some portions.

Kazakhstan is an example a country introducing an additional (narrower) gauge in the hope of commercial gain by bridging and plugging into the attractive Asia-Europe commercial routes.

5. IMPLICATIONS OF MULTI-GAUGE SYSTEMS

5.1 General (also refer to §2.2)

When systems of different gauges operate as separate systems there is no break of gauge. Where break of gauges occur on a freight or passenger transport corridor, operational and time consuming problems add to the cost of transport. Railways all over the world deal with this in a variety of ways:

- ***Transhipment***

  Freight is loaded from train to train or from train to ground and later from ground to train in a transhipment yard.

  This procedure works best when containerised freight is moved directly from train to train.

- ***Bogie changing***

  The wagon or coach is retained whilst the bogies are swapped out underneath the rolling stock using lifting equipment.

- ***Dual gauge rolling stock (Variable gauge wheelsets)***[27]

  Gauge-adjustable wheelsets use advanced technology where the wheels can move along the axles to accommodate a different gauge. During a slow forward motion through a tapered transition installation, the wheels are guided mechanically to slide and then locked into the new position. It's an expensive system that has to be fitted to every bogie and adds unsprung mass.

It is mostly used in Europe/Asia to bridge the break of gauge problem between Russian BG (1 520mm) to European SG (1 435mm). The difference is only 85 mm in gauge. At 368 mm, the difference between SG and NG (1 067) is substantially more, and the mechanism potentially more complicated.

Japan could use such a system and has developed a solution based on Spanish technology. Plans to implement it commercially do not yet seem to have materialized.

- ***Platform crossing***

  Human "trans-shipment" where passengers walk from train to train.

- ***Dual and multi gauge track***[8]

  A solution where three or even four rails are fixed to one sleeper to effectively create two or even three track gauges on more or less the same centre line. This alleviates the problem but the extra hardware and complicated turnouts and signalling systems add to infrastructure costs.

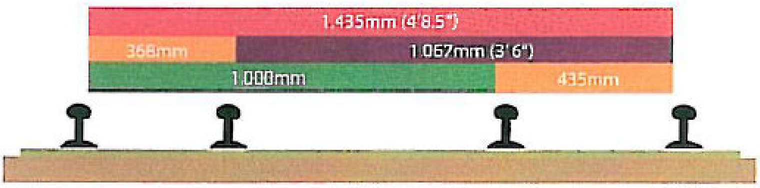


Diagram showing how four of the rail gauges used in different countries on the African continent can be arranged to use the same route by laying four rails on the same set of sleepers. By this means the expense of changing the gauge of a railway and its rolling stock is avoided.

In several countries, trains of two or more different gauges are able to use the same route by providing mixed gauge track.

5.2 How Rail Systems deal with multi-gauge problems

All countries saddled with mixed gauges use one or more of the above mentioned processes. Transhipment is the most common and range from elementary to extensively mechanised systems depending on the volumes to be handled.

Bogie changing and gauge adjustable wheelsets are mostly used on the SG to BG interfaces at international borders between France and Spain, and between Europe and the Commonwealth of Independent States.

A notable example in the SADC region can be found in Tanzania where transhipment is the method used where 1 067mm gauge meets the 1 000mm gauge network of Tanzania, Kenya and Uganda.

6. COUNTRIES WHERE GAUGE WAS OR WILL BE CHANGED

6.1 General

Going back to distant history, even South Africa will be found on the list of countries where gauge was changed. (see § 1.3). The purpose of this section is to discuss countries that changed in recent history or who have taken a firm decision to change in the near future.

6.2 Spain

The situation in Spain is discussed in §4.2. For the interim Spain has actually added SG lines to their BG network. But they have also embarked on a 40 year program to migrate most of their lines from BG to SG.

Once they made the decision that rail transport would play an important role in their country's future, they had to get rid of their operational isolation from the rest of Europe (railway wise) Their plans are driven by the need to become part of Europe's high speed network and to eliminate the break of gauge and its associated problems on their border with France.

6.3 Australia

Australia has three different track gauges (1 067mm NG in Western Australia and Queensland, 1 435mm SG in New South Wales, and 1 600mm BG in South Australia and Victoria).

The different gauges were always a major impediment to the flow of freight between States. It took 140 years for Australia to overcome its gauge problem on its interstate links. The interstate standard gauge network was completed in 1995, with the conversion of the Melbourne-Adelaide broad gauge line. The SG network of the NSW state was extended to connect all the state capitals. This required gauge conversion andsome dual gauging (especially on the West Australian NG network, and the South Australia and Victoria BG networks). A new standard gauge line was built to connect Darwin in the north to this network. Apart from the national SG network the rest remained largely as before. Their railway heritage is discussed in §1.2.

In 1999 the State of Victoria decided to eliminate the inefficiencies due to double handling at breaks of gauge by converting their more important 2 000 km of BG to SG. By 2005 the estimates for track and rolling stock almost trebled to A$359 (± R2.3bn). The benefits were in doubt and the Auditor-General severely criticized the project for having spent 14% of the budget on consultants by 2006 whilst showing zero physical progress[30].

Apart from a short SG connection from NSW into Brisbane, Queensland is physically separated from the Australian SG network. It has remained a NG rail network carrying more than 100Mt/a on ± 10 000 km. Japan, South Africa and Queensland are the Big 3 in NG terms (1 067 mm) based on track length and volume of traffic. Queensland is continuing to expand in NG-terms despite having SG inside its doorstep. (Other big players in the NG field but in the 1 000 mm gauge grouping are Brazil and India)

Along with Japan, Queensland also operates tilting passenger trains on NG. This takes place on the Brisbane to Rockhampton and Brisbane to Cairns routes (1 680 km)[32]. The trains are capable of tilting up to 5 degrees and runs at speeds up to 160 km/h. Tilting trains do not make curving safer or more stable against over turning but makes it more comfortable for the passenger. Passengers are sensitive to lateral acceleration parallel to the floor of the coach. A 5 degree tilt on NG is equivalent to ± 100mm increase in track super elevation. Tilting trains can accordingly negotiate the same curve at higher speeds than conventional trains. The gain in speed is of the order of 10 – 20km/h.

6.4 India[33, 34]

India is predominantly a BG (1 676mm) country. The 16 000km NG (1 000mm) lines form less than 25% of its network. India is steadily converting its NG lines to BG under its "unigauge" policy which envisages the eventual conversion of all non-broad gauge lines. The aim is to reduce the inefficiencies of operating across breaks of gauge.

6.5 Kazakhstan

Kazakhstan attempted to add a new SG route with a specific strategy in mind (refer to § 4.5). Economic and political forces in the Community of Independent States however kept them aligned with Russia's 1 520mm BG hegemony.

Kazakhstan is thus more a case of adding a gauge than changing gauge.

6.6 Thailand[29]

The Thai Ministry of Transport announced in 2006 that it is to investigate options for widening the country's 1 000mm NG to the SG 1 435mm. The purpose would be to handle the increasing freight demand and to raise passenger train speeds.

An earlier study in about 2003 put the cost at US$1bn to convert Thailand's 4 000km network.

Should the move take place it would mean that cross-border traffic to neighbouring countries would face a change of gauge back to 1 000mm, increasing transit times and operational costs

Thailand should be seen in the context of the so-called Trans-Asian Railway, from Kunming in China, through Vietnam, Cambodia, Thailand, and Malaysia, to Singapore. At present there are missing links, and some existing portions would not contribute meaningfully to the whole. It is therefore questionable whether there will ever be wholesale gauge conversion in ASEAN countries, so some portions could well be lost. One could argue that the Trans-Asian does not make sense in meter gauge, and the concept is thus likely to remain in limbo until such time as a pro-standard gauge decision is taken..

6.7 Nigeria[35, 36, 37, 38, 39]

Nigeria is the only example that could be found where it was decided to convert their current NG (1 067mm) network to SG. The network is 3 505km long and in 2000, carried 2.6 million tons of freight and 54 million passengers.

In 2003 the railway press already reported on Nigeria's 25-year strategic plan of US$40bn to upgrade the railway. In 2006, it was reported that plans had been approved to rebuild a 1 010km line to standard gauge at a cost of US$8.3bn. It was to be funded in part by a loan from China.

The plan envisaged maximum speeds of 150 km/h for passengers and 80 km/h for freight.

Most of the network is said to be more than a 100 years old. Passenger train speeds are limited to 30 km/h. The rail infrastructure is outdated and poorly maintained. The signalling system is similarly obsolete. Most of the locomotives and rolling stock are old and inadequate and cannot guarantee appreciable service delivery.

The 25-year strategic vision for the development of rail in Nigeria was supposed to be implemented in three phases, starting in 2002 and ending in 2027. Part of this modernisation includes the conversion to standard gauge. To date financial and contractual problems have prevented any physical progress.

It is clear that the run down condition of the rail network coupled to its limited extent (also compare relevant country figures in the table in §4) is placing Nigeria in a position to make a gauge decision almost as if it were a green fields situation.

Nigeria is bounded by four countries of which two have no railways (Niger and Chad) whilst the other two (Cameroon and Benin) operate small 1 000mm narrow gauge networks presenting already existing breaks of gauge.

7. COUNTRIES THAT DECIDED NOT TO CHANGE GAUGE

This is largely a recap of information from previous paragraphs.

7.1 Russia and Surrounding Countries[25, 40]

In 2006 then Russian President Putin ruled out any possibility that Russia would convert any of their almost 90 000 km of BG (1 520mm) to standard gauge as used by Europe to its west and China to the south-east. Russia decided to continue heavy investment in upgrading and expanding their network.

Late in 2006 a railway business forum involving all the former Soviet Union states was held in Kazakhstan. The forum concluded that 1 520mm gauge should become the consolidating force to unite all rail operators in the Commonwealth of Independent States (CIS) and Baltic States to work together on key routes, common IT systems, and to overcome border issues.

This has effectively sidelined for now Kazakhstan's proposal to develop a standard-gauge landbridge between China and Iran.

7.2 Japan

In the 1960's Japan embarked on a high speed network in SG dedicated for passenger trains. This network has grown to more than 3 000km.

Today Japan still operates, develops and invests in its 20 000km NG network. Small portions of it has been dual gauged to permit access for SG rolling stock, and other small portions of it have been re-gauged to standard gauge, both to allow Shinkansen trains to access cities/towns off the main Shinkansen network.

8. WHY RAILWAYS CHANGE GAUGE

8.1 General

The literature revealed several reasons why gauge was changed, or a new gauge added in recent history. The main reasons are listed below.

8.2 Compatibility with other systems

Prime examples are:

- Spain - cross border break of gauge (adding SG and moving from BG to SG)
- Australia - internal breaks of gauge (adding SG & converting some NG and BG to SG)
- India - internal breaks of gauge (converting most NG to BG)

8.3 Speed (higher stability)

Prime examples are:

- Japan - add extensive SG high speed dedicated network for passenger trains
- Taiwan - add SG high speed dedicated line for passenger trains
- South Africa - add SG medium speed Gautrain line for passenger trains
- Argentina - planning to add SG high speed dedicated line for passenger trains.

8.4 Avoid compatibility with other Systems

The Gautrain project is such an example where it was considered that the running of the old low performance trains on the new system would have a negative impact on the total Gautrain Rapid Rail Link system.

The Gautrain vehicles will also have a much higher performance profile than the present SARCC vehicles and therefore it was considered advisable to keep the two systems separate.

8.5 All round better and more available technology

Only one example could be found in the literature reviewed of a country deciding to make such a change as far as freight railways is concerned. Although there has been no physical progress to date, Nigeria has decided to replace their NG network with SG. Being a small network (3 500 km) in an old and run down condition, this is virtually comparable to a green fields scenario.

There were also reports in the railway press suggesting that Thailand (4 000 km NG) was investigating a similar strategy.

On the other hand high speed intercity passenger rail as well as urban rail is converging on standard gauge – both in broad and narrow gauge countries.

8.6 Load

No examples were found where a desire for higher axle loads or larger loading profiles influenced decisions to change an existing gauge or to add a new one. Countries wanting to move into double stack container trains will have to consider the better stability provided by wider gauges. No such examples were found in the literature.

8.7 Availability of Rolling Stock

This was one of the more important reasons for choosing SG for the Gautrain.

9. THE ROLE OF RAIL IN THE MARKET PLACE

9.1 **General**

Standard gauge dominates the world railway scene by sheer volume comprising more than 60% of the world's railways. It is also the dominant gauge in the world's developed countries of North America and Europe. Russia and the CIS together with India operate on different broad gauge systems.

Despite arguable technical superiority, broad gauge opposes the critical mass of standard gauge. Network economics predicts that market dominance will outweigh technological advantage[43].

9.2 Global trends[41, 42, 43]

Railways cannot match the ubiquitous access of their most aggressive competitor, road transport. Railways must demonstrate alternative strengths to attract customers.

Three genetic technologies distinguish railways from other transport modes - ***Bearing***, which supports carrying heavy axle loads; ***Guiding***, which supports running at high speed; and ***Coupling***, which supports scaling conveyance, i.e. train, configuration to meet capacity requirements. Exploiting these genetic technologies to the limits of their respective technologies, either individually or in mutually reinforcing combination, and progressively extending those limits as technology advances, enable railways to position themselves in market niches where they confidently dominate other transport modes

Through exploitation of these genetic technologies, railways came to dominate the heavy haul (bulk commodities), high speed intercity (passengers), and heavy intermodal (double-stacked containers) market spaces.

Of applications that strongly exploit rail's genetic technologies (heavy axle load, high speed, and long trains), only heavy haul is present on NG with South Africa and Queensland and to some extent Brazil, as examples.

Introducing the outstanding railways' competitive applications (double-stack container trains and high-speed intercity services) into NG countries will, as a minimum, require overcoming the constraints of their narrow track-gauge technologies.

Successful railways differentiate themselves from competing transport modes, rather than competing head-to-head against them, by avoiding settings where rail cannot exploit the strengths of its genetic technologies. They compete in three niches, so distinct that they are virtually separate transport modes:

- Heavy haul competes against sources in *other countries*, with <1 000km hauls and aggressive cost reduction.
- High-speed intercity competes against road and air in the 300-1 000km mobility niche.
- Heavy intermodal competes against *other modes* in the 3 000-12 000km niche between road- and maritime

The pace of railway development for the last four decades has been set by heavy haul, high speed intercity, and heavy intermodal.

Double-stack container trains are an extension of the heavy haul application to general traffic routes, rather than raising the axle-load bar. Narrow- and diverse track gauges do however not support the high centre of gravity that associates with double stacking.

9.3 **Urban and suburban rail systems**

The differences between line-haul railways and urban railways are substantial enough to warrant taking separate positions on track gauge for each of them[44].

Urban rail is a low speed, low axle load, railway application that derives its competitive strength from being able to couple vehicles to maximize capacity. There is therefore no compelling reason to change track gauge, and existing track investments in a country such as South Africa could still serve adequately for many years.

Where interoperability with national railways is not a compelling requirement, it is a global trend in urban rail, to consider standard gauge for new integrated infrastructure- and rolling stock projects, to minimize technical and financial risk, and to benefit from the lower cost of standard rolling stock designs in volume production. The Gautrain project is a local manifestation of that trend.

9.4 SADC

All SADC countries operate 1 067mm NG railways with thus no break of gauge with South Africa. Deep into Tanzania there is a break of gauge where the 1 067mm tracks meet with the rest of Tanzania, Kenya and Uganda's 1 000 mm gauge tracks.

10. COUNTRIES THAT APPEAR NOT TO HAVE CONSIDERED GAUGE CHANGE

The foregoing material is based on a review of countries that either changed their track gauge or introduced a different track gauge, or that considered one of the preceding alternatives and decided not to proceed. They represent a particular subset of the world's railways, whose behaviour has been captured in the public domain, which source of primary data can be used for a study such as this.

A second subset of the world's railways, not directly reviewed but nevertheless referenced by implication, is those countries that have standard gauge. Whether fortuitously or by appropriate strategic adaptation, they happen to have a track gauge that supports entry to the heavy haul (bulk commodities), high speed intercity (passengers), and heavy intermodal (double-stacked containers) market spaces, and many of them have successfully exploited one or more of those opportunities. Their behaviour has also been captured in the public domain, and therefore also provides primary data for a study such as this. Many of them have been clustered as Enlightened Railways, Progressive Railways, or Assertive Railways[49].

There exists also a third subset, namely those countries whose railways have not enjoyed the strategic freedom to exploit one or more of the market spaces that rail can dominate. There could be several reasons for them being strategically challenged, such as being set on islands that have no opportunity to network widely, low axle load and low speed, and a downward spiral of unsustainability that precludes implementing competitive technologies. Their behaviour has not been explicitly captured in the public domain, and it would therefore be fallacious to assert that no evidence could be found of railways not changing gauge to enter one or more of the heavy haul, high speed intercity, and heavy intermodal market spaces, without including this subset in the study. In many instances such railways have not been able to adapt simply because they are inherently unsustainable, and do not have the economic and/or political wherewithal to rise from the circumstances to which lack of competitiveness has relegated them. Their position is nevertheless significant in a study that compares countries that have changed track gauge with those that have not. The present literature study did not include the third subset, and therefore drew no conclusions about them.

The third subset generally does not attract research, possibly because there is very little to research. However, one study that compared the world's total line-haul railway population[49], which thus included all three subsets, found a cluster named Insecure Railways. It contains countries whose railways have no strong attributes but have low competitiveness, i.e. low maximum axle load and -speed; no distributed power-, heavy haul-, high-speed intercity-, and heavy intermodal presence; and low networkability. They failed to leverage any of rail's competitive strengths, and therefore lacked attributes with which to project a distinctive corporate citizenship. They could hence be vulnerable to external threats or withdrawal of political support. It is significant that many countries in this cluster have narrow gauge railways[50].

11. FACTS ABOUT THE RAIL NETWORK IN SOUTH AFRICA

11.1 **Transnet** [28,47]

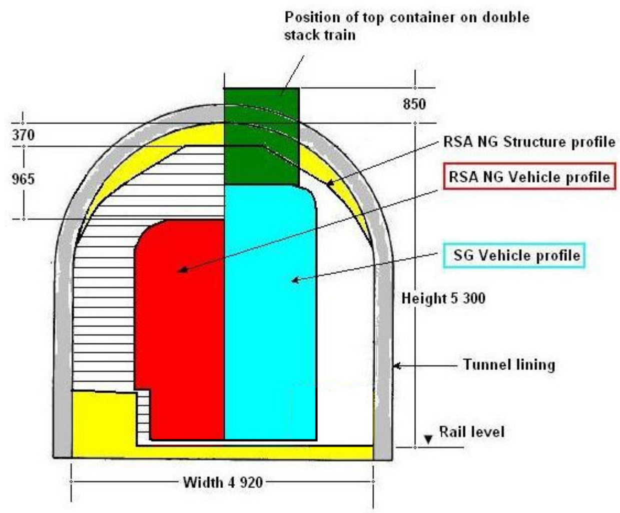
Transnet has about 15 000 km classified as Core Lines, a further ± 6 000 km of Branch Lines and about 3 000 km where the lines have been picked up or where no services are provided.

There are about 150 tunnels of 110 km total length on the core lines. About 20 of these exceed 1 km in length with a total length of 48km. The longest tunnel is 13,5km long.

The latest generation tunnel profile is presented in the diagram. Both the width and height are less for tunnels constructed before 1973. (See §3.6 for more details).

The latest generation tunnel profile appears to be suitable for the height of standard gauge vehicle profiles. Clearances in curves might be a problem and will require special investigation.

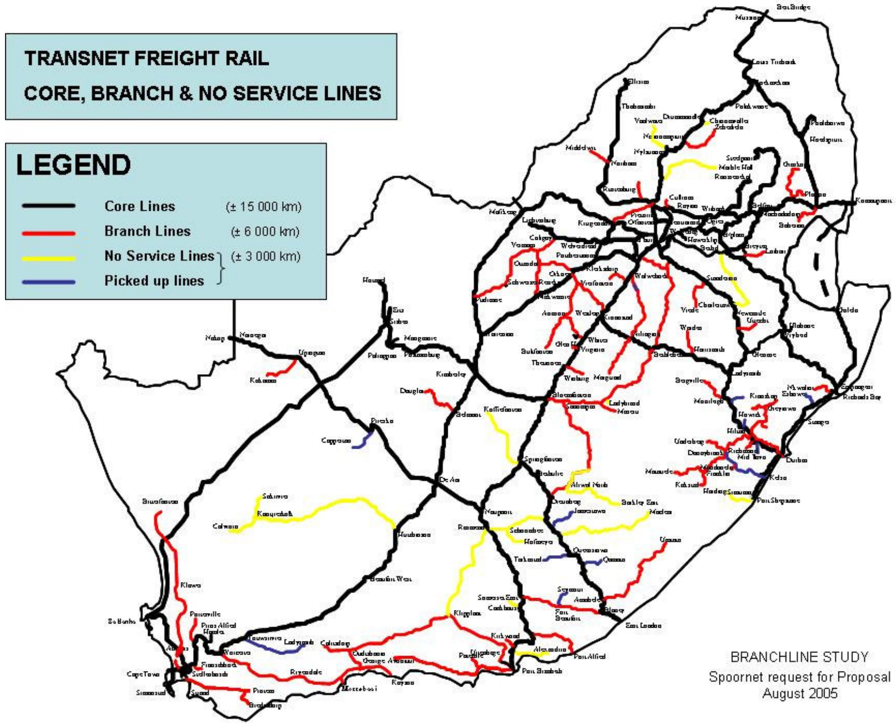
There is no space to accommodate double stacked containers let alone space for the electrification.



SOUTH AFRICA TUNNEL PROFILE 1973 to date

Tunnels built before 1947 were 4 572 wide & 4 876 heigh
Between 1947 and 1973 width was increase over two periods
Height was increased over three periods

STRAIGHT



11.2 Metrorail [48]

Metrorail operates over 2 223 km of 1 067 mm NG track in South Africa. Metro owns and operates railway lines in four areas known as Wits (915 km), Tshwane (337 km), Durban (365 km) and Cape (606 km). Interconnectivity exists with Transnet Freight Rail (TFR) in these centres and both parties operate on each other's territories.

Metrorail also operates rolling stock in Port Elizabeth and East London making use of TFR's network.

11.3 Others

Extensive private networks and sidings exist in South Africa at industrial, agricultural, mining and port complexes. All of these are interconnected with TFR's network.

12. VIEWS ON RAIL GAUGE CHANGE IN SOUTH AFRICA

12.1 Minister of Transport [45]

"I believe it is high time that we begin to think 50 years ahead at least and think about planning our new systems as uniform and standardised to take advantage of the new technologies that promote speed, safety and freight capacity but which our current systems make redundant. In the South African context may I be so bold as to suggest that we really must consider whether the advantages of the Cape Gauge, such as they are, actually outweigh moving towards more standard gauge systems in the longer term. I am intrigued by the level of technical debate on the issue, not only here but internationally as well, and would really urge the specialists to engage government on the question quite soon."

Minister J. Radebe (AfricaRail Conference and Exhibition June 2005)

12.2 Department of Transport (DoT) [45]

In an extensive 70-page document on the DoT website, a change of South Africa's gauge to the world's dominant 1 435 mm standard gauge is presented as a visionary 50-year forward looking catalyst that will solve rail problems in South Africa and redress imbalances of the past as far back as the colonial era.

It is clearly stated that it does not pretend to be a technical report but that the intention is to encourage debate and to dwell at a high level of policy development. Aiming for that level, parts of the document also skirts close to being of a political nature. Some parts tend to be a bit vague.

It nevertheless lays a heavy finger on the fact that all is not well in the railways of South Africa.

Readers of this report and students of the railway gauge issue will be well advised to read the full discussion document as well as the critical analysis thereof in Railways Africa[8].

12.3 Railway Press

In a 5-page article Railways Africa[8] agrees that there are problems with railways in South Africa but makes its position quite clear that a change of gauge would by no means present a solution.

The DoT discussion document is extensively analysed and its credibility questioned for not having its facts straight and for listing things as problems despite that these are not current problems (such as break of gauge).

It considers that both sides of the story were not adequately presented and labels the discussion document's argument of highlighting the gauge of a railway as contributory to the closing of branch lines, run-down infrastructure and commuter travel time as "novel but unconvincing".

12.4 Rail*Road* Association of South Africa (RRA) [44]

The RRA represents South Africa's railway industry comprising the full spectrum of private and state owned operators, suppliers, contractors, consultants and other interested parties. It can thus justifiably claim to have authoritative views on important railway issues such as this. In a 14-page reasoned document the RRA took the following position on track gauge in South Africa:

- ***Whatever decisions are taken should be economically viable*** - the authorities should prescribe neither that all new track should be standard gauge, nor that all existing track should be changed to standard gauge.

- ***It is unlikely that it will be found economic or realistic to change all existing track to standard gauge***.

- ***Existing meter gauge track should be operated as a going concern***, until it can no longer economically serve its intended purpose.

- **Major new railway projects should use the dominant applicable technology** - that is application to new corridors of double-stack container trains, and/or high-speed intercity trains, should use standard gauge track. For example, application of double-stack container trains, and/or high-speed intercity trains to new corridors should use standard gauge. Similarly, standard gauge could be considered in the urban context, but only if appropriate.

- ***As and if such projects gain momentum***, it will then be up to future generations to convert appropriate portions of the existing rail network to standard and/or dual gauge lines.

12.5 Transnet [46]

Speaking at the recent Africa Union Rail Conference, TFR's CEO pointed out a number of pros but mostly cons for South Africa to convert to 1 435 mm standard gauge.

Some of his statements were:

- Speed for freight trains was not related to Cape Gauge but rather a derivative of gradients, curvature, train authorization systems and number of crossings
- Axle loading was not a constraint and could be increased on Cape gauge
- Cape Gauge had no greater requirement for maintenance
- Standard containers are carried on Cape Gauge
- The current unified gauge within SADC did not require wagon change
- Although Cape Gauge may constrain speed, journey time was a small factor in the overall turnaround time
- Costs for a conversion was estimated to be of the order of R300bn excluding costs associated with terminals, handling facilities, sidings and operational constraints during such a conversion
- TFR's current Capital Programme was of the order of R34bn over 5 years

He went on to acknowledge that standard gauge rail component procurement was likely to be more economic in a global market place than Cape Gauge and that standard gauge could be considered if operated as isolated systems i.e.

- Hub-to-hub operations with transfer facilities of freight at the end-points
- Double stack container trains from a port hub to an inland hub
- High-speed passenger services – centrally funded

He remained skeptical whether this will provide economic benefit to South Africa.

13. CONCLUSION

From the literature reviewed, the countries that changed the gauge of part- or all of their rail systems did so for two reasons. First, to be compatible with other rail systems, either domestic or international. Spain is even changing from broad gauge to standard gauge to be compatible with neighbouring countries to the north-east. Second, to build additional independent systems with a different gauge for dedicated high-speed passenger services.

In addition to compatibility (requiring track gauge wider or narrower than standard gauge) and speed (requiring at least standard gauge), a number of other arguments also cropped up in the literature as being in favour of standard gauge. These are characteristics that favour capacity improvements such as double stacking of containers and double deck passenger coaches. Other advantages included larger vehicle profiles to enable higher axle loads and the ability to exploit the advantages of standard gauge rolling stock

The ease of procuring standard equipment (off the shelf) and a reduction in maintenance costs were also mentioned.

No evidence could be found of any country that changed or is planning to change the gauge of their rail network from 1 067mm to 1 435mm to improve productivity of the system or to be able to purchase “standard” rolling stock.

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RAILWAY GAUGE

ANNEXURE 2

LITERATURE REVIEW - AFRICA FOCUS

(Version 4 - 200904)

1. EXISTING RAILWAYS IN AFRICA

Africa has about 80 000 km of railways. This is about 7% of the world's total.

About 85% of Africa's total is represented by narrow gauge (NG) of the 1 000 and 1 067 mm varieties. The remaining 15% is 1 435 mm standard gauge (SG) with all of it north of the equator.

The adjacent table and diagrams below provide a picture of the layouts, gauge distribution and statistics.[1,18,19]

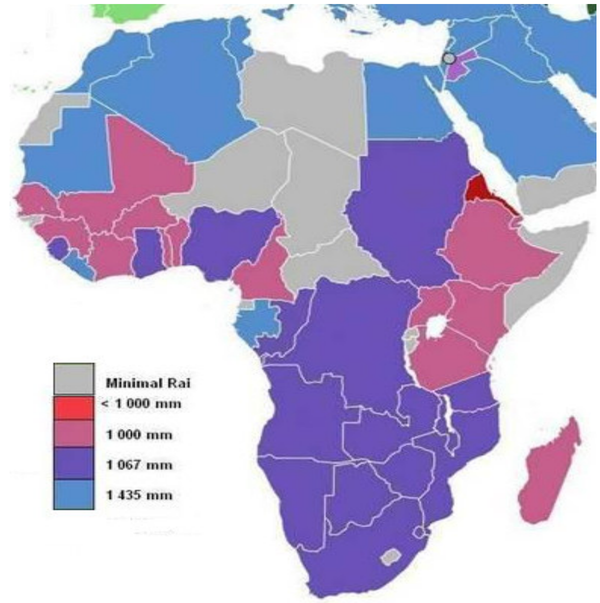
There are no working lines connecting African railways with those of Europe or the Middle East.

The NG railway lines in Africa are generally in a poor to very poor condition.

Gauge mm	1 000	1 067	1 435	Ranking
Country	NG		SG	
	Kilometers			
South Africa		**22 300**		1
Egypt			5 024	2
Tanzania	3 000	1 581		3
Sudan		4 578		4
Algeria		1 085	3 138	5
Congo, Dem.Rep.		3 641		6
Nigeria		3 505		7
Angola		3 000		8
Mozambique		2 974		9
Zimbabwe		2 898		10
Namibia		2 382		11
Tunisia	1 762		496	12
Zambia		2 232		13
Kenya	1 918			14
Morocco			1 907	15
Cote D'Ivoire & Burkina F	1 260			16
Uganda	1 241			17
Guinea	936		236	18
Cameroon	1 016			19
11 Others (< 1 000 km ea)	3 222	3 736	1 353	20
Totals	**14 355**	**53 912**	**12 154**	
Percentage	**18%**	**67%**	**15%**	
	80 421	**< 7% of world railways**		

Exceptions are South Africa, where its two heavy haul lines are world class and in good condition whilst the core main lines are in a fair to good condition[2]. Limited portions of the NG lines in Botswana, Mozambique, Namibia, Zambia and Zimbabwe are also in fair condition[3]. The world class classification of South Africa's coal line has come under pressure of late as service disruptions and strife with customers appears to be on the increase.

Most of South Africa's non core and branch lines are also in a poor to very poor condition[2].



2. RAIL TRAFFIC IN AFRICA

Only 10 countries in Africa move more than 3 Mt/a in freight traffic as per the adjacent table[18]. South Africa sits at the top of the list overshadowing the rail freight activities in all other African countries.

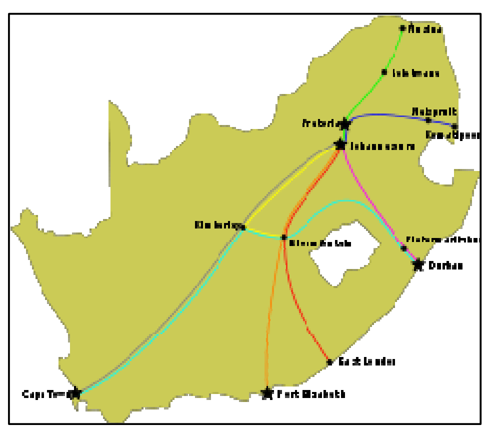
> 3 Mt/a FREIGHT	Freight Tons p.a (Mt)	Ranking
South Africa	**176.0**	1
Morocco	30.7	2
Guinea	20.8	3
Egypt	12.0	4
Mauritania	11.4	5
Tunisia	10.8	6
Algeria	7.1	7
Mozambique	5.4	8
Swaziland	5.1	9
Gabon	3.0	10

Apart from South Africa, Mozambique and Swaziland (all 1 067 mm NG), the other seven in the top ten are all north of the equator and exclusively or predominantly employ 1 435 mm SG railways.

Much of the traffic of the top 10, is heavy haul. In the south, Swaziland and Mozambique are largely transit routes for traffic originating in South Africa.

Intercity passenger traffic by rail is currently fairly insignificant in Africa. It only totals about 100 million passenger journeys p.a. which is less than the figure for countries like Austria or Belgium[18].

The figure of 100 million journeys p.a is probably excessive for intercity traffic as it appears that the figures of a number of countries in North Africa also include commuter traffic.



In South Africa, intercity passenger traffic is predominantly limited to the routes shown in the adjacent figure and totals about 4 million passenger journeys per year[4].

3. AFRICAN UNION GUIDELINES

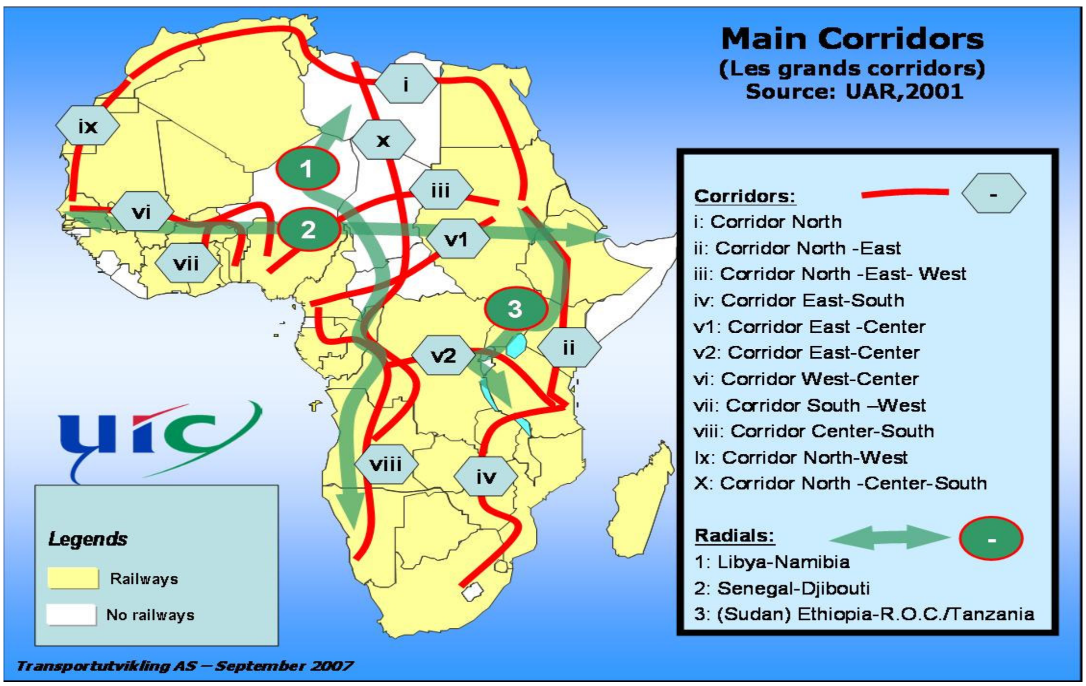
In November 2007 the African Union (AU) held a Conference on Rail Interoperability in South Africa and resolved the following[5]:

- "***To this end and to facilitate interoperability of rail transport networks in Africa, standard 1 435 mm gauges should be adopted and retained for construction of new rail lines in the Continent***"

and concluded that:

- "***The conversion to standard gauge (1 435 mm) for new railway lines should enable African railways to benefit further from the wide range of material and equipment at global level, and will contribute significantly to resolving the problem of interoperability in the future Pan-African railway network***."

Ten **Corridors** and three **Radials** feature in the vision of the Union of African railways and member states are encouraged to keep these in mind for future integration whenever new lines are considered[6,7] .



4. EXISTING RAIL NETWORKS IN AFRICA

There are only two cross border networks in Africa.

A small network in North Africa connects Morocco, Algeria and Tunisia with 1 435 mm SG lines.

A large network in the south links all the SADC countries together by means of 1 067 mm NG lines up to Kidatu in Tanzania.

At Kidatu there is a break of gauge, from where 1 000 mm NG extends northwards into Kenya and Uganda.

Transhipment is the chosen method whereby rail freight proceeds across the break of gauge at Kidatu.

5. MAJOR RAIL PROJECTS CURRENTLY UNDER CONSTRUCTION IN AFRICA

- **Libya** - Construction started in 2008 on a €2·2bn, 554km, 1 435mm gauge double-track railway along the coast of Libya from Surt to Benghazi[8]. This will fit in with the UAR's Corridor North (number 1 on the diagram in paragraph 3 above). First operations are expected in 2009. It is planned to ultimately link with Egyptian Railways to the east, and Tunisian Railways to the west. When complete, this will link North Africa by means of a 6 000 route-km coastal railway. As a minimum in Tunisia, this will require constructing a missing link of some 70km from the Libyan border to Mélenine, completion of some 115 km under construction from Mélenine to Gabès, re-gauging some 215km of narrow gauge from Gabès to Tabeditt, and constructing a missing link of some 35km across the border to the standard gauge railhead at Djebel Onk in Algeria.

- **Angola's** 1 314 km Benguela Railway to the Democratic Republic of the Congo has been out of action for some 30 years. The 1 067 mm NG line is being reconstructed at a cost of $US2 billion[9]. A Chinese company is doing the work and completion is still some years in the future.

- **South Africa**

  - Construction is well underway for the new Gautrain medium-speed (160 km/h) standard gauge (1 435 mm) intercity passenger train project. Opening of a first section is scheduled for 2010, with completion due in 2011.
  - A major expansion project is also underway to increase the capacity on the Sishen-Saldanha heavy haul iron ore export line[17].
  - Extensive investments are being made in purchasing hundreds of new locomotives.[17]

- **Mozambique** – The complete rebuilding of the 562km 1 067 mm NG main-line from Dondo to Tete seems likely to be completed during 2009. It was destroyed during the lengthy civil war and has been inoperable for two and a half decades. The cost of reconstruction is estimated to amount to about $US175 and is being borne mainly by a World Bank loan[10].

6. MAJOR RAIL PROJECTS CURRENT UNDER CONSIDERATION IN AFRICA

A large number of projects are under consideration in Africa. Some have been reported on for a number of years without any tangible progress.

- **Morocco** - The new rail developments are initially all along the Atlantic seaboard, which contains the country's main population centres. The 1 435 mm SG high-speed line will cover the 308km distance from Tangier in the north to the country's largest city and commercial centre, Casablanca. It will eventually cut the journey time to 2hr 10min from the present 5hr[11]. The $2.61bn contract is on a design, build, operate and maintain basis. Projected loadings are for 8 million passengers per year following the projected opening in 2013.

- **Morocco – Gibraltar -** A long-term project overseen by a Moroccan-Spanish committee is a 40km rail tunnel beneath the Strait of Gibraltar, opening the prospect of TGVs or their successors travelling between Europe and Africa from 2025[12].

- **Algeria -** A new 930km east-west railway is being designed by German and Austrian consultants. It is hoped to open the line to traffic in 2015 [13]

- **Nigeria's** 1 067 mm NG network of about 3 500 km is in poor condition. More than 5 years ago it was decided to rebuild the whole network whilst converting it to 1 435 mm SG at the same time. (see Annexure 1). Multi billion dollar contracts were signed with Chinese contractors in 2006, only to be suspended again 2008. Progress to date is reported as "zero"[14].

- **Kenya and Uganda -** At a meeting at state house in Nairobi on 27 October 2008, Kenyan President Mwai Kibaki and his Ugandan counterpart Yoweri Museveni agreed to create a joint ministerial commission with a mandate to expedite the construction of a standard gauge rail network starting at Mombasa and extending through Kenya and Uganda to the Sudan, DRC, Rwanda and Burundi. The commission will comprise the finance and transport ministers as well as attorney-generals of Kenya and Uganda.

  The ineffective and inadequate existing system is largely blamed for "economic stagnation", with commerce in the region unable to compete with countries possessing more efficient railways or – in the case of Rwanda and Burundi – no railways at all[15].

- **Burundi & Rwanda -** Work will start in 2009 to build a 691 km railway line connecting both countries to Tanzania, according to Burundi's transport minister **Philippe Njoni.** Construction will cost an estimated $4-billion and will take five years[16].

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ANNEXURE 3

SOME INFLUENCES OF TRACK GAUGE ON ROLLING STOCK[1]

(version 4 – 200904)

1. Some general perspectives

1.1 Introduction

Until globalization touched the railway system integrator industry, i.e. the industry that integrates subsystems[2] into complete powered- or trailing vehicles, or fixed formation trains, rolling stock builders usually responded to tenders from individual railways. Frequently they built the equipment in the country in which the inquiry originated. In that era, railways played on a level playing field because, although their procurement process elevated prices, they all followed the same process.

Globalization has many meanings: In the context of this document, it is generally taken to have started at the fall of the Berlin wall in 1989, followed by the reintegration of the East Bloc countries into global trade, and ultimately leading to highly intensified global competition. In respect of the railway rolling stock industry, long-established national builders consolidated into global system integrators, followed by emergence of new system integrators in South Korea, China, and lately India. In this process, particular competencies came to be concentrated in relatively few global centres of excellence: For survivors, the outcome was higher volume business, fierce competition, downward pressure on prices, and emergence of industry-standard solutions in particular market spaces where railways have a natural competitive advantage over other transport modes. Bespoke rolling stock became unaffordable, and went the way of most other bespoke goods. This course of events has profoundly affected procurement of narrow gauge rolling stock, as unpacked below.

1.2 Research and development

Research and development was one of the critical areas that changed, arguably irreversibly. It became concentrated in the abovementioned centres of excellence. No new developments, which fundamentally raise competitiveness , have emerged in narrow gauge railways for a long .time.

For example, derivatives of the GSI bogies that were introduced on the Class 6E1 locomotives are still used on TFR's new Class 15E and Class 19E without fundamental further development. The design is therefore already 40 years old, and does not reflect advances possible since then, e.g. the steering or limited steering that could assist narrow gauge locomotives to attain the high adhesion exploited by standard gauge railways.

Another recent example is efforts to introduce bimodal rail/road technology to South Africa[3]. The technology and equipment are available in standard gauge, but the supplier has no interest in adapting it to narrow gauge, and even in South Africa there has been little interest in taking on such work.

[1] Compiled by D vd Meulen - 20080924

[2] Such as traction, coupling, braking, power auxiliaries, door systems, climate control, and many more.

[3] Private communication.

It appears that research and development to raise the competitiveness of gauge-related attributes of narrow gauge railways is non-existent. It is not undertaken in any of the global centres of excellence, which naturally focus on the standard gauge or broad gauge environments within which they are set. At best, one would expect such research to originate within (TFR) in South Africa, QR in Australia, Vale (formerly CVRD) in Brazil in respect of its Estrada de Ferro Vitória a Minas (EFVM) narrow gauge operation, and Japan Railways in respect of its narrow gauge operations. A structured search of the proceedings, since the abovementioned commencement of globalization in 1989, of the two leading forums in the railway research and development fields, namely International Heavy Haul Association and World Congress on Railway Research, found no evidence of research and development aimed at addressing the gauge-related disadvantages of narrow gauge railways. Authors from the abovementioned countries predominantly addressed questions related to capacity, maintenance, and reliability, which apply equally to any track gauge. In South Africa itself, railway research effort of any sort appears to have reduced to the activities of a few individuals. The inevitable conclusion is that, despite the hypothetical possibility that the competitiveness of narrow gauge railways can be raised, there is no evidence of it being proven: Narrow gauge railways have therefore unfortunately stagnated since globalization of the railway industry.

1.3 Vehicle profile

1.3.1 General

Vehicle profile (sometimes termed moving structure gauge) is not inherently a function of track gauge, although some gauge-derived parameters have nevertheless effectively been cast in concrete. For example, South Africa's vehicle profile is particularly narrow at the bottom (2540mm below station platforms), but wider above station platforms. This inhibits the prospect of adapting rolling stock from the global market to South African requirements, because standard-gauge vehicle profiles typically maintain their full width to near rail level. It is interesting to compare this situation with that of Japan, where there has long been an aspiration, unfortunately not yet realized, to convert its narrow gauge railways to standard gauge: Their vehicle profile does make the necessary provision for wider bogies by maintaining the full vehicle profile width to near rail level. The following are some basic requirements of a vehicle profile.

1.3.2 Containers

The basic requirements are to accommodate containers to ISO dimensions, namely 2438mm (8 feet) wide, and 2591mm (8 feet 6 inches) or 2896mm (9 feet 6 inches) high. Intermodal transport in North America also uses so-called domestic containers, based on ISO width and height, but reflecting road vehicle lengths, initially 45 feet, and later 48 feet and 53 feet. This has enabled railways to accommodate load units that are dimensionally the same for rail and for road, rendering the modalities of movement transparent to shippers. Since November 2007, 48-ft and 53-ft containers have been used also for international ocean shipments. Most railways, irrespective of track gauge and including South Africa, can accommodate the ISO height and width, at least above station platform height. However, the length of 53-ft containers might challenge some of them.

Containers are double stacked on railway wagons to achieve an axle load that is competitive vis-à-vis road. The AAR Plate H vehicle profile is based on two 9 feet 6 inch containers, plus one foot for floor structure, and two inches for clearance to top of rail, to give a total height of 20 feet 2 inches, or 6147mm. This challenges many railways, including North America where double stacking originated. Special clearing of designated routes is frequently required. The challenge of high centre of gravity has not yet been overcome on narrow gauge railways.

It is interesting to note that the Betuwe route, from Rotterdam in the Netherlands to the German border has had tunnels, electrification and other parts of the railway engineered to allow double stacked container trains, although no such trains will be in use for years to come. The European Union-funded NEW OPERA project also envisages double stacked containers being conveyed on dedicated freight rail corridors.

It is evident that the width required to convey containers fits in most railway structure gauges. However, South Africa does have a problem with its cutout below vehicle floor level. Even if track were standard-gauged to carry containers, the residual problem of routes passing station platforms would need to be addressed.

1.3.3 Bulk commodities

Bulk commodities can usually be accommodated reasonably well within the vehicle profile of most railways, irrespective of gauge. For example, some years ago a study found that TFR's Coal Line could accommodate 30 tonne/axle wagons within existing wagon length- and centre-of-gravity-height parameters. The additional capacity is achievable by widening wagon bodies within the existing vehicle profile. Beyond 30 tonnes/axle it would be necessary to consider a gauge similar to that used on most standard gauge railways.

1.3.4 Passenger

TFR's new vision to separate commuter and freight operations is sound. Among other it will create an opportunity to confine urban commuter trains to urban routes, and thereby create space to revisit the vehicle profile width below station platforms on trunk lines.

South Africa will however need to think thoroughly about intercity commuter trains. There may be scope to drastically reduce the number of station platforms, and position those essential platforms that remain to allow vehicle profiles with stronger presence in the global market, such as AAR and UIC. This would considerably widen rolling stock sourcing possibilities, including entry to the global second hand market.

1.3.5 Conclusion

South Africa's interpretation of vehicle profile, in particular width below station platform level and to a lesser extent height above rail, does not accommodate a free or even wide choice of rolling stock from global sources. This imposes a track-gauge-related constraint on rolling stock selection.

2. Locomotives

2.1 Traction motors

2.1.1 Heavy haul and high speed applications

It is useful to appreciate that two of the fundamental railway application regimes, namely high speed and heavy haul, require fundamentally different traction motor characteristics. Heavy haul locomotives must exert high tractive effort at relatively low speed. Their traction motors are therefore built for comparatively high current and comparatively low voltage. High speed locomotives must exert relatively low torque at relatively high speed. Their traction motors are therefore designed for comparatively low current and comparatively high voltage. High currents require large conductor cross sections, and heavy haul motors are therefore more robust than high speed motors. The differences are so large that the two applications cannot be reconciled by means of different gear ratios.

2.1.2 Rating

Narrow gauge motored bogies, whether for locomotives or multiple unit stock, typically use axle-hung traction motors. This means that one side of the traction motor is attached to the axle by means of bearings, while the other side of the traction motor is suspended from the bogie frame. Axle-hung motors therefore carry a portion of their substantial mass directly on the axle. The portion carried on the axle is known as unsprung mass. It is a comparatively low cost arrangement, which is why it is widely used. However, the comparatively high unsprung mass limits maximum speed to around 140km/h. This exceeds the maximum speed of narrow gauge rolling stock, for which reason sophisticated motor suspension arrangements are rare on narrow gauge motored bogies.

Beyond 140km/h, which in practice means the range 160-200km/h, traction motors are typically suspended from the bogie frame, to reduce unsprung mass, while the gearbox is still carried on the axle. This requires a flexible coupling between the traction motor and the gearbox, to accommodate primary suspension movement. For context, the Gautrain Electrostar uses this arrangement.

For high speed operation, 200-250km/h, unsprung mass must be reduced further by mounting the motor and gearbox on the bogie frame. This requires a flexible quill drive from the gearbox to the axle, again to accommodate primary suspension movement[4].

In all three cases, traction motors must fit between the back-to-back wheel set dimensions of a motored bogie. The challenge is illustrated in Figure 1, which depicts a motored bogie that has been painted to identify the various components by colour—the traction motor, gearbox, and flexible drive are painted light green. Note how tightly they fit between the wheels. This requirement defines the key constraint on traction motor size. In the past, this constraint prevented the use of full size DC traction motors on metre gauge locomotives. Narrow gauge railways expected the development of smaller, lower mass traction motors, plus the more recent availability of AC traction systems, to progressively eliminate this constraint. However, this expectation has turned out to be a mirage: The torque of a traction motor, whether AC or DC, and hence its tractive effort, is a function of magnetic flux, armature current, number of conductors, and conductor length, plus of course gear ratio and wheel diameter. All other things being equal, and generally they are equal, torque is thus a function of conductor length, which in turn is a function of back-to-back wheel set dimensions, and hence ultimately of track gauge. Hence traction motor torque is a function of track gauge. Three examples will illustrate the position.

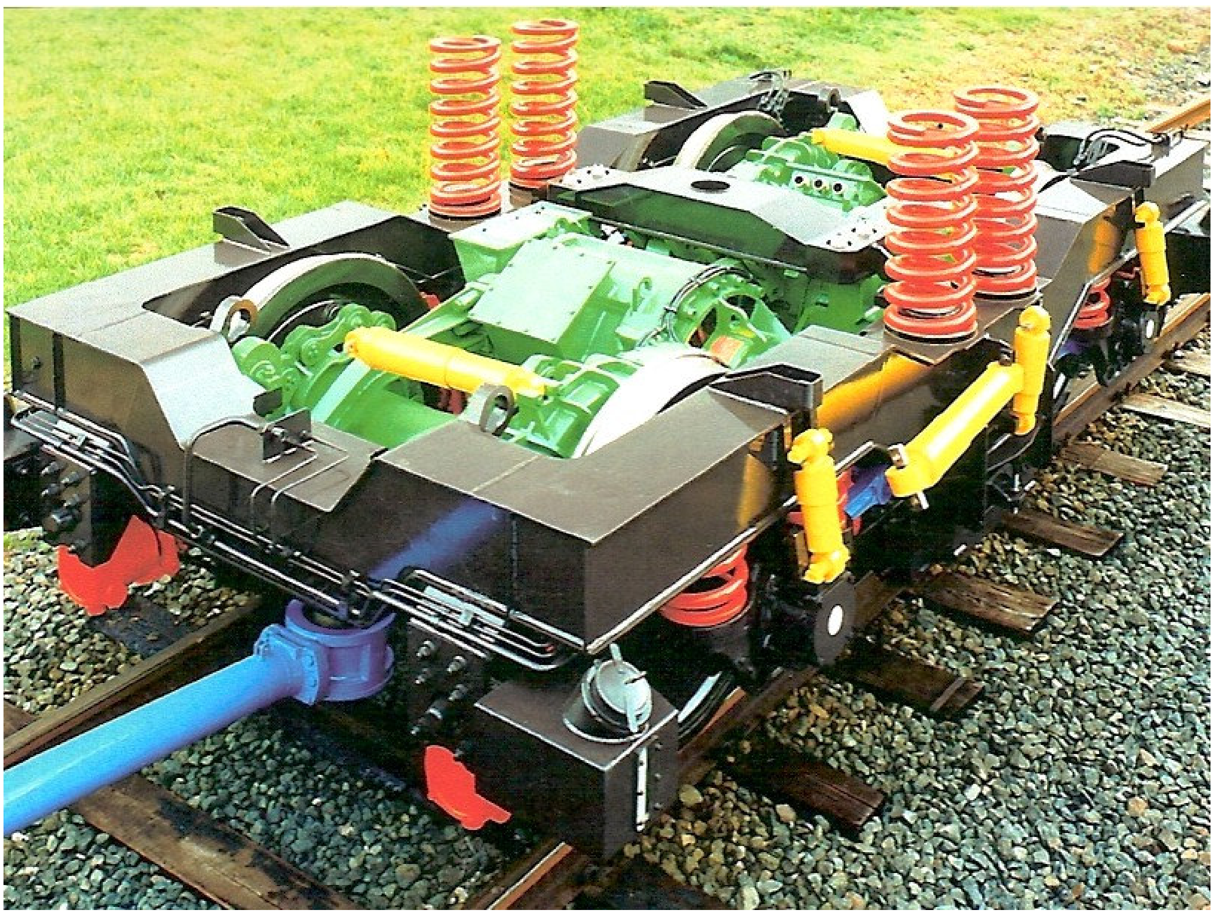

Figure 1: A motored bogie[5]

[4] Note that very high speed applications, beyond 270 km/h, use body-mounted traction motors, to further reduce the mass of motored bogies. This is mentioned here for completeness only, but is not applicable to narrow gauge railways.

[5] From Baur, K.G. 2006. Bogies. Freiburg: EK Verlag, P. 99.

First, consider TFR's locomotive with the most powerful traction motors, the Class 14E, which the diagram book rates at 4080kW. It is a four-axle high-speed electric locomotive with AC traction motors, rated at 194kN (only 21% adhesion), but at the relatively high speed of 72km/h. Comparable standard-gauge locomotives[6] are rated at around 5500kW, almost exactly in proportion to the difference in track gauge[7].

Second, consider QR's application of AC traction motors to its high powered narrow gauge Series 4000 diesel locomotives. These 120-tonne six-axle heavy-haul locomotives have a continuous tractive effort of 460 kN. Comparable standard-gauge locomotives, adjusted for their 32.4-tonne axle load, but at the same 39% adhesion, would be rated at 745kN: At a more realistic 35% adhesion, they would be rated at 660kN, again almost exactly in proportion to the difference in track gauge[8].

Third, consider the Kiruna-Narvik IORE locomotive. It sustains a running adhesion of 35%, which with its six 30-tonne axles[9] exerts a tractive effort of 620kN, and is rated at 5400kW, which gives it a balancing speed of 31km/h. It is good for 700kN, or just shy of 40% adhesion. Compare TFR's Class 15E. Also with six 30-tonne axles, it sustains a running adhesion of 25½%, exerts a tractive effort of 450kN, and is rated at 4400kW, which gives it a balancing speed of 35km/h. Once again the difference in tractive effort is almost exactly in proportion to the difference in track gauge[10]. Both locomotives use AC traction motors.

It is thus important to specify the application, because traction motor design is fundamentally different for heavy haul and for high speed: Either way, 1375kW high-speed traction motors, or 110kN heavy-haul traction motors, do not fit on narrow-gauge wheelsets. Even if technology advances further, which it surely will, narrow gauge traction motor performance will always trail that of standard gauge motors because of the difference in conductor length.

2.1.3 Performance

Note furthermore that permissible axle load constrains the size or power of diesel engine that can be installed: The QR AC Series 4000 locomotive mentioned above is rated at 2424kW gross, compared to the 3200kW rating typically offered on standard gauge heavy haul locomotives. Even if they could deliver the same ratings, production volumes would nevertheless remain outside the mainstream, with the price premium that goes with that. So AC traction motors cannot reduce the performance handicap of narrow-gauge railways vis-à-vis standard-gauge railways.

2.1.4 Sourcing

Traction motors are a critical component of locomotives. They are therefore best sourced from builders that have deep and long experience in the intended applications. For high speed electric locomotives this means European standard gauge traction motors. For heavy haul locomotives this means US standard gauge traction motors. US builders have also built large numbers of narrow-gauge traction motors for export markets, and the robustness of the conservative standard gauge designs rubbed off onto the narrow gauge motors, of course within the lower tractive effort and speed ratings applicable to narrow gauge. Outside this experience base, service-proven-ness decreases.

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[6] Alstom Prima, Bombardier Traxx, and Siemens EuroRunner.

[7] 4080kW x 1435/1067 = 5487kW.

[8] 460kN x 1435/1067 = 618kN.

[9] The IORE locomotive is deployed with two units in tandem: The values herein apply to a single unit.

[10] 450kN x 1435/1067 = 605kN

2.2 *Pricing*

2.2.1 Diesel locomotives

The indicative price for North American-sourced diesel locomotives is USD2 million apiece, irrespective of track gauge[11]. Standard gauge models are manufactured in series production at a rate of around 1200 per year (EMD and GE combined), and are capable of exerting at least 660kN tractive effort. Narrow gauge models are built in small quantities, and are capable of exerting 260kN tractive effort. At USD1 = ZAR7.71 on 2008-07-10, the price for either amounts to ZAR15.4 million.

The price per unit tractive effort for a 660kN standard gauge locomotive is thus ZAR23333 per kN. The price per unit tractive effort for a 260kN narrow gauge locomotive is ZAR 59231 per kN. The narrow gauge premium in this instance is 154%.

Maintenance costs per locomotive would in general be similar, because they are powered by the same or similar engines. However, for the same aggregate tractive effort, the number of locomotives is reduced by 2:1 or better, which reduces maintenance costs in the same ratio. The heavier locomotives of course balance at lower speed, although most heavy haul railways find this solution superior to lighter locomotives with higher balancing speed[12]. All other things being equal, operating costs per kilowatt hour of tractive output would be independent of track gauge.

2.2.2 Electric locomotives

Bombardier, in cooperation with Dalian, is building a version of the Swedish IORE locomotive for Chinese Railways, with an output of 4800kW on 25 tonnes/axle. At a running adhesion of 35%, it will exert a tractive effort of 515kN. The contract for 500 locomotives was valued at EUR1.1 billion when it was announced on 2007-02-12. At EUR1 = ZAR9.34 on that day, the price per locomotive amounts to ZAR 20.5 million. The price for TFR's Class 15E locomotive is R35million apiece. The price per unit tractive effort for the Chinese locomotive is ZAR39806 per kN. The price per unit tractive effort for the Class 15E is ZAR77778 per kN. The narrow gauge premium in this instance is 95%.

2.2.3 Adaptation of standard locomotives

The limited market for new narrow gauge locomotives, and the price premium they attract relative to standard gauge locomotives, has led the above mentioned EFVM in Brazil to an interesting solution.

North American locomotives come in the range 415000lb to 429000lb gross mass, i.e. respectively 31.4 to 32.4 tonnes per axle on six axles. Increasing the number of axles from six to eight can reduce the axle load to respectively 23.5 to 24.3 tonnes, i.e. comfortably within narrow gauge capability. EFVM has sourced such locomotives in several batches since the mid 1960s—new locomotives from EMD (with D_o-D_o axle arrangement) and from GE (with B_o+B_o-B_o+B_o axle arrangement), as well as second hand locomotives from North America that were modified in-house to accommodate eight axles, by reworking the ends of the underframe, and making the fuel tank smaller, providing new bogie frames, and fitting second hand traction motors. As a corollary, this has resulted in a global shortage of used narrow-gauge EMD and GE traction motors.

This solution is workable, because the heavy equipment components such as engine, alternator, compressor, bogies, fuel tank, and bogies, are all mounted at approximately the same height, independent of track gauge. The remaining, lighter, equipment does not materially raise the centre of gravity of a locomotive, built to the generous AAR Plate C vehicle profile. It attracts a 6% price premium compared to standard gauge locomotives[13].

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[11] Private communication.

[12] Compare the 620kN tractive effort at 31km/h balancing speed of the Kiruna-Narvik IORE locomotive with the 450kN tractive effort at 35km/h balancing speed of TFR's Class 15E, both with the same axle load of 30-tonnes.

[13] Private communication.

2.2.4 Market share

The share of locomotives acquired by the three narrow gauge railways with heavy haul operations (QR, TFR, and Vale) is down to around 1% of the total locomotive market. At this level, it is not a buyers market, and it is sometimes difficult to get major suppliers to take such railways seriously.

2.2.5 Conclusion

Locomotive prices are influenced by many factors, such as order quantity, technological complexity, country cost structure, and probably many more. The inescapable conclusion nevertheless must be that narrow gauge locomotives incur substantial performance- and price disadvantages compared to standard gauge locomotives. To the extent that the performance disadvantages of narrow gauge locomotives result in a larger locomotive fleet to perform the same task, the maintenance cost will also be higher. All other things being equal, it costs the same to maintain narrow gauge locomotives as standard gauge locomotives, and a higher locomotive count simply costs proportionately more to maintain. Sometimes other things are not equal, such as narrow gauge electric locomotives, which are built to customer requirements. This can result in low-volume or orphan designs, which drives the cost of spares procurement up, and drives availability down.

3 Wagons

3.1 Design

Two characteristics distinguish wagons from other rolling stock. They are usually deployed in large fleets, and they usually run in long trains. The former requires interchangeability among a wide variety of trains, and frequently also among diverse operators. The latter requires a set of functionality additional to that of individual wagons. Both requirements are met by building wagons to appropriate standards. Several such standards are found around the world: Among competitive freight railways, Association of American Railroads (AAR) standards, or standards similar to them, are generally accepted. They regulate interchangeability and performance of running-, coupling-, and brake gear. Individual railways may have further, local standards, such as vehicle profile and possibly several more, which may or may not influence the performance and price of rolling stock.

3.2 Load-to-tare ratio

The items mentioned above are applied to wagons whatever their track gauge. Thus a 1067mm gauge wagon built to AAR standards would contain the same componentry as would a standard gauge wagon built to AAR standards, with due adjustment for items that must necessarily match track gauge, such as axles, bogie bolsters, and brake beams. The contribution of these components to tare mass, and to wagon price, are therefore a constant, whatever the track gauge of the wagons.

The proportion of fixed component mass to tare mass thus reduces as axle load increases. In addition, criteria such as abrasion-, corrosion-, deflection-, and penetration resistance, rather than axle load or track gauge, determine plating thickness in areas of wagon bodies that are not subjected to high stress. There is therefore a natural tendency for higher axle load wagons to have higher load-to-tare ratios. This is illustrated by the Table 1 for coal wagons, and Table 2 for iron ore wagons.

Table 1: Comparison of coal wagon attributes

Rotary dump coal wagons

Category	Global best practice	South African best practice	Projected best practice*	South African baseline 1	South African baseline 2
Axle load, t	32.4	26	20	20	20
Designation	BethGon II Aluminum/steel composite	CCL-5	Aluminum/steel composite	Transnet Freight Rail CCL-1, CCL-2	Transnet Freight Rail CCL-3
Body, t	7.034		5.526		
Bogies, t	10.000		9.500		
Coupler system, t	1.386		1.386		
Body-mounted brake gear, t	0.500		0.500		
Total tare, t	18.920	20.250	16.912	20.820	21.200
Payload, t	110.844	84.000	63.088	59.180	58.800
Gross mass, t	129.764	104.250	80.000	80.000	80.000
Load/tare, ratio	5.86	4.15	3.73	2.84	2.77

*Projected from global best practice.

A rising trend of load-to-tare ratio versus axle load is evident[14]. Note that global best practice in column 2 reflects the current 286 000-pound load limit in unrestricted interchange in North America. Wagons built to the 315 000-pound load limit (35.6 tonnes/axle) in restricted interchange would have a higher load/tare ratio.

Table 2: Comparison of iron ore wagon attributes

Rotary dump iron ore wagons

	BHP Billiton Iron Ore						Fortesque Metals Group	Transnet Freight Rail		
Year	1970	1974	1986	1996	1999	2005	2008	1978	2000	2000
Designation								CR-5	CR-14	CR-13
Axle load, t	28.500	30.000	32.500	35.000	37.500	40.000	40.000	26.000	30.000	30.000
Gross mass, t	114.000	120.000	130.000	140.000	150.000	160.000	160.000	104.000	120.000	120.000
Payload, t	89.000	96.000	107.000	116.000	126.000	136.000	137.000	85.500	99.500	100.600
Tare, t	25.000	24.000	23.000	24.000	24.000	24.000	23.000	18.500	20.500	19.400
Load/tare, ratio	3.56	4.00	4.65	4.83	5.25	5.67	5.96	4.62	4.85	5.19

A rising trend of load-to-tare ratio versus axle load is once again evident[15]. The almost constant BHPBIO tare mass appears over-designed in the early years of the operation. It is perhaps significant that BHPBIO's original wagons were acquired second hand after being used to build the Oroville dam in the United States, and that their relatively high tare therefore reflects that they were originally designed with sufficient volumetric capacity to carry a payload less dense than iron ore.

Axle load and load-to-tare ratio reinforce one another to become key determinants of the size of the wagon fleet required to deliver a particular throughput tonnage. For example, throughput and all other things being equal, from Table 1 the coal wagon fleet size for South African best practice would be 30.9% larger[16] than global best practice, while from Table 2 the ore wagon fleet size for South African best practice would be 36.2% larger[17] than global best practice. In turn, the size of the wagon fleet determines capital-, operating-, and maintenance expenditure. All three are driven

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[14] BethGon data from www.freightcaramerica.com; component masses from private communication; projected best practice derived from BethGon.

[15] BHP Billiton Iron Ore time series to 1999 from www.bhpbilliton.com/bbContentRepository/Presentations/BHPBillitonIronOreOV.pdf;

2005 data from Mike Darby, Global Rail Freight Conference, New Delhi, India, 2007.

Fortesque Metals Group data from http://railwaysafrica.com/index.php?option=com_content&task=view&id=3016&Itemid=36.

[16] 110.844/84.000 = 1.319

[17] 137.000/100.600 = 1.362

largely by item count—more wagons mean more capex, and more expenditure on operations and maintenance. In practice, high axle loads associate with standard gauge track: Track gauge is thus an inverse driver of the cost of wagon ownership.

3.2 Production and sourcing

Standard running gear (wheels, axles, bearings, side-frames, bolsters, snubbers, liners, centre castings), coupling gear (fixed- and rotary couplers, knuckles, yokes, wear-compensating devices, drawgears, and pockets), and brake gear (brake shoes, brake beams, rigging, slack adjusters, brake cylinders, control valves, empty/load devices, and handbrake mechanisms), tend to be high value added components. Their price, which reflects their research and development content, high-performance materials, and manufacturing complexity, therefore is higher than the price of aluminium or steel plate and -sections. For this reason, and noting also that wagon capacity increases with the cube of physical dimensions whereas the plating increases with the square of physical dimensions, the price of a basic wagon body[18] is relatively insensitive to payload.

However, the price of wagon bodies depends more on factors such as production volume, material price, overheads, production techniques, labour costs, and of course shipping to site if manufactured in a different country. Standardization can substantially raise production volumes, and open opportunities to use breakthrough techniques, e.g. pressing entire wagon sides in one piece, rather than assembling them from a variety of extruded- or rolled sections.

The price of running-, coupling-, and brake gear depends on where it is manufactured. Much of it has been manufactured in South Africa, although current volumes are so low that most of the manufacturing capacity has dwindled. In addition, globalization has concentrated production of value-added components on a few intensely competitive centres of excellence.

The overall outcome is that global sourcing has become the most competitive way to acquire wagons, because pricing is keen. US heavy haul coal wagons go for around R500 000, while Chinese heavy haul wagons go for around R400 000, landed in South Africa[19]. This compares with Transnet Rail Engineering prices upwards of R700 000.

4 Passenger rolling stock

4.1 Introduction

Nowadays very little traditional coaching stock is built anywhere in the world. Traditional long distance passenger trains, which share infrastructure with freight trains, are competitive against neither road on the one hand nor air on the other hand. Traditional long distance passenger trains are slower than alternative transport modes, hence their equipment utilization is lower, and their vehicles need to be heavier to accommodate in-train forces, hence they are more expensive to build and to operate. The outcome is that passenger rail has moved to the more competitive, and hence more sustainable, applications mentioned below. Bangladesh is probably the only country to have acquired new traditional coaches in the present century.

4.2 Urban rail

Human beings as payload do not support the high axle load required to make rail naturally competitive against other transport modes. Beyond private cars, minibuses and buses, entry level urban mass transit employs rubber-tyred vehicles, such as bus rapid transit with axle load comparatively heavy by road standards, although comparatively light by rail standards, and increasingly some form of automated guidance, mechanical-, magnetic-, or optical. It may even go as far as the VAL system, which in the current generation provides continuous electrification and, which will with the advent of ultra capacitors, in the next generation provide discreet electrification at stations during dwell times. In many respects entry level urban mass transit is thus emulating the

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[18] That is the basic structure, body and underframe, if the wagon has an underframe. In its naturally competitive market spaces, such as heavy haul of bulk commodities, double stacking of containers, and movement of bulk chemicals in tank wagons, competition has eliminated separate underframes—an integral structure does the job.

[19] Private communication.

attributes that distinguish rail from other transport modes, and underpin rail's competitiveness. Pukka urban rail, whether light rail or heavy rail, must therefore raise the game by offering higher capacity, higher quality service to secure and grow its market.

The response from the railway industry has been to standardize extensively to reduce costs and raise competitiveness. A basis of standard offerings from global system integrators has already emerged, namely multiple unit sets, on standard gauge track, with 25kV power supply where electric traction is provided, and diesel- and electro-diesel variants readily available where they make sense in a particular setting. State-of-the-art light rail features low-floor designs, to facilitate passenger access and to minimize the environmental impact of stations. The latter in particular has become a key consideration in urban rail applications. State-of-the-art heavy rail features driverless trains and automated station operation, to ensure consistent performance as daily operating hours extend and approach 24 hours.

Urban rail is probably the passenger application that demands the most customization. Aside from greenfields projects, where design parameters can and should be optimized to attract industry-standard solutions, many urban rail applications need to respect hard legacy parameters such as curve radius, vehicle height, vehicle width, track gauge, and power supply, to mention some. Customization involves designing to small, sometimes circular, tunnel cross sections; narrow track centre distances; existing platform height and length, and so on. While competition among system integrators generally elicits responses to tender inquiries, and they employ tricks such as matching standard body sides to different floor and roof widths, it is axiomatic that deviations from standard designs must attract a price premium that reflects both non-recurring engineering costs and set-up costs for small production runs.

To illustrate the development trajectory, in Europe, the *Modular Urban Guided Rail System* project, or *MODUrban*, brought together all major rail industry suppliers and all major rail operators. The main target of the project was to design, develop and test an innovative and open common core system architecture and its key interfaces, covering command control, energy saving, and access subsystems, paving the way for the next generations of urban-guided public transport systems[20]. This approach will be applied to new lines as well as the renewal and extension of existing lines, and will encourage cost effective migration from driver to driverless operation. It will also avoid the risk of new rolling stock and subsystems being built from unproven prototype sub-assemblies.

As further illustration, the under mentioned urban rail systems have been or will be built to standard gauge, which differs from their national gauge, in the following two categories:

Broad gauge countries with standard gauge urban railway systems:

1872	Porto	STCP
1959	Lisbon	MTS
2002	Porto	Metro do Porto
2002	São Paulo	Line 5
2004	Dublin	Luas
2007	Lisbon	ML
2011	Bangalore	Metro Line 1 and Line 2,

Narrow gauge countries with standard gauge urban railway systems:

1984	Manila	Line 1 and Line 2
1995	Christchurch	Tramway
1996	Kuala Lumpur	Ampang Line
1997	Taipei	Metro
1998	Kuala Lumpur	Kelana Jaya Line
1999	Bangkok	BTSC
1999	Manila	Line 3
2004	Bangkok	MRTA
2007	Kaohsiung	Metro

[20] http://www.modurban.org

2014	Ho Chi Minh City	Metro

Of urban rail systems inaugurated in the present century in non-standard-gauge countries, New Delhi is the only example to have opted for the national (broad) gauge for its metro.

Urban rail applications allow-, encourage-, or expect passengers to enter and exit systems, or interchange between modes or systems, on foot. This requires no more interoperability between road and rail as it does between rail and rail. The instances above suggest that standardization, price, and risk increasingly favour standard gauge urban rail over national gauge urban rail, even if interoperability is excluded or sacrificed.

4.3 Regional modes

Where non-motored trailing coaches are used, the industry has migrated to double deck coaches which are deployed in regional services. The double deck configuration provides more seats, and simultaneously raises axle load to raise competitiveness vis-à-vis other transport modes. Regional services typically have fewer stops over longer routes, hence the two-doors-per-side that typically comes with the configuration do not materially affect cycle time due to slightly longer dwell times at stations[21]. The longer distances can benefit from higher speed, and regional double deck coaches are therefore designed for the 160-200km/h range.

Double deck stock utilizes available space so efficiently that it is difficult to accommodate traction equipment in it. Such trains are therefore typically hauled by locomotives in push-pull mode, although a few double-deck EMUs do exist.

The high speed and high centre of gravity make standard gauge obligatory. An AAR or UIC vehicle profile is needed to accommodate the height of the coaches. This is the solution proposed for Moloto Rail.

4.4 High speed

High speed trains, capable of 200km/h or more, are used on comparatively few routes, but can cover long distances, which requires comprehensive interoperability. In addition, societal expectations and climate change are driving railway cost reduction to enhance competitiveness and encourage modal shift from road to rail. One significant effort in this field is the MODTRAIN project.

MODTRAIN stands for *Innovative Modular Vehicle Concepts for an Integrated European Railway System*, and as an integrated project it is the first of its kind in joint European railway research[22]. The project started in 2004 with a total duration of four years. MODTRAIN will define and prove the necessary functional, electrical and mechanical interfaces and validation procedures to deliver the range of interchangeable modules, which will form the basis for the next generation of intercity trains and universal locomotives.

The concept of modularity aims at economic advantages for both railway suppliers and operators, such as reduced manufacturing cost and economies of scale, increased productivity of new rolling stock as well as increased reliability founded on a rise in proportion of service-proven components in new rolling stock designs. The project's economic advantages together with the technical solutions fulfill the objectives of increased railway competitiveness and interoperability.

As a starting point, MODTRAIN will concentrate on fixed-formation passenger trains and universal locomotives capable of 200 km/h or more. As the programme advances, it hopes to extend the scope to embrace all rolling stock likely to operate over both the high-speed and conventional interoperable networks across Europe. It embraces running gear, control and monitoring system, on-board power system, man-machine and train-to-train interfaces.

The implications regarding availability and price of narrow gauge rolling stock should be self-evident. In this regard, it must be noted that the other group of non-standard gauge railways, namely broad gauge, does not suffer nearly the same disadvantage as narrow gauge. Broad

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[21] Due to the higher ratio of passengers to doors compared with single-deck stock.

[22] http://www.modtrain.com

gauge is as competent as standard gauge and can therefore compete in all the naturally competitive rail market spaces. The difference in gauge can be fairly small, only 85mm separating standard gauge and the next largest group, the 1 520mm gauge railways of the Baltic States and the Commonwealth of Independent States. This means that standard gauge equipment can easily be adapted to broad gauge, with no loss of competence, usually by simply fitting standard gauge traction motors on longer axles. Even larger differences can be similarly accommodated: Vale's Carajás 1600mm gauge heavy haul operation in Brazil uses locomotives of North American origin so adapted. The difference between broad gauge and standard gauge is thus a nuisance, which can be overcome at modest cost, whereas the difference between narrow gauge and standard gauge is a barrier, which cannot be overcome at any cost.

4.5 Very high speed

Very high speed trains, for 300km/h or higher, together with their supporting infrastructure, are highly specialized systems. Around the world, those that have been built, or announced thus far, have all been standard gauge systems. In instances such as Taiwan and Argentina, they are standalone standard gauge systems that cannot use the existing rail infrastructure, respectively narrow gauge and broad gauge. This situation illustrates the high level of standardization the supply industry has already attained. Even though very high speed trains may be a distant prospect for countries with narrow gauge railways, the implications of standard solutions speak for themselves.

5 Second-hand equipment

Where vehicle profile permits, railways can access a global market in second hand standard gauge railway rolling stock. There are of course several issues which must be thought through. As with any second hand equipment, the buyer must beware. First generation solid state propulsion systems are now at the stage when spares are unobtainable and mid-life upgrades are indicated. Buying such equipment before upgrading could be perilous, and after upgrading it is no longer likely to be on the market. Shifting equipment that does not comply with latest anti-pollution requirements, but that is otherwise in sound condition, from more developed countries to less developed countries, is a sensitive issue. There may nevertheless be value in taking a look. The market reduces risk in the rolling stock leasing and public-private partnership industries, by providing alternative deployment for assets from deals that do not work out as intended. Lower-technology items such as coaches and wagons may offer sound value. Narrow gauge railways are denied access to that market.

6 Conclusion

The global rolling stock industry has developed a critical mass that favours standard gauge railway solutions. Narrow gauge railways cannot participate in those solutions, and must make do with whatever adaptation of such solutions they can afford. Such adaptation usually attracts a premium, so narrow gauge railways start off with a capex handicap, which is exacerbated by a lower-level performance handicap, and may also attract an inherently higher maintenance cost structure. This situation is not tenable in a global economy where the competitiveness of nations is at stake.

7 Summary of rolling stock pricing[23]

- In best practice operations the load-to-tare ratios of SG wagons generally exceeds that of NG wagons by 25 – 35%. Wagon fleets for similar throughput will therefore be 25 – 35% larger for NG operations. The same ratio will apply to capital cost and maintenance cost requirements.
- The capital costs of SG and NG locomotives are best compared on a cost per tractive effort basis. Paragraph 2.2 show costs of ± R40 000 per kN for SG electric locomotives compared to ± R78 000 per kN for NG electric locomotives, and ± R23 000 per kN for SG diesel locomotives compared to ± R60 000 per kN for NG diesel locomotives. This projects that the capital cost of

[23] Addition to Dr D vd Meulen's document

the locomotive fleet in a best practice NG operation will be about two- to two-and-a-half times the number required for a similar operation in SG, depending on the choice of motive power.

NATMAP RAILWAY WORKING GROUP (RWG)

RAILWAY GAUGE

ANNEXURE 4

ANALYSIS OF A NOTIONAL HEAVY HAUL COAL LINE

(Version 5 - 200908)

BACK GROUND

The purpose of this analysis is to determine the order of magnitude of the advantages of a standard gauge operation over a narrow gauge operation.

A notional greenfields heavy haul coal line moving 30 Mt/a is chosen as the basis for the analysis. The capital cost to build the infrastructure and to acquire all the necessary rolling stock is determined for both the narrow and standard gauge options. The operational parameters are also analysed and the life cycle costs determined for both options.

The standard gauge option has a major advantage with respect to the capital cost and operational cost savings linked to rolling stock. The infrastructure however costs more and this exercise aspires to provide a means to determine what premium can be spent on standard gauge infrastructure before it will neutralise the financial advantages of standard gauge over narrow gauge.

This approach can be extended to also evaluate the pros and cons of converting narrow gauge operations to standard gauge.

A number of new railway lines are currently being planned in Southern Africa. As yet none of these has advanced far enough to enter the public domain.

Knowledge of the feasibility studies however makes it possible to distil sufficient elements of these projects into a realistic notional picture to demonstrate some of the thinking currently going into the choice of rail gauge for these projects.

Existing networks in the vicinity of these projects are of the narrow gauge variety, but connectivity is generally considered to be a fairly minor issue. The project(s) are therefore classified as being quite close to a green field scenario.

The anchor commodity is coal, with a density of around 1 000 kg/m^3, which is relatively light compared to iron ore's density of around 2 500 kg/m^3. This presents quite a challenge in designing a wagon of sufficient volumetric capacity to utilize the available best practices in heavy axle loads.

Transnet Freight Rail's CCL5 coal wagon with a tare of 20,25 ton has a volumetric capacity of 85,66 m^3. Its load capacity is 84 tonnes of coal, giving it a load-to-tare ration of 4,15. It has an axle load of 26 tonnes and is the largest capacity coal wagon in the world running on NG. QR in Australia also operates 26 tonne/axle coal wagons but their payload is 82.6 tonnes. (Equipped for bottom dumping,)

In order to increase the total mass to 120 tonnes (30 t/axle), the volumetric capacity must be increased to about 100 m^3. This can be achieved by doing one of the following:

- Increasing the wagon's height by ± 490 mm (higher centre of gravity and thus less stable)
- Increase the width by ± 550 mm (thereby exceeding conventional standards for the NG vehicle profile by 500 mm and that of SG by 300 mm)
- Increase wagon length by ± 1 680 mm (a factor to be considered in negotiating sharp curves such as found with balloons used in terminal yard layouts)

Optimizing a combined extension of height, width and length might then achieve a payload of 100 tonnes (axle load of about 30 tonnes). Aspiring to wagons of even larger volumetric capacity and thus coal axle loads approaching 36 tonnes, could be technically viable. No known research and development has however taken place in this direction.

Iron ore is much denser and Transnet Freight Rail operate 30 tonne/axle wagons on the Sishen-Saldanha line with a volumetric capacity of less than half that of their coal wagons.

Increased payload per wagon contributes to the goal of increased payload per train. The size of the required wagon fleet is also reduced accordingly.

Using the current world best practice norms for bulk coal transport the gauge choices are as follows:

- A narrow gauge line (1 067 mm) running with wagons of 26 tonne per axle and a payload of 84 tonne per wagon (TFR's current coal line operation).

- A standard gauge line (1 435 mm) running with wagons of 36 tonne per axle and a payload of 123 tonnes of coal. (Union Pacific's current operation in the USA).

PARAMETERS FOR THE NOTIONAL PROJECT

Table A below describes the basic parameters of such a notional project and compares the important differences between the NG and SG options.

A	PROJECT CHARACTERISTICS	Unit	NG	SG	NOTES
1	Coal througput envisaged	Mt/a	30		Design considerations
2	Ruling grade	1 in	250		
3	Length of line	km	1 000		
4	Traction		Diesel		
5	Loco mass	tonne	180	194	Current world best practice (Transnet and Union Pacific)
6	Running adhesion (see Annexure 3)		25,5%	35%	
7	Tractive Effort per locomotive	kN	450	667	
8	Axle load (wagons)	tonne	26	36	
9	Wagon payload	tonne	84	123	
10	Train running time per direction	hours	22		Assumptions
11	Loading and unloading time per terminal	hours	8		
12	Train turn around time*	hours	60		

* The higher axle load of standard gauge locomotives tends to lower their balancing speed. Their running times are therefor likely to be somewhat longer. In this example it was kept at the same level.

The capital costs of SG and NG locomotives are best compared on a cost per tractive effort basis. Annexure 3 offers fairly wide norms but a fair summary would put the cost per kN of tractive effort in the vicinity of ± R25 000 for SG locomotives and about R60 000 for NG locomotives. The capital cost of the locomotive fleet in a best practice NG operation will therefore be about double the figure required for a similar operation in SG.

In **Table B** the wagon and locomotive fleet sizes as well as the capital costs are calculated. It shows that the project can save about R1 507m or 42% on the capital cost of the rolling stock if it is built in SG.

B	ROLLING STOCK CALCULATIONS	Unit	NG	SG	NOTES
1	Grade resistance	N/t	40		Calculations
2	Train resistance*	N/t	12	9	
3	Wagons per loco	no	78	90	
4	Operating Efficiency	%	82		Assumption
5	Trips per wagon p.a	no	120		Calculations
6	Throughput per wagon p.a	tonnes	10 056	14 726	
7	Wagons required	no	2 983	2 037	
8	Locos required	no	38.41	22.57	
9	Wagons out of service	%	10		Assumptions
10	Locos out of service	%	10		
11	Wagon fleet size	no	3 281	2 241	Calculations
12	Loco fleet size	no	42	25	
13	Cost per wagon	Rm	750 000	750 000	Assumptions
14	Loco cost per kN tractive effort	R	60 000	25 000	
15	Cost per loco	Rm	27	17	Calculations
16	Wagon fleet cost	Rm	2 461	1 681	
17	Loco fleet cost	Rm	1 141	414	
18	Capex saving on wagons	Rm		780	
19	Capex saving on locos	Rm		727	
20	**CAPEX SAVING ON ROLLING STOCK**	**Rm**		**1 507**	

* Per Transnet Freight Rail formula: $f_r^{'} = 137.3\,(w)^{-0.754}$ (f = resistance in N/t and w = axle load)

The infrastructure costs will however be higher for SG due to the requirement of a wider formation together with longer sleepers, more ballast and longer culverts. The project is assumed to traverse fairly moderate terrain not requiring any tunnels or viaducts.

Based on a cost of R10m per km, **Table C** shows the infrastructure costs to be ± R10 000 m for the narrow gauge option. The additional capital cost to do the project in SG is estimated to be about R0,7m per km which equates to an extra R700 m on the project (+ 7%).

C	TOTAL PROJECT COST		NG	SG	SG SAVING	% SAVING
1	Cost of infrastructure	Rm	10 000	10 000		
2	Additional width of formation and earthworks	Rm		300		
3	Longer sleepers and extra ballast	Rm		300		
4	Longer culverts (+ 3%)	Rm		100		
5	Total Infrastructure capital cost	Rm	10 000	10 700	(700)	-7.0%
6	Total Wagon fleet cost	Rm	2 461	1 681	780	32%
7	Total Locomotive fleet cost	Rm	1 141	414	727	64%
8	**TOTAL PROJECT COST**	**Rm**	**13 602**	**12 795**	**807**	**5.9%**

On a capital outlay of R13 602m for the total project, almost 6% (R807m) can be saved should the SG option be chosen.

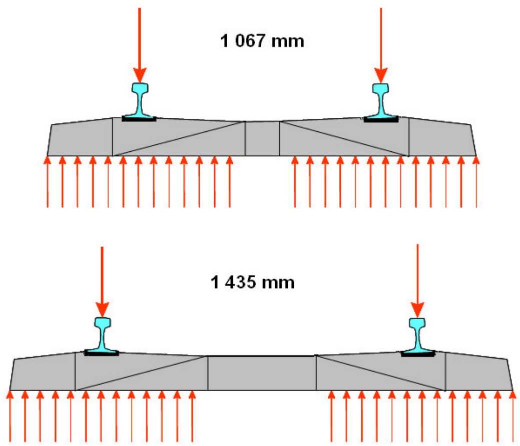
Projects should be compared on a life cycle cost basis by also taking the differences in operating costs into consideration.

Table D below provides the unit costs that were used in calculating the operational costs.

D	OPERATIONAL UNIT COSTS		NG	SG	NOTES
1	Train crew cost per train hour	R	400		Assumptions
2	Loco maintenance cost per loco per year	R	1 100 000		
3	Wagon maintenance cost per wagon per year	R	45 000		
4	Track maintenance cost per km per year	R	275 000		
5	Fuel cost per MGT (Million gross tonne)	Rm	8		

- Track maintenance cost is assumed to be at the same level for both options. Operationally one would expect a reduction in track maintenance cost for the SG option because of:

  - larger footprint of the sleeper on the ballast (better stress distribution in the foundation)
  - improved lateral stability (larger composite beam represented by the track structure)
  - reduced effect of geometric twist errors on track riding quality
    (a 5 mm error in twist on SG will have the same effect as a 3,7 mm error on NG – more or less in proportion to the difference in gauge)



  It is difficult to quantify these SG advantages in financial terms. The larger footprint of the sleeper should also be taken into account conservatively, because of the nature of ballast tamping machines. The centre portion of the sleeper provides minimal to zero vertical support as per the adjacent sketch, although it does provide higher resistance to cross-level disturbance.

  On standard gauge the track also experiences about 10% less gross tonnes for the same throughput of 30 Mt/a (see Table E). This is a further advantage in favour of SG.

  In this analysis, these advantages are countered by a 38% higher axle load. This will increase contact stresses on the rails as well as on the foundation layers. Thus the approach to use R275 000 per km p.a for both options.

Table E applies these unit costs to the operating factors applicable to the notional project and indicates that the total annual operating costs will be about 13% less for the SG option.

E	OPERATING FACTORS & COSTS p.a		NG	SG	SG SAVING	% SAVING
1	Number of locos	ea	42	25	17	41.3%
2	Number of wagons	ea	3 281	2 241	1 040	31.7%
3	Track kms	km	1 000			
4	Number of locos per train	ea	3			
5	Number of wagons per train	ea	233	271		
6	Payload per train	tonne	19 571	33 313		
7	Number of trains per year (loaded + empty)	ea	3 066	1 801	1 265	41.3%
8	Ratio of gross to net tonnes for wagons		1.476	1.341		
9	Wagon gross	Mt/a	44.286	40.244	4.042	9.1%
10	Loco gross	Mt/a	1.656	1.048	0.607	36.7%
11	Total gross	Mt/a	45.941	41.292	4.649	10.1%
12	Train hours per year (loaded + empty)	hr	67 447	39 625	27 822	41.3%
13	Train crew cost per year	Rm	27	16	11	41.3%
14	Loco fleet maintenance cost per year	Rm	46	27	19	41.3%
15	Wagon fleet maintenance cost per year	Rm	148	101	47	31.7%
16	Track maintenance cost per year	Rm	275			
18	Total fuel cost for 30 Mt/a throughput	Rm	368	330	37	10.1%
19	**TOTAL ANNUAL OPERATING COSTS**	**Rm**	**864**	**749**	**114**	**13.2%**

The Table further indicates that the major advantages for SG will come from:

- A reduction in maintenance costs for wagons (32% less wagons)
- A reduction in maintenance costs for locomotives (41% less locomotives)
- A reduction in train crew costs (41% reduction in train hours)
- A reduction in fuel costs (10% reduction in gross tonnes)
  (The absence of an actual line profile precludes a proper simulation for fuel consumption)

Table F integrates the operational savings with the capital cost premium and calculates the unit transportation cost for the notional project.

F	**TRANSPORTATION COST** cent/ton.km (ZAR)		NG	SG	SG SAVING	% SAVING
1	Capital Cost of infrastructure	Rm	10 000	10 700	(700)	-7.0%
2	Capital Cost of Rolling Stock	Rm	3 602	2 095	1 507	41.8%
3	**Total Capital Cost of Project**	**Rm**	**13 602**	**12 795**	**807**	**5.9%**
5	Discount period in years	25				
6	Interest rate (% p.a.)	15				
7	Total capex loan repayment p.a.	Rm	2 104	1 979	125	5.9%
8	Total operating cost p.a.	Rm	864	749	114	13.2%
9	Total cost p.a.	Rm	2 968	2 729	239	8.1%
10	Payload	Mt.km	30 000			
11	**Unit transport cost**	**c/t.km**	**9.89**	**9.10**	**0.80**	**8.1%**

Based on the relevant assumptions **Table F** illustrates an advantage of some 8% in unit transport cost for standard gauge over narrow gauge in what could be termed a “best case greenfield scenario”.

DISCUSSION

In heavy haul projects, the name of the game is maximum throughput with minimum hardware. This calls for the longest and heaviest trains within the capabilities of available technologies.

Axle load and train length drive the best practice operations.

On NG the current best practice for coal traffic is 26 tonne per axle on South Africa's Coal Line and on Australia's QR. It would be fair to say that 30 tonne per axle is within reach of NG. The ultimate limitation might be the volumetric limits to which a wagon can be designed for the relatively light density of coal.

On SG the current best practice for coal traffic is Union Pacific's 36 tonne per axle in the USA.

Iron ore is 2,5 times denser than coal, so that volumetric limits in wagon design are not a factor for NG. The current best practice for iron ore traffic is South Africa's 30 tonne per axle on the iron ore line.

On SG the current best practice for iron ore traffic is BHP's 36 tonne per axle in the North-West of Australia. Others operators elsewhere in the world also run at similar axle loads. BHP is however already running part of its operation at 40 tonne per axle. This is pushing towards a new limit for world's best practice.

The tractive effort of NG locomotives is however limited by the back-to-back wheel-set dimensions of a motored bogie. SG locomotives are way ahead of their NG counterparts in terms of cost per kN tractive effort. It would be fair to say that there is no indication that NG will be able to catch up or overcome this handicap (also refer to Annexure 3)

The crux of this Annexure is to determine the point where the standard gauge advantages provided by rolling stock and operational savings will be neutralised by the premium required for the infrastructure.

Table G shows that this point is reached when the capital cost required for a standard gauge operation exceeds that for a narrow gauge option by R743m or 5,5% for the notional project. Bearing in mind that the SG option has a rolling stock capex advantage of R1 507m, it means that the infrastructure disadvantage can escalate to R2 250m. (compared to R700m in Tables C and F).

This represents a figure of R2,25m per km in the notional project. That is a ± 23% increase in infrastructure costs in stead of 7%.

G	**TRANSPORTATION COST** cent/ton.km (ZAR)		**NG**	**SG**	**SG SAVING**	**% SAVING**
1	Capital Cost of infrastructure	Rm	10 000	**12 250**	(2 250)	-22.5%
2	Capital Cost of Rolling Stock	Rm	3 602	2 095	1 507	41.8%
3	**Total Capital Cost of Project**	**Rm**	**13 602**	**14 345**	**(743)**	**-5.5%**
5	Discount period in years	25				
6	Interest rate (% p.a.)	15				
7	Total capex loan repayment p.a.	Rm	2 104	2 219	(115)	-5.5%
8	Total operating cost p.a.	Rm	864	749	114	13.2%
9	Total cost p.a.	Rm	2 968	2 968	(1)	0.0%
10	Payload	Mt.km	30 000			
11	**Unit transport cost**	**c/t.km**	**9.89**	**9.89**	**0.00**	**0.0%**

Extrapolating this to a total conversion scenario for South Africa's freight network, shows that the advantages would be wiped out if the cost of conversion exceeds R2,25m per kilometre.

In practice such a figure of around R2,25m/km can be considered to be quite high as it is based on a "best case greenfield scenario". A conversion to SG scenario that does not allow for increases in axle load must cost substantially less than say R2m/km before any meaningful economic advantage will be provided.

The advantages presented by rolling stock and general operational savings increase with larger traffic volumes.

The advantages decreases for lesser traffic volumes and reaches a point where the advantages are neutralized by the additional cost required to establish standard gauge infrastructure compared to that of narrow gauge.

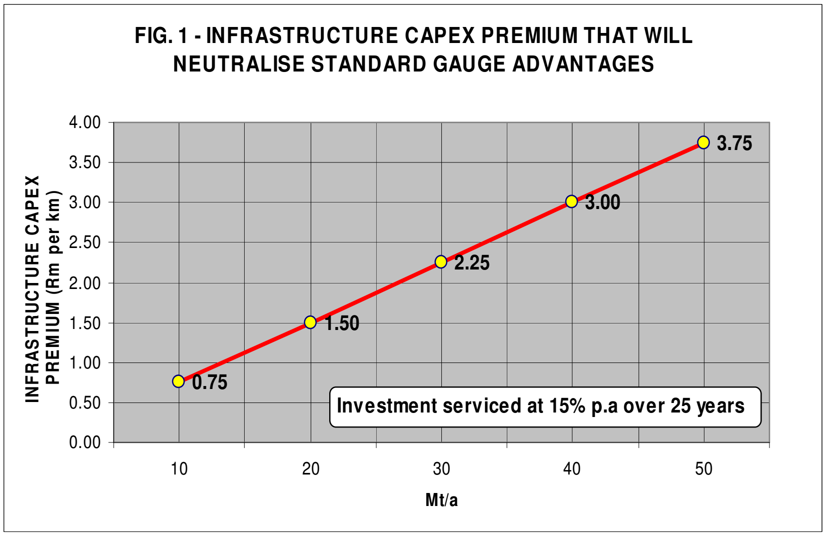


Figure 1 illustrates the affordable premiums that can be spent on infrastructure before the SG advantages will be neutralized.

The affordable premium ranges from about R1m to R4m per km for traffic volumes ranging from 10 to 50 Mt/a.

(Figure 1 was obtained by reworking Tables A to G for different traffic volumes)

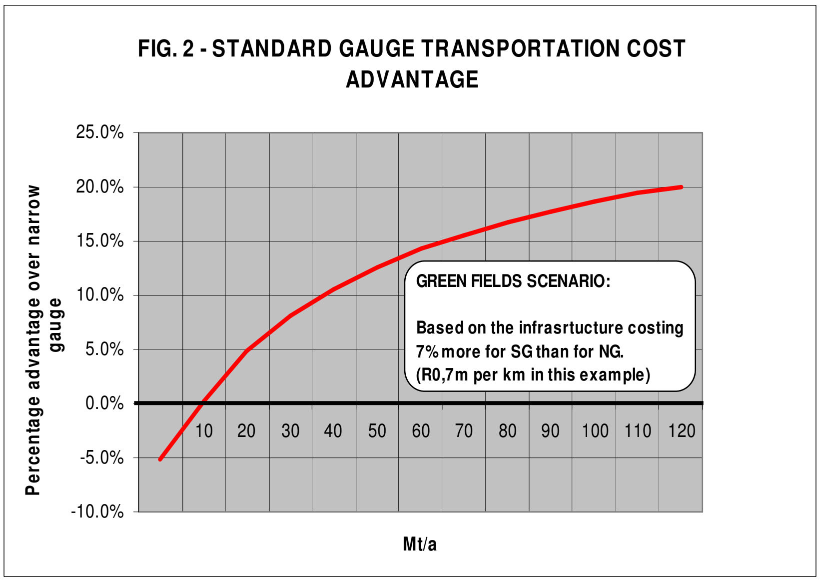


Figure 2 was obtained in similar fashion by varying the annual tonnage in Table A and recording the percentage saving in favour of standard gauge as reflected in Table F.

Below 10 Mt/a the advantages created by the rolling stock and operations are wiped out by the additional cost of the track infrastructure.

From 10 Mt/a upwards the standard gauge advantage in unit transportation cost increase to about 10% at 30 to 40 Mt/a and to about 20% for traffic volumes exceeding 100 Mt/a.

The calculations have been based on a discount period of 25 years and a discount rate of 15% p.a. Different rates will change the results but will not have any meaningful effect on the percentage savings between the SG and NG options.

A sensitivity analysis indicated that the numbers in Figure 1 will decrease by only 3% if the discount period is reduced to 15 years. The results are also not meaningfully sensitive to a change in discount rate. For rates varying between 8% and 22%, the values in figure 1 will not increase or decrease by more than 10%.

This analysis achieves the objective of determining the order of magnitude of the advantages of a standard gauge operation over a narrow gauge operation. It will be useful to evaluate the pros and cons of converting a narrow gauge line to standard gauge.

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ANNEXURE 5

CONSIDERATIONS FOR A PASSENGER LINE FROM JOHANNESBURG TO DURBAN

(Version 5 - 200908)

PURPOSE OF THIS ANNEXURE

To do a desktop study determining choice of technology as well as overall costs, throughput times and unit seat-trip costs for a notional high speed passenger train service between Johannesburg and Durban.

Look at current and possible future demand as well as other scenarios that can possibly contribute to make such a service feasible.

BACKGROUND

The corridor between Gauteng and Durban is the prime inter regional corridor in South Africa for passengers, and general- and specialised freight. Most of the exports and imports for Gauteng, the economic hub of South Africa, move through the Port of Durban. The KwaZulu-Natal coast is also the major holiday destination for the people of Gauteng and the surrounding provinces.

The current rail corridor between Johannesburg and Durban follows a route of 760km via Standerton, Volksrust, Newcastle, Ladysmith and Pietermaritzburg.

The main road route in this corridor is about 600 km long, and under constant pressure for all the critical elements - capacity, maintenance, and safety. The current high volume of heavy vehicles on this corridor is creating frustrating and dangerous situations for motor vehicles.

The current 1 067mm gauge double rail line is underutilised, with no significant passenger traffic on the line.

The integrated demand forecast by Transnet[1] indicated that the traffic on this corridor was 56 million ton in 2006 (8.2 million ton on rail and 47.8 million ton on road), and that the volumes would most likely grow to 112.2 million ton by 2026. The container traffic might grow form 0.84 million TEU in 2007 to 3.18 million TEU by 2036. The motor vehicles to be transported might grow from 3.18 Mt/a in 2007 to 28.42 in 2036, while the break bulk is expected to grow from 28.32 Mt/a to 114.45.

The forecast by Transnet indicates that operational improvements would be needed by 2020 and infrastructural capacity improvements by 2036 to cope with the expected demand.

All the domestic airlines in South Africa operate a substantial number of daily scheduled flights between the two metros.

[1] Transnet National Infrastructure Plan of February 2008

The current door-to-door commuter travelling time between Gauteng and Durban exceeds 14 hours by train and is approximately 6 to 8 hours by motor vehicle and 3 to 4 hours by airline.

Travelling by motor vehicle is done with the same mode of transport for the entire trip; hence total flexibility in the choice for departure time is available for the traveller.

The travelling by airline is combined with a trip to the airport by another mode of transport, checking in and waiting time at the airport, and a trip from the airport with another mode of transport. The flexibility in choice of departure time is limited to the available scheduled flights, as well as demand for specific flights, particularly those in peak periods.

Table 1 gives an indication of the various options currently available between the two cities.

TABLE 1: JHB - DBN (Door to Door)

MODE	TRIP TIME hrs	COST ZAR pp	COMMENTS
Air (low cost economy)	3½	750	1 hour flight + depart & arrival allowances + road connect
Air (standard full price economy)	3½	1 250	1 hour flight + depart & arrival allowances + road connect
Private Midsize Car (total running costs)	7	1 100	2 persons; AA rates of ± R3,40/km; Toll fee; 120 km/h; 2 x 30min comfort stops
Private Midsize Car (total running costs)	7	550	4 persons; AA rates of ± R3,40/km; Toll fee; 120 km/h; 2 x 30min comfort stops
Private Midsize Car (fuel & toll cost only)	7	300	2 persons; 120 km/h max; Toll fee; 2 x 30min comfort stops
Minibus (Fixed timetable)	9	180	Often door to door
Minibus (Flexible timetable)	9 - 11	140	Wait for full load
Passenger Bus (Luxury)	9	180	8 hour bus + depart & arrival allowances
Train (Prasa) - Eonomy class (Sitter)	14	90	13 hour by train + depart & arrival allowances (Daily)
Train (Prasa) - Tourist class (Sleeper)	14	190	13 hour by train + depart & arrival allowances (Thu only)
Train (Prasa) - Premier class	14	870	13 hour by train + depart & arrival allowances (Tue & Fri only)

TILT TRAIN OPTION TO REDUCE RAIL JOURNEY TIME ON THE EXISTING LINE

The passenger journey on the current narrow gauge line requires about 13 hours. An average of 40 minutes is allocated to five interim stops. The average running speed is therefore about 60 km/h with the actual speed varying between 40 and 90 km/h.

Queensland Railways in Australia run a tilting train at speeds of up to 160 km/h on their narrow gauge lines[2]. The train is capable of tilting by about 5 degrees which is equivalent to a virtual increase in cant or super elevation of about 100 mm.

Passengers experience discomfort due to out of balance lateral accelerations when a train is travelling faster than the speed for which the curve is canted. Tilting trains can negotiate curves at higher speeds than conventional trains before passengers will experience discomfort. The level of safety against overturning is however not improved by tilting.

[2] Railway Gazette International, June 2007 (Queensland Rail)

On narrow gauge, tilting can provide an extra 10 – 20 km/h around curves compared to conventional trains. As a rough approximation, assuming that the entire route is on curves limited to 90km/h, a tilting train should be able to increase the average speed between Johannesburg and Durban from 60 km/h to at best about 70 km/h. Other things remaining equal, this should reduce the current 13 hour journey time by about 2 hours to 11 hours. Of course, there are many other determinants of train speed, including balancing speed on long up gradients, and curves limited to much less than the 90km/h line speed. The actual gain, which should be determined by simulation, could thus be less than 2 hours.

Such a reduction is neither here nor there. Any substantial improvement in journey time will therefore require a new railway line with suitable easy horizontal alignment and matching high performance rolling stock.

A number of mishaps have plagued the Queensland tilt train operation such as an overturning accident as well as a level crossing collision with a heavy road vehicle. The service was suspended earlier this year pending further investigations.[3]

CONVERTING THE EXISTING LINE TO STANDARD OR DUAL GAUGE

The only practical way to go would be dual gauging. Converting the existing 760 km double line by means of dual gauging is estimated to cost about R6,7m per km (see Annexure 7) or a total of R50bn. From a passenger point of view one would remain stuck with the old alignment and geometric standards.

Speeds on straights and curves could be increased and whereas a tilt train operation might improve journey time to 11 hours, it is doubtful whether a standard gauge operation on the existing line will do much better than 9 or 10 hours.

Apart from the risk factor, mixing such a medium speed (130 to 150 km/h) passenger operation with the existing freight service will place much strain on the operations.

Although this will open the door to procuring standard passenger rolling stock on the international market the improvement in journey time is still neither here nor there when compared to the alternative modes (Table 1). The pros will be far outweighed by the cons and such a project would be tantamount to throwing good money after bad.

REQUIREMENTS FOR A NEW LINE

The major motivation for a new rail line in this corridor would be to provide time sensitive services for passengers and possibly freight.

The UIC task group on high speed lines found that high speed lines could be divided into 3 types[4]:

Type 1: **Exclusively high speed** (Speeds of 250 – 350 km/h)

Type 2: **High speed** mixed with **conventional passenger trains** at lower speeds

Type 3: **Mixed passenger traffic** (high speed and conventional) **and freight**.

A high speed rail service would also require additional trips to and from the stations as for air travel, although the location of stations might however be more favourable relative to business and residential origins and destinations. The checking in and boarding times of a train could also be substantially less than for an airline, due to the absence at present of security screening.

[3] Australian Tilt Train Taken Off. Railways Africa, April 2009.
[4] Design of new lines for speeds of 300 – 350 km/h. State of the Art; UIC 2001

The scenario that follows is based on using the world's current best practice norms for high speed intercity passenger rail and is based on the 1 435 mm standard gauge.

Time sensitive freight could also make use of such a line. The justification for such a line would be based mainly on the speed and safety competencies of the system, and would require flat curves but not necessarily flat gradients.

Heavy intermodal and other freight traffic require flatter gradients because of the size of the trains. Moderate speeds up to 100 km/h are sufficient, as customer expectations dictate predictable origin to destination times rather than high point to point travelling speeds.

A dedicated high speed passenger line needs very flat curves (3 000 to 6 000 m radius) but can accept gradients as steep as 1 in 25[5]. Building a line for both high speed and heavy freight require flat curves and flat gradients, as well as a number of operational and other compromises. In difficult terrain the capital cost penalty can also be severe.

To provide a service with a choice of departure and arrival times comparable with that of the airlines, most of the route would have to be on a double line. A single line through critical tunnel sections might however provide sufficient initial capacity.

Phase 1 of the NATMAP report for KZN indicates the current passenger traffic on this route, as: (according to tables 74, 76 and 78 which are based on the National Household Transport Survey of 2003)

- 13 500 business trips per month from Durban to Gauteng,
- 16 500 business trips per month from Gauteng to Durban
- 4 400 migrant trips per month from Durban to Gauteng
- 41 600 migrant trips per month from Gauteng to Durban
- 68 600 holiday trips per year from Durban to Gauteng
- 301 400 holiday trips per year from Gauteng to Durban

All the trips will generate return trips. The average trips per direction per day was therefore 3 560 in 2003.

The NATMAP report for KZN also indicates in table 32 that Durban domestic air passenger numbers to as well as from all destinations amounted to 6 550 per day in 2007.

LENGTH OF LINE AND TRAVELLING TIMES

A balance would need to be struck between the length of the line and the construction cost for earthworks, tunnels, and viaducts. A dedicated passenger line could be built at steeper ruling grades and the track could be canted in the curves solely for the high speeds of the passenger trains.

The UIC specified that for high speed lines the track centres should be increased from 4.00 m to 4.5m and that the minimum radius for the different speeds should be as shown in Table 2 below[6].

[5] For example, the Frankfurt-Cologne high speed line in Germany.
[6] Design of new lines for speeds of 300 – 350 km/h. State of the Art; UIC 2001

***Table 2:* Minimum standards for standard gauge rail lines for general mixed traffic and high speed lines**								
	Standard Lines					**High Speed Lines**		
Maximum Speed (Km/h)	**80**	**100**	**120**	**150**	**200**	**270**	**300**	**350**
Min. Radius for Horizontal Curves: (m)	900	1 000	1 450	2 250	2950	3 846	4 545	7 143
Min. Radius for Vertical Curves: (m)	2 600	4 000	5 800	9 900	16 000	25 000	25 000	25 000
Maximum Cant *(mm)*	120	120	120	120	120	180	180	180
Cant deficiency – Passenger comfort *(mm)*	100	100	100	100	100	100	85	65
Cant deficiency – Freight Trains (*mm)*	70	70	70	70	-	-	-	-
Excess cant – Passenger Comfort *(mm)*	70	70	70	70	70	-	-	-
Excess cant – Freight Trains *(mm)*	50	50	50	50	-	100	100	-
Maximum Gradient	1:40	1:40	1:40	1:40	1:40	1:35	1:35	1:35

The dilemma is however to balance the cant of a curve between the maximum speed of the high speed train and the much lower maximum speed (minimum speed for the curve) of a freight or ordinary passenger train.

For any combination of curve radius and speed, there is an equilibrium cant. Once the cant on a curve is fixed faster trains will experience a cant deficiency. Limits are set for this deficiency for reasons of passenger comfort. Likewise slower trains will experience excess cant. This also requires limits for reasons of safety and also for passenger comfort.

Figure 1 **MAX IN MIN SPEEDS (based on cant)**

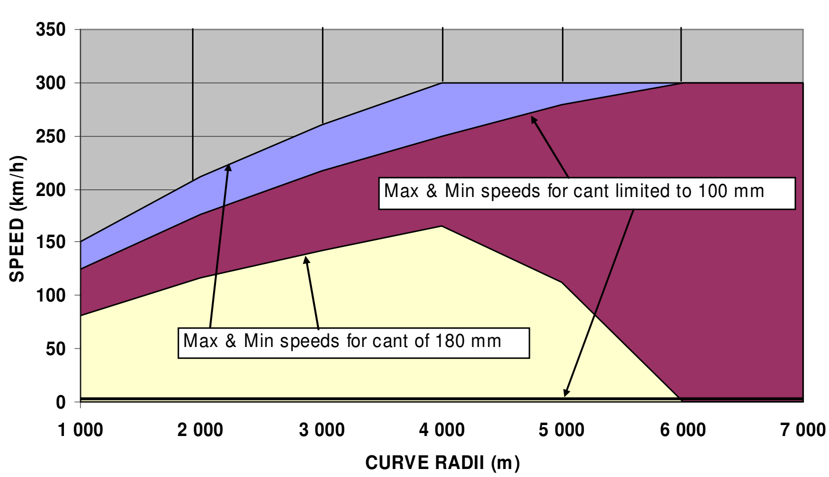


Figure 1 indicates the maximum and minimum speeds around curves for different cant conditions. The UIC task team on high speed lines recommended a maximum cant of 180 mm for high speed lines, a maximum cant deficiency of 85mm and excess cant of 100mm for speeds of 300 km/hr.

When curves are canted optimally for high speeds (180 mm cant), there are limits to how slow other trains may travel. For example Figure 1 shows that the minimum speed for a slow train will be about 115 km/h on a 2 000m radius curve canted at 180 mm for a 210 km/h fast train. On a 4 000m curve where the fast train can go at 300 km/h, the slow train may not drop to below 165 km/h!

The only way to handle this is to reduce the cant to about 100 mm maximum. Slow trains can then move at any speed but the fast trains have to sacrifice 25 to 50 km/h of its potential for radii below 4 000m. For flatter radii the problem starts to fade away.

A summary of a desk top exercise for such a line is reflected in Table 3 below.

The direct distance between Johannesburg and Durban stations is 500km, while the road distance is 605km along the N3 and 665km via Volksrust and Newcastle. The distance of a new high speed line should be of the order of 650km.

Table 3: *Distances between Johannesburg and Durban Stations*

ROUTE	Distance (Km)
Direct Distance (as the crow flies)	500
Road: N3 via Harrismith	605
Road via Volksrust & Newcastle	665
Existing Rail via Volksrust	760
New High Speed Line: Probable Conceptual Average	650

The total length of new line will be influenced by how the ruling grade and minimum curvature are balanced against the capital cost for earthworks, viaducts and tunnels. The assumption is made that the standard of the line will vary through the different sections in order to reach a balance between capital and operating cost and travelling times.

Table 4 below gives an indication of the probable standard and travelling times for different alternative rail systems. It indicates that a reasonably fast total travelling time of less than four hours could be achieved on the conceptual line. Such a line would enable high speeds in the easier terrain and relatively low speeds in the mountainous terrain. The current average air travelling time from airport door to airport door is more than 2 hours.

Table 4: *Comparison between different speed alternatives for a 650 km Line*											
LOW SPEED LINE			**MEDIUM SPEED LINE**			**HIGH SPEED LINE**			**CONCEPTUAL LINE**		
Dist. *(km)*	Max. speed *(km/h)*	Travel time *(h:m)*	Dist. *(km)*	Max. speed *(km/h)*	Travel time *(h:m)*	Dist. *(km)*	Max. speed *(km/h)*	Travel time *(h:m)*	Dist. *(km)*	Max. speed *(km/h)*	Travel time *(h:m)*
120	80	1:39	80	100	0:53	40	100	0:27	40	100	0:24
140	100	1:33	150	120	1:23	60	150	0:27	60	120	0:31
390	120	3:20	180	150	1:20	50	200	0:17	110	150	0:45
			240	200	1:20	50	250	0:14	120	200	0:38
						100	300	0:22	120	250	0:31
						350	350	1:06	200	300	0:44
Average Speed (km/hr)											
	102			**132**			**225**			**174**	
Total Travelling Time (excluding intermediate stops)											
		6:22			**4:56**			**2:53**			**3:33**

ESTIMATED INFRASTRUCTURE CAPITAL COST

Such a line would go through moderate to severe hilly terrain with numerous mountainous areas and three distinct escarpments. Numerous tunnels and viaducts would be required especially in the exceptionally difficult terrain through the "Little Drakensberg" escarpment and the mountainous terrain between Estcourt and Durban.

The estimate below is based on conceptual assumptions to obtain an order of magnitude indication of the capital requirements for such a line.

- **Civil Construction**

The estimate is based on the following assumptions for the conceptual alternative:

- ➢ The line would be built for:
  - high speed (maximum of 300km/hr) in the sections where the requisite standards could be achieved with reasonable earthworks, tunnels and viaducts.
  - moderate speeds (150 – 250 km/hr) where the terrain is hilly and
  - low speeds (less than150 km/hr) in mountainous and suburban areas.
- ➢ Approximately 120 km of the line could be on viaducts that should be built for double lines.
- ➢ Approximately 100 km of the line could be in tunnels. Tunnels could be double line profiles where the ground conditions permits and twin in less suitable ground conditions. The line could be single in long tunnel sections.
- ➢ The line would be built at 4.5 meter centres.
- ➢ The best location for the line will be used without attempting to link directly with any intermediate locations.

  - **Rail Structure**

    The track should be built with UIC60 rails on concrete sleepers at 600mm centres.

  - **Electrification**

25 kV AC would be used.

- **Signalling**

  The line would be signalled in accordance with the latest standards set by the UIC for high speed lines with moving block signalling.

- **Facilities**

  Maintenance facilities would need to be provided for the rolling stock and locomotives. Depending on the route of the line relative to existing infrastructure facilities new facilities would need to be provided.

  Maintenance tools and equipment would need to be provided because the available equipment in the country is designed and built for 1067 mm gauge lines.

- **Other**

  Such a line would initially be a stand alone system in South Africa. All backup, spare and emergency equipment, rolling stock and locomotives would be dedicated to the system.

  Table 5 below indicate the assumptions for the length, speed and travelling times for such a line.

***Table 5*: Estimated length of a standard gauge line and possible speeds that could be achieved.**

Section	Direct Distances *(Km)*	Route Distance *(Km)*	Ave. Speed *(Km/hr)*	Traveling Time *(Hrs)*
JNB – Harrismith	260	290	300	0.97
(The line would be reasonably flat and straight with high speeds possible.)				
Harrismith - Bottom of escarpment	34	80	120	0.67
(The line would need to wind down the escarpment with numerous tunnels and viaducts. The traction needed for the high speeds on the flatter sections would be used at steeper grades with lower speeds.)				
Bottom of escarpment - Mooirivier	100	120	160	0.75
(The area is moderate hilly which should make a medium speed line possible with relative few tunnels and viaducts.)				
Mooirivier - Durban	120	150	120	1.25
(The section of the line is going through mountainous terrain down two escarpments. Many tunnels and viaducts would be required, while the speed on some sections would be low)				
TOTAL & AVERAGE SPEED:	**514**	**640**	**180**	**3.54**

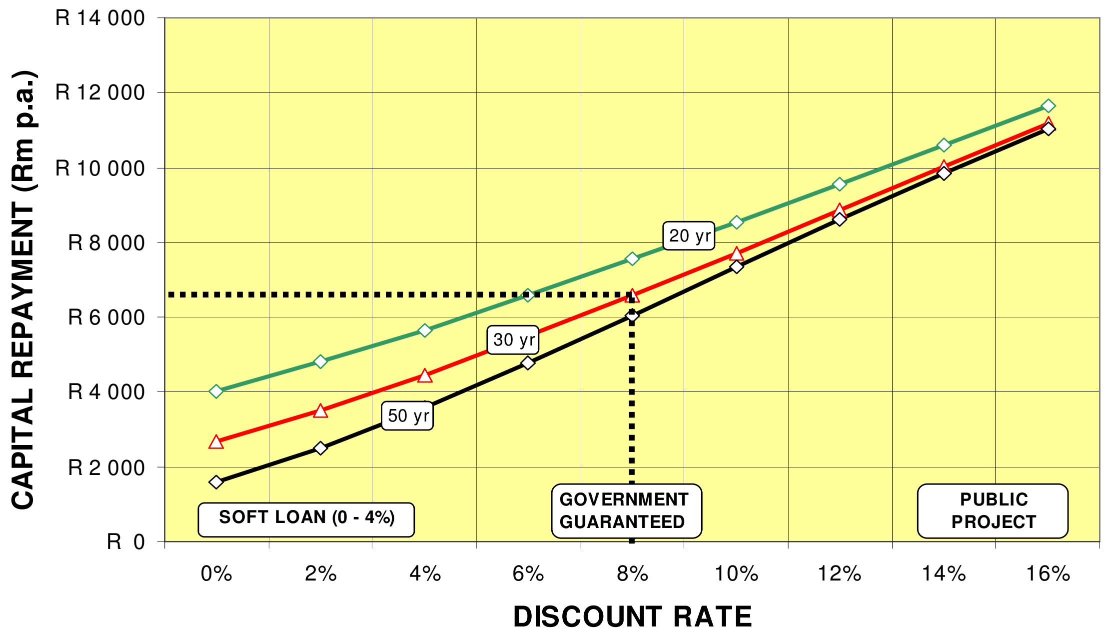
Table 6 below gives an indication of the possible capital requirements, in 2008 money, for the infrastructure of such a line.

Table 6: **INFRASTRUCTURE**	**Unit**	**Rate *(Rm)***	**Quantity**	**Total *(Rm)***
Standard Gauge Rail Line (Double line)	km	25	640	16,000
Extra for Tunnels (Double line)	km	160	200	32 000
Extra for Viaducts (Double line)	km	275	100	27 500
Electrification (Double line)	km	4	640	2 560
Signalling	item	2	640	1 280
Maintenance Facilities (Rolling Stock & Track)	each	500	1	500
Contingencies & Rounding	item	160	1	160
TOTAL	**Rm**			**80 000**

INFRASTRUCTURE CAPITAL COST PER PASSENGER SEAT

The annual amount required for capital repayment of the infrastructure capital cost will depend on the discount period and the discount rate. Figure 2 below shows the influence of these parameters.

Figure 2: DISCOUNTING R80 BILLION ACCORDING TO RATE & PERIOD



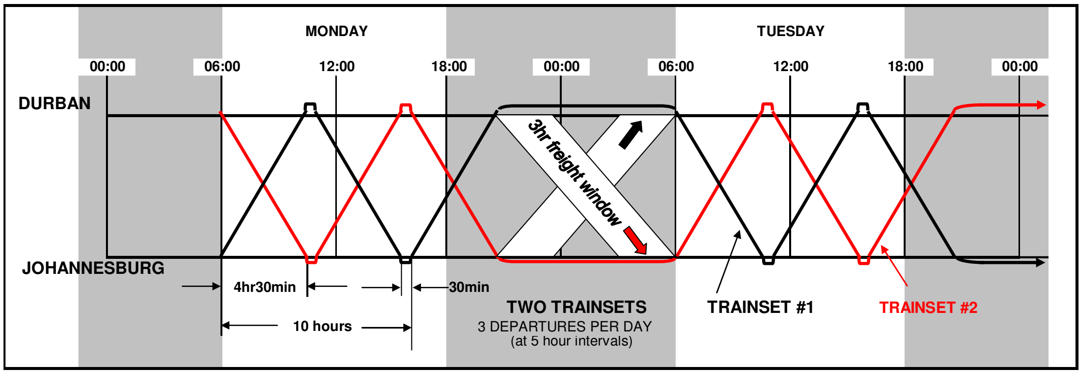
The capital repayment is less sensitive to the discount period at the higher discount rates. A discount rate of 8% over a period of 30 years is considered suitable for state funded projects with a social flavour. This will require capital repayment of about R6,6bn per year.

Soft loans at a rate of say 2% could reduce the required repayment to R3,5bn per year.

Another option would be to utilize some slots at night for freight trains (possibly double stack container trains). This will reduce the portion of the infrastructure cost that the passenger service needs to carry.

Figure 3 provides an indication of a time table for 1 800 seats per day per direction.

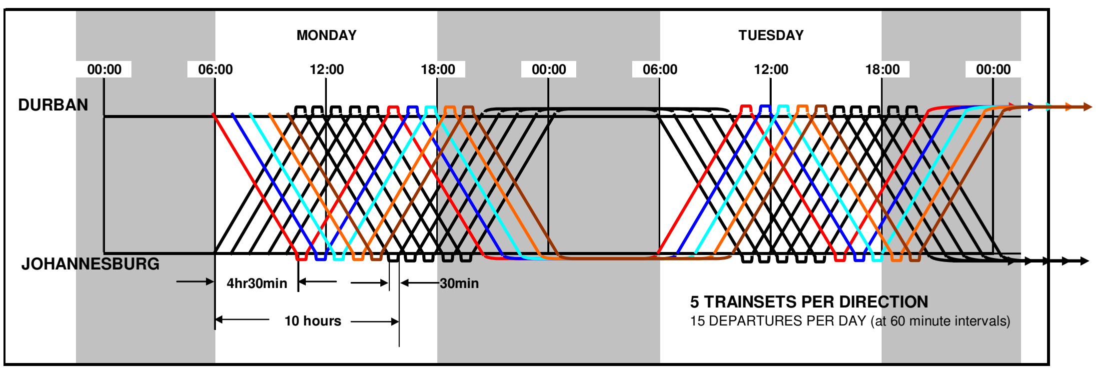
Figure 3: Conceptual time table with two trainsets providing 1 800 seats per direction per day



Two train sets can provide three departures per day per direction at 5 hour intervals.

Figure 4 shows how the time table can be upgraded to 9 000 seats per day per direction by increasing the number of train sets to 10. This provides 15 departures per day at 60 minute intervals.

Figure 4: Conceptual time table with ten trainsets providing 9 000 seats per direction per day



ESTIMATED CAPITAL COST FOR ROLLING STOCK

It is assumed that such a service would commence with 10 coach high speed train sets, powered with traction motors on all the bogies. The estimated cost of a train set is R150m.

Should the capital cost of a train set be recovered over 15 years at 8% and one train set would do one and a half round trip per day then the capital cost of the trains would be R50 per seat-trip (or R38 if recovered over 30 years).

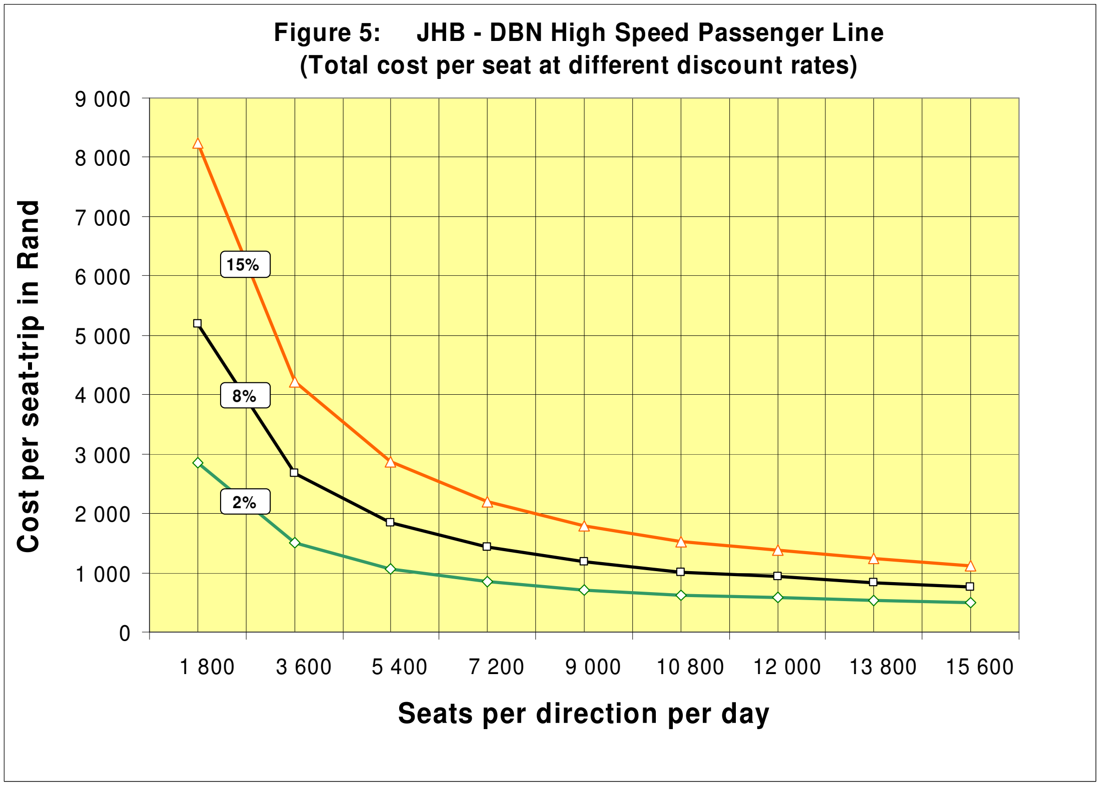
ESTIMATED OPERATING COST

The estimated maintenance, energy and staff cost per seat-trip is estimated at **R130.**

ESTIMATED COST PER SEAT-TRIP

The capital repayment on R80bn will be about R6,6bn p.a at a discount rate of 8% (see figure 2). For 2% and 15% the repayment will be R3,5bn and R10,6bn respectively.

Figure 5 shows the cost per seat-trip based on different discount rates with a fixed amount of R180 added throughout for train and operating costs.



A rate of 15% is considered to be a reasonable average that private investors would require on an investment of this nature. At this rate the annual recovery of capital cost will almost double compared to the 8% rate. On the other hand subsidized or soft loans at say 2% will bring repayment down to almost half compared to the 8% rate.

It is clear that there is a strong sensitivity for choice of discount rate.

The capital cost will remain constant in nominal Rand value during the discount period while the maintenance and operating cost as well as the ticket selling price will increase with escalation.

FREIGHT TRAIN CONTRIBUTION TO COST RECOVERY

The spare capacity shown in Figure 3 could be made available for freight trains. This will reduce the need for the passenger service to carry the full financial burden of the fixed infrastructure costs. For safety and operational reasons, high speed passengers and medium speed freight should not be mixed.

As no passenger trains will run between 21:00 and 06:00 (Fig. 3) this will be an ideal opportunity to use this window for freight and maintenance purposes. If container trains are capable of completing the journey in 6½ hours (running at up to 130 km/h), there will be a 3 hour moving window that can accommodate 6 freight trains per night in each direction at about 30 minute intervals.

For 9 000 seats per day per direction the window for freight trains will be reduced to only 5 hours per night (Fig 4). This will be insufficient for a medium speed freight train to complete its journey. With some adjustment to the schedule it will be possible to stretch the gap between the last passenger train arrival and the first morning departure to about 7 hours and so still accommodate about two freight trains per direction.

It is clear however that the availability of a night time window for freight trains will reduce as the demand increases for more passenger seats. By the time this demand exceeds 9 000 to 10 000 seats per day per direction there will be little to zero scope to accommodate freight trains.

Based on the 8% discount rate and provided there are takers for the freight slots that might be on offer, it should be possible to cap the cost per seat trip at about R1 000 for all scenarios below 10 800 seats per direction per day. This is still a substantial price if compared to other options open to a commuter as per Table 1.

There will be one important issue that is not discussed here. High speed passenger trains require very easy curves but can operate on gradients as steep as 1 in 35. Freight trains use head end or distributed locomotives requiring flatter gradients but can operate on much sharper curves due to the reduced speeds. If a high speed passenger line is built with flatter curves in order to also accommodate freight trains, there will be a capital cost penalty. An alternative would be to use additional motive power. That will increase the cost of operations.

PROJECTED PATRONAGE AND COST ASPECTS

In 2007 about 1,7 million passengers travelled by air between Johannesburg and Durban[7]. This equates to 4 660 per direction per day. At a growth rate of 6,7% p.a. this figure will escalate to 10 800 per day by 2020 and to 20 000 per day by 2030.

Inspection of Fig. 5 reveals that the cost per seat will only come down to around R750 per direction (8% discount scenario) when the number of passengers per day rise to above 15 000 per direction. That is more than the total number of passengers projected per day per direction for air traffic between these two cities by 2020.

It must be kept in mind that the recovery of the capital cost would remain constant and thereby reducing the real cost of a ticket with the inflation rate. Based on an average inflation rate of 5% the real capital cost portion of a ticket would be reduced to 60% after 10 years and 40% after 20 years.

On the other hand average occupancy will be less than 100%.

Pricing the tickets will have to take all these factors into consideration.

[7] ACSA Flight statistics

SUMMARY

Reducing journey time between Johannesburg and Durban over the existing line by introducing tilting trains on the narrow gauge or by running standard gauge rolling stock after dual gauging the existing line is not considered workable solutions.

It would however be possible to provide a new standard gauge line where a high speed passenger train service can complete the journey in less than 4 hours. A few stops will add somewhat to this throughput time but it can be expected to be fairly competitive with air travel's 3½ hour door-to-door times.

Such a railway line can only be provided on standard gauge.

The train service will only be able to compete with the cost of airline tickets if there is a substantial growth in passenger volumes and/or some cost sharing with freight rail services and/or the provision of subsidized loans.

According to this desk top study it does appear that such a high speed passenger rail service between Johannesburg and Durban might be feasible sometime in the future. Proper market research into all aspects will be a prerequisite.

NATMAP RAILWAY WORKING GROUP (RWG)

RAILWAY GAUGE

ANNEXURE 6

THE MOLOTO CORRIDOR[1]

(Version 4 - 200904)

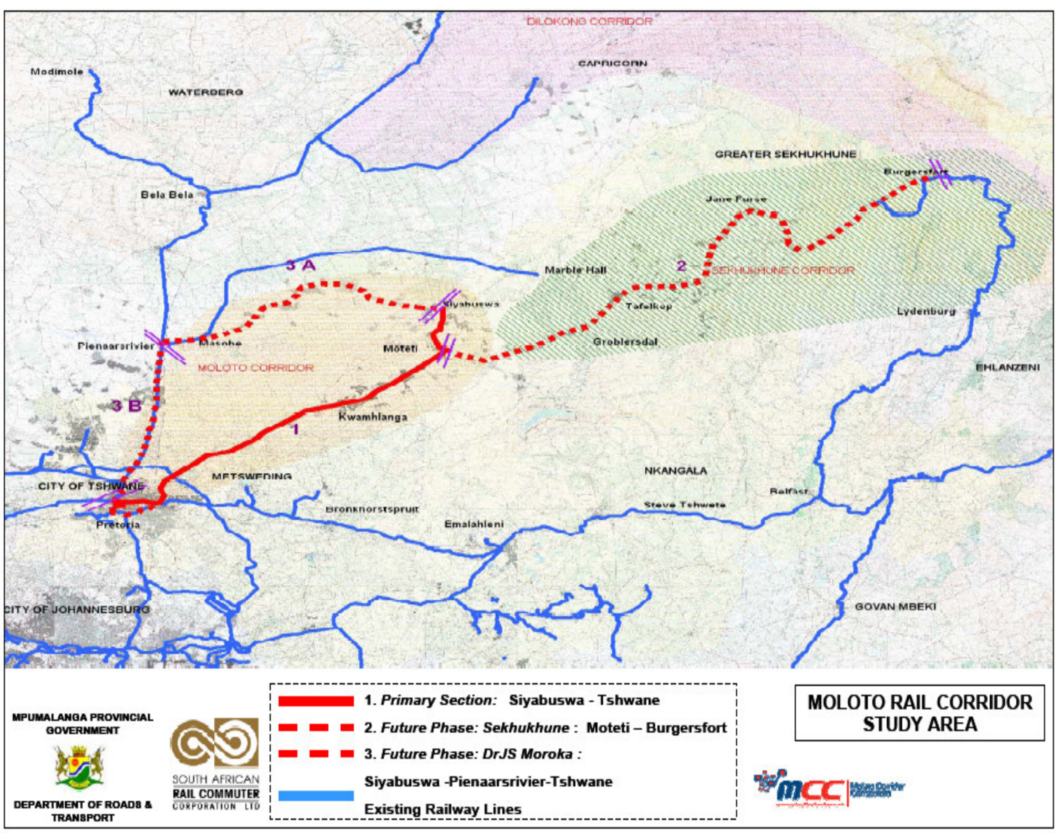
BACKGROUND[1]

A large number of people who live in the western areas of Mpumalanga Province, (north-east of Tshwane) travel daily by bus to their place of work in Gauteng

A detailed feasibility study was done by the MCC (Moloto Corridor Consortium) for the Department of Roads and Transport of the Mpumalanga Provincial Government for the transportation of commuters within the Moloto Corridor from their residences to places of employment in Gauteng, mainly in the greater Tshwane area.

The extent of the corridor, which runs from Burgersfort in the north-east through Siyabuswa to Tshwane in the south-west, is shown on Figure 1 below.

Figure 1 *Moloto Corridor Study Area (Obtained from: Moloto Rail Corridor Development Initiative – Detailed Feasibility Study)*



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[1] Moloto Rail Corridor Development Initiative –Detailed Feasibility Study

Large numbers of commuters travel daily by bus over long distances resulting in excessive travel times and high financial impact on both the commuters and authorities. The majority of the communities with in the corridor are poor, have low levels of education, have high levels of unemployment, and are dependent on public transport. The main problems associated with the existing transport system include:

- unacceptable levels of service quality;
- an insufficient road network particularly in the local residential areas,
- increasing traffic congestion in urban areas and
- in particular the road accidents with injuries and loss of life.

An average of 642 busses with 46 000 passengers per direction per day serviced this area in 2006. The 5-year average growth rate of the bus passengers was 9%.

The 2006 cost of the bus services was R651m of which R425m was subsidized. The average cost of a single direction trip was R30.80. The average taxi fares were R7 for local trips, R10-R15 from smaller villages to the bigger areas and R20-R30 for long trips across the provincial boundary, resulting in an economic value of R440m-R500m per year for the estimated daily trips of between 150 000 and 173 000.

OBJECTIVES OF THE PROJECT

The **objectives of the project** are aimed at the design and the feasibility of a new integrated multi-modal transport system that is proposed for the Moloto Corridor to serve as a spine and catalyst for economic development within the western regions of Mpumalanga. The Moloto Rail Corridor Development Initiative therefore consists of two components, namely to review the transport system, not only to solve the commuter problem, but also to establish an economic activity spine to stimulate local economic development. The initial project is aimed at the feasibility of the primary section only, namely the section between Siyabuswa and Tshwane as indicated in figure 11.4.1 above.

SOLUTIONS INVESTIGATED

The study investigated the following options:

(i) **The Current Bus System** using public roads. The study found that this system would not be technically and financially capable to provide the service along the corridor within the acceptable levels of cost efficiency, service quality, safety and technical sustainability.

(ii) A **Bus Rapid Transit System (BRT)**, using exclusive bus lanes for combination busses, was also found not to improve the current bus services sufficiently.

(iii) **Current 10M5 Metrorail technology,** which is used in the Tshwane metropolitan area. It operates on narrow gauge on gradients of 1:40 and flatter, with a maximum speed of 100km/h. (See Figure 2)

Figure 2 – 10M5

(iv) **Contemporary EMU** technology on narrow gauge, which can operate on gradients of 1:25 and flatter with a maximum speed of 120km/h. If they were suitably adapted for 120km/h, among other by re-gearing and fitting appropriate pantographs, one could consider the 8M contemporary EMUs deployed by Metrorail in the Cape Peninsula an example.

(v) **High-speed EMU** technology, which requires standard gauge for stability reasons and that can operate on gradients of 1:25 and flatter, with maximum speed of 160-200km/h and possibly higher.

(vi) **High-speed locomotive-hauled double deck trains,** with similar speed as for the high speed EMU but that uses double deck coaches and that offer much higher passenger carrying capacity.

Figure 3 – Double deck EMU

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The study found that any road based solution operating as a long haul system was not viable along the Moloto corridor. By using the core competencies of a rail based solution the goals of reduce transit times, safety and capacity to deal with the high volume of commuters would be achieved the best.

The rail system would be supported by road feeder- and distribution systems, to optimize accessibility to the main system for the majority of the population. The system would also link into the current Metrorail system as well as the bus and taxi services in Tshwane to accommodate intermodal transfers.

They achieve the objective of reducing the traveling times by at least 30 minutes and preferably 45 minutes trains should be able to achieve average cruising speeds of at least 140 km/hour.

COMPARISON BETWEEN NARROW GAUGE AND STANDARD GAUGE

The study compared the rail options, using the narrow gauge suburban services currently operated by SARCC in the Tshwane area with **10M5** rolling stock as the base case, against a narrow gauge contemporary EMU solution (Option (iv) above), and two standard gauge rail solutions (Options (v) and (vi) above).

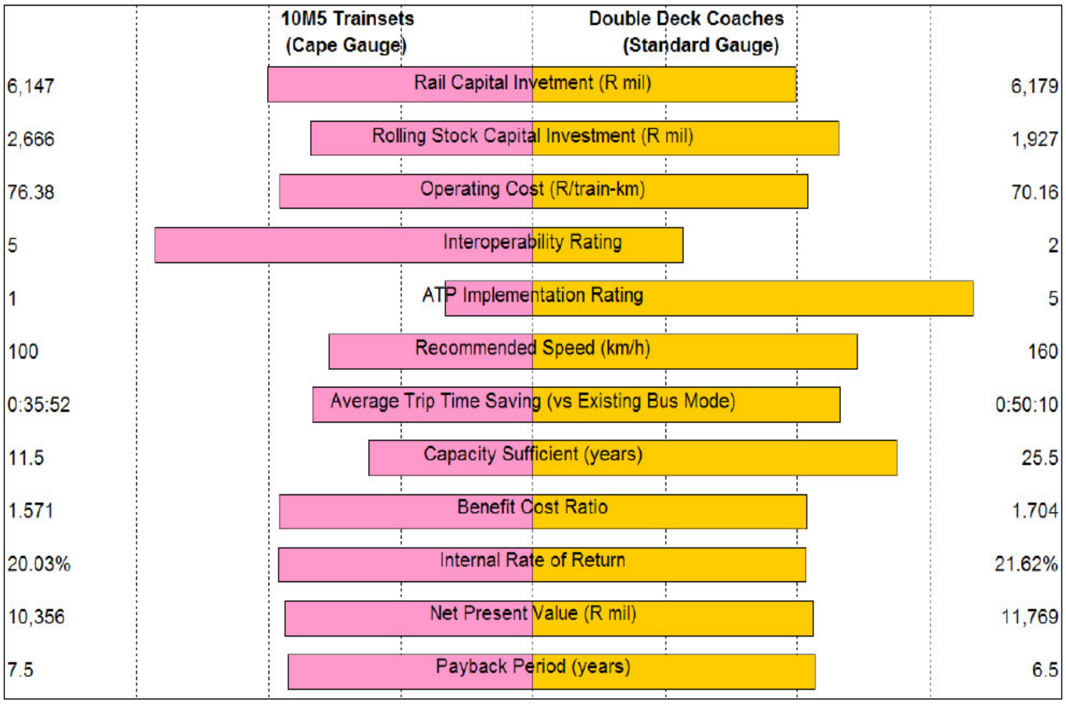
All the rail options for the primary section between Siyabuswa and Tshwane make provision for a new double line of 124 route kilometers with running from Siyabuswa in a new rail reserve to connect with the Mamelodi rail system at Koedoespoort. The 16 kilometers from Koedoespoort would be built in the existing rail reserve to terminate at Belle Ombré Station.

The study found that there would not be sufficient capacity on the existing rail lines between Koedoespoort and Belle Ombré to accommodate the additional traffic. All the options would therefore require additional new lines in this section.

The primary Moloto rail system makes provision for 12 new stations and the use of 3 existing stations.

Figure 4 schematically compares the critical parameters of a standard gauge line operated with Double Decker Coaches with a narrow gauge line operated with 10M5 Train Sets.

Figure 4 *Moloto Corridor – Comparison between narrow gauge line with 10M5 train sets and standard gauge lines with Double Decker Coaches for the primary section between Siyabuswa and Tshwane. (Obtained from: Moloto Rail Corridor Development Initiative –Detailed Feasibility Study)*



CAPITAL REQUIREMENTS

The study compared the 4 rail options described in (iii) to (vi) above.

The infrastructure cost of the standard gauge line is estimated to be approximately R32m (0.5%) more than that of the narrow gauge line. This is mainly due to the longer sleepers and additional ballast that would be required.

The Double Decker rolling stock would cost 38% (R739m) less than the10M5 rolling stock. This is because a train with five Double Decker coaches and one locomotive could carry approximately the same number of passengers as a 12 coach 10M5 train set.

ECONOMIC AND FINANCIAL FEASIBILITY

The study determined the economic (without inflation) and financial (with inflation) feasibility parameters for the different rail options.

The report drew the following conclusions from the economic and financial analyses:

(i) In economic terms, i.e. constant 2007 money, the cost-benefit analysis indicates that the primary section of the Moloto Rail Corridor is positive for all the various options of rail technology tested,:

(ii) In financial terms, which add the inflation effect, these values are more significant and strengthens the positive outcome of the project:

(iii) The financial analysis also indicates that the expected breakeven point for positive cash flow is between years 6 and 8, depending on what option is applied.

(iv) Whilst the cost-benefit analysis indicates that any of the rail technology options is better than the existing bus system, the analysis also concludes that the best rail technology is the High Speed Double Deck option that operates on standard gauge. This option outperforms the best- and worst-case current Metrorail technology options using Cape gauge with between 5% and 14% over the full evaluation period.

LINE CAPACITY

The study determined the capacity (number of trains during peak periods) for each rail option.

Table 3 below indicates the time within which the initial capacity of each rail option would be sufficient to accommodate the estimated growth in commuters. The table indicates that the **double-deck rail technology** option would provide sufficient capacity far beyond the other options.

The contemporary EMU and the high speed EMU technology also offers significant longer periods than the current 10M5 Metro technology being used in Tshwane.

Table 3: *Table indicating the time before the line capacity will need to be increased for the different systems.*

TYPE OF RAIL LINE	**NARROW GAUGE (1 067 mm = 3' 6")**		**STANDARD GAUGE (1 435 mm = 4' 8½")**	
TYPE OF TRAIN SET	**10M5**	**EMU**	**Double Decker Coaches**	**EMU High Speed**
No. of years before line capacity needs to be increased.	11.5	15.9	25.5	15.9

TRAVEL TIME SAVINGS

In comparison to the existing bus system, simulations indicate that the expected savings in average travel time per direction would be about 34 minutes for the 10M5 rolling stock, travelling at a maximum speed of 100km/h. The saving would be about 50 minutes for the high speed standard gauge technology, based on a maximum speed of 160km/h.

The annual savings in travel times for the commuters in comparison to the bus mode are estimated at R180m for the 10M5-option and R266m for the high speed rail options.

SAFETY

The report concluded that the rail mode will be superior to any road-based solution in terms of traffic safety and that the feasibility of the rail project is beyond doubt.

CONCLUSIONS IN THE REPORT

From the perspectives of all the feasibility criteria that were set, the report concluded that the primary section for the Moloto Rail Development Corridor project between Siyabuswa and Tshwane, is feasible in all respects.

A number of aspects justify special mention such as:

(i) A comparison between the total cost of the current bus system and the integrated rail system indicates that a total direct cost saving of between R10,356m - R11,828m can be achieved over the evaluation period of 25 years (assuming the current bus system is replaced and road feeder services used in conjunction with a rail system)

(ii) The analysis not only indicated a considerable net benefit for the rail options, but the sensitivity analysis also indicated that there is no significant risk that any of the variables could have a substantial influence on the main outcome.

(iii) Whilst any of the rail options prove to be feasible regardless of the choice of technology, the feasibility analysis also reveals substantial financial and technical differences between the two alternative rail technology options (the current low speed Metrorail technology versus the high-speed Standard gauge technology).

(iv) In terms of the initial capital requirements, the High Speed Double Deck train sets proved to be the most cost efficient. It requires about R700m less capital at the outset of the project. Further additions to the rolling stock fleet for capacity expansions as well as rail operating costs will also favour the double deck option.

(v) The high-speed options offer 47% more travel time savings than the 10M5, i.e. 50 minutes versus 34 minutes per direction. The high speed double deck system is also less demanding on the limited rail line capacity than the 10M5 trains. With the 10M5 narrow gauge technology the double line will run out of capacity after about 11 years compared to only 25 years for the double deck standard gauge technology.

(vi) By contrast, the current 10M5 rolling stock has the advantage of being interoperable with the existing network as compared to the new technology that is not yet common in the local rail industry. The report considered this advantage as questionable for this project.

(vii) In overall terms the standard gauge High Speed Double Deck train option outperforms the current narrow gauge Metrorail technology option by between 5% and 14% over the full evaluation period.

(viii) The total capital budget requirement for the proposed rail system is estimated to be between R8 554m and R9 260m, depending on which option is chosen.

NATMAP RAILWAY WORKING GROUP (RWG)

RAILWAY GAUGE

ANNEXURE 7

CONVERTING SOUTH AFRICA'S RAIL NETWORK TO STANDARD GAUGE

(Version 5 - 200908)

OBJECTIVE OF THIS ANNEXURE

The advantages of a standard gauge freight operation originate largely from the rolling stock. Annexure 4 quantified these advantages for a greenfield example of a heavy haul coal line. The advantages presented by rolling stock and general operational savings increase with traffic volumes.

On the other hand, the infrastructure for standard gauge track demands a cost premium over that of narrow gauge.

The affordable premium that can be spent on infrastructure before the standard gauge advantages are neutralised, diminish in line with the reduction in traffic. This was also illustrated in annexure 4. It was shown that the affordable premium ranges from about R1m to R4m per km for traffic volumes ranging from 10 to 50 Mt/a.

This annexure (7) has one main objective in mind. That is to determine the order of cost magnitude to convert one kilometre of narrow gauge railway line to standard gauge. This figure can then be compared to the advantages of a standard gauge operation as set out in annexure 4.

The focus for this annexure is on the freight network as operated by Transnet. Passenger rail is involved to the extent that the Passenger Rail Agency of South Africa (PRASA) operates intercity services over the Transnet network.

Suburban rail is not addressed here. It is a special rail application in its own right and is the subject of a separate study.

BACKGROUND

The original narrow gauge rail lines in South Africa were built without significant structural design of the formation. The emphasis was mainly on the balancing of the earthworks between cut and fill without selecting suitable material for the different layers, while compaction of the layers was also done to low standards. The result was frequent differential settlement of embankments requiring regular re-alignment of the rail top. This problem was partially overcome in many areas by increasing the thickness of the ballast underneath the sleepers and thereby lifting the rail top. The effect was that the shoulders of the formation were taken up by the increased ballast, which fulfils the same function as the sub-ballast in later formation designs. Any widening of the ballast profile for a wider gauge would therefore require that the formation be widened.

The formations of the lines built since the 1960's were built to improved specifications and standards for the specific purpose that the lines were designed for. These design standards had axle loads of 18 to 22 tonnes in mind and would therefore generally be inadequate to cope with substantial increases in axle loads. The formations of many of these later lines might be wide enough to accommodate the ballast profile for a standard gauge line. It would nevertheless result in very limited and inadequate space between the toe of the ballast and the edge of embankments, or the drainage channel in cuttings.

ASSUMPTIONS

The following assumptions were made to estimate an order of magnitude cost to convert the existing 1 067mm gauge rail lines to 1 435mm standard gauge lines. Upgrading is excluded from the calculation in order not to cloud conversion with upgrading.

(i) **Axle loads** remain as before

Most of the main lines are being used for 20 ton axle loads (rated 22 ton) and the export lines for 26-30 ton axle loads (rated 30 ton).

(ii) **Curvature** remains as before

The existing lines were in general built for a maximum speed of 90 km per hour.

(iii) **Ruling Grades** remain as before

(iv) Double lines remain at **4,00 m centres**.

(v) **Track centres in yards** remain the same as currently for the narrow gauge lines.

(vi) The standard gauge line can generally fit into the structural **horizontal clearance** of the narrow gauge line except below platform height where NG is considerably narrower. (The SG standard is 200 mm wider than that of NG)

The horizontal clearance of some of the older steel bridges, structures and tunnels are less than what would be required for the standard vehicle profile of a standard gauge line. Some allowance is made for this in Table 1.

(vii) The standard gauge line can fit into the **vertical clearance** of the narrow gauge line.

SG vehicle profiles are generally much higher than that of NG. All core lines in South Africa are electrified and therefore generally provide some additional vertical clearance. Double stacking of containers will however not be possible without substantial height clearing, which is not included in the estimates.

The vertical clearance of some road-over-rail bridges, tunnels and structures are less than what would be required to utilise the full vertical vehicle profile of a standard gauge line. Some allowance is made for this in Table 1.

LAND REQUIREMENTS

There should be sufficient land in almost all the rail reserves to accommodate the widening of banks and cuttings.

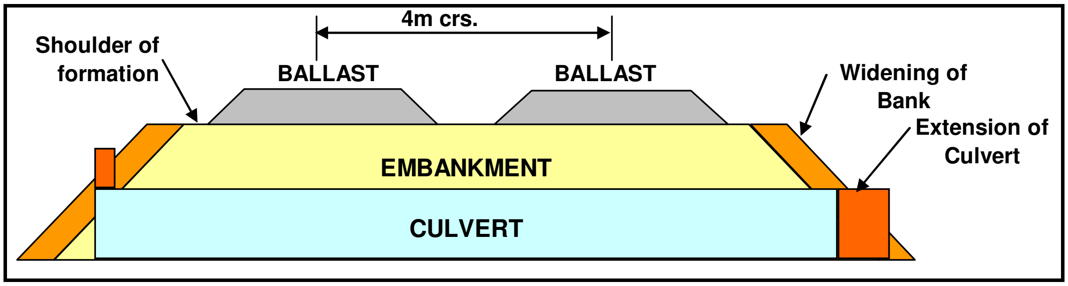
It is assumed that no significant additional land would be required to change a line from narrow to standard gauge, except where such an exercise would also be used to improve the alignment of the line at the same time (flatter curves and grades, shorter routes, etc.). Such improvements have not been included in this annexure.

EARTHWORKS

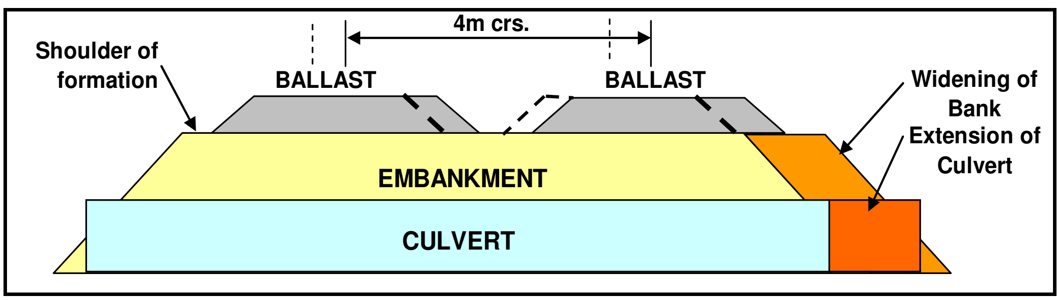
Widening of embankments

The wider ballast profile of the standard gauge line would require that the formation be widened on both sides of the outer rail if the centre line of the standard gauge line is to be kept in the same position. Widening the formation would require culverts to be extended. It might be possible to only raise the wing walls of some bridges and culverts. Each case should however be investigated and optimized on its own.

Construction and adequate compaction of narrow extensions to embankments would be difficult and relatively expensive. The width of standard earthworks equipment will dictate the width of extensions. Some sections will not require any widening (but to a limited extent only)



Another alternative would be to do the extension on one side only. The centre lines of the tracks would then have to be moved. Such extensions could then be done with heavy earthmoving equipment to a minimum width of approximately 2.5 meters. Fairly substantial benching could then be done into the existing embankments without endangering the tracks on the embankments. This method would however also require moving of the electrification masts and other structures.

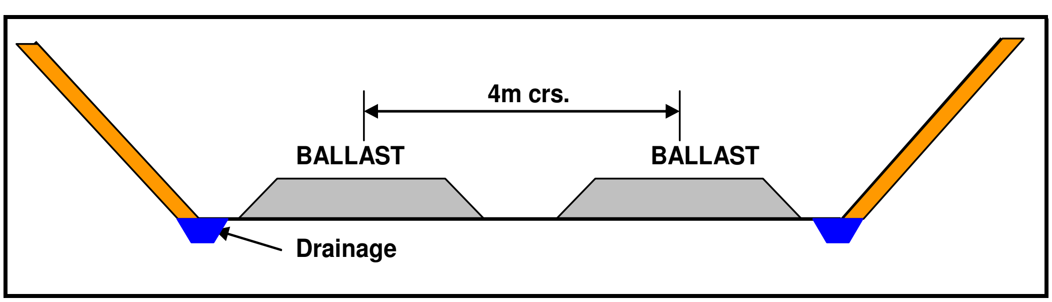


Widening of Cuttings

Widening of cuttings will be necessary where the standard gauge ballast profile would spill into the existing side drains.

The widening of cuttings would be easier than embankments because the sides of a soil cutting could be trimmed back by any amount within the reach of the construction equipment. Special protection would be required where this work is required close to electrification structures. Special equipment and processes would also be required in deep cuttings.

Rock cuttings would however require blasting with the associated protection of the infrastructure and delays to the rail traffic.



BRIDGES

Following the assumption that the standard gauge line, when built on the same centre line as the narrow gauge line, and for the same axle loading, bridges would not require any changes.

Some steel bridges protruding above rail level are likely to present width and height clearance problems that will have to be addressed. (See Table 1)

The vertical clearances of some road-over-rail bridges are less than what would be required to utilise the higher vertical vehicle profile of a standard gauge line. Some allowance is made for this in Table 1.

Should it be required to utilize the additional vertical vehicle profile such as for double stacking of containers and double deck coaches, the decks of all the road-over rail bridges should be raised together with the road profile over the bridge, or alternatively, in some cases, the track could be lowered. This would be an upgrading project and is not allowed for in this estimate.

STRUCTURES

The structures adjacent to and above the rail lines would have to be evaluated individually.

PLATFORMS

Where the track centres of the standard gauge line would be on the same line as the existing narrow gauge line, most of the platforms could probably be reworked by adjusting the coping blocks.

TUNNELS

Both the vertical and horizontal clearances of the narrow gauge tunnels are less than what would be required for an unrestricted standard gauge rail line. The older tunnels built for the steam profiles are even narrower and lower than the tunnels built since the 1950's.

The vertical clearance of tunnels could be increased by lowering the floor. A substantial portion of the tunnels was built through bad ground conditions. Lowering these floors might require substantial lateral support to prevent the linings from sagging or even dropping during construction. The reinforced track slabs would also need to be broken out and replaced.

To increase the horizontal clearances would require the breaking out and re-building of the tunnel lining. In some cases it may be possible to convert the tunnel to a cutting.

Such alterations would only be possible if total occupation could be taken on a tunnel for a significantly long period.

ELECTRIFICATION

A modest allowance is made in the estimate (Table 1) for adjusting the electrification, primarily to accommodate dual gauge track.

In a serious gauge conversion scenario, electrification will however require a major investigation. Standard track gauge will require standard gauge locomotives for which 25 kV AC is the electrification system of choice. It would not be prudent to acquire 3kV DC standard gauge locomotives because they are not a global standard (although they do exist, e.g. Italy). So locomotives and electrification should really become part of a gauge-conversion deal.

The estimate does not include for a general traction conversion to 25 kV AC and is therefore probably under-estimating the cost of a gauge conversion by a substantial margin.

SIGNALLING

The existing signalling and train authorization systems could remain if the wider gauge lines would be used for the same type of functions as the existing rail lines. Where a third rail would be provided to create dual gauge, substantial alterations would be required to the signalling layout.

Improving the signalling systems and train authorization techniques in order to increase capacity, speed and safety is not included in the estimate.

RAIL LINE

The gauge of a corridor could be changed by:

(i) Building a new line to standard gauge, or

(ii) Changing a line to dual gauge by replacing the sleepers and providing a third rail, or

(iii) Rebuilding sections of a line to standard gauge and either transfer the passengers and tranship the cargo at the end of a section.

A practical approach would be to provide a third rail in order that both narrow gauge and standard gauge trains could be used during the transition period.

Dual Gauge 1 435/1 067 mm WestRail Ausralia

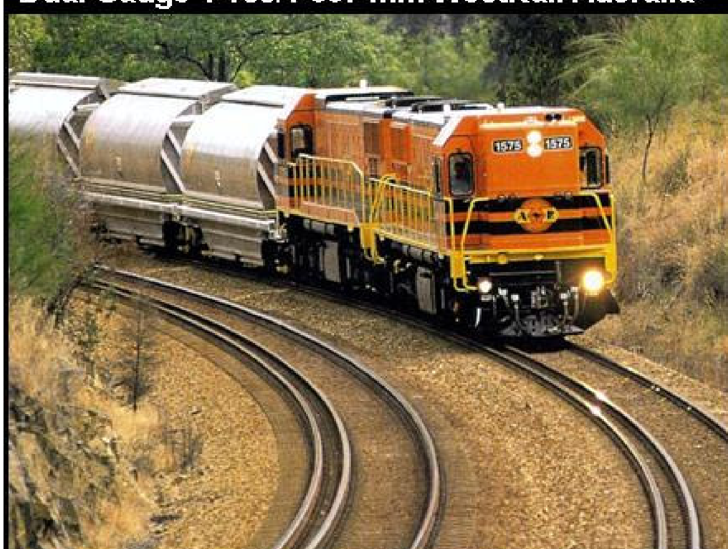


Illustration: Railway Corporate Strategy cc

The sleepers would have to be replaced with either dual gauge or standard gauge sleepers.

The existing rails could be retained based on the assumption that axle loads will remain as before in this theoretical exercise.

Turnouts will have to be replaced with complete new dual gauge or standard gauge turnouts.

Approximately 150m^3 per kilometre additional ballast will be needed for the 370mm wider ballast profile

The estimate is based on converting the complete core network to dual gauge as this would be the best way to limit the operational problems associated with a change of gauge. In practice this will probably be done in stages.

INDICATIVE COST TO CONVERT SA's NG NETWORK TO SG

Transnet's current 22 300 route km rail network (30 000 km of track) consists approximately of[1]:

- 15 000 km core network (including the heavy haul lines)
- 10 000 km non core network
- 5 000 km of no service/ abandoned lines

The suburban networks in the four metro areas (Cape Town, eThekwini, Johannesburg, Tshwane) belonging to the SARCC consist of:

- 2 200 km of track

The estimate is limited to converting the 15 000 km core network to dual gauge in order to achieve as smooth a transition as possible. It is also assumed that approximately 80% of the core network consists of double track.

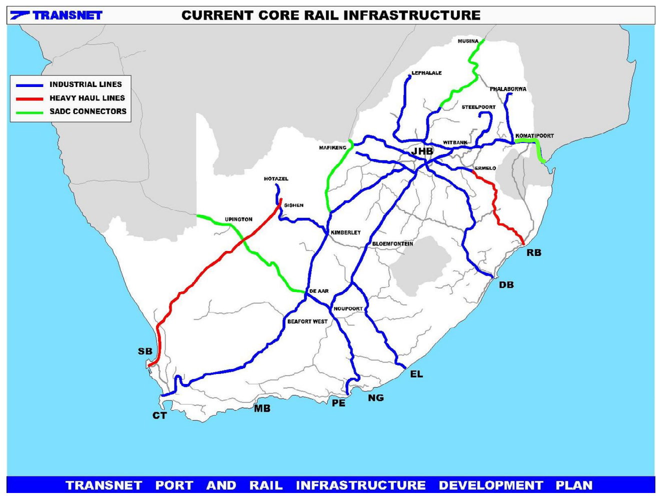


Table 1 provides an indicative cost of **R100 000 million** for the conversion. This excludes provision for rolling stock.

At R100 000m per 15 000km, the average conversion cost is R6,7m per km of track of which the dual gauging alone will cost R4m per km.

TABLE 1	**CONVERSION OF 15 000 Km CORE NETWORK TO DUAL GAUGE**			
Item	**Unit**	**Rate (Rm)**	**Quantity**	**Total *(Rm)***
Widen formation (cuttings & embankments) (double line)	km	1.0	6 000	6 000
Widen formation (cuttings & embankments) (single line)	km	1.0	3 000	3 000
Adjust electrification	km	0.5	15 000	7 500
Lengthen culverts & some bridges (double line)	km	0.3	6 000	1 800
Lengthen culverts & some bridges (single line)	km	0.3	3 000	900
Replace certain steel bridges	ea	20.0	50	1 000
Increase vertical clearance at road over rail bridges	ea	8.0	500	4 000
Convert tracks to dual gauge (replace sleepers, add 150 cub m ballast and add a 3rd rail)	km	4.0	15 000	60 000
Remodel signalling	km	0.2	15 000	3 000
Increase vertical clearance in 30% of tunnels	km	50.0	30	1 500
Remodel handling equipment (Tiplers, loaders etc)	ea	200.0	10	2 000
Contingencies (10%)				9 300
TOTAL INFRASTRUCTURE COSTS				**100 000**

[1] Transnet Integrated Port and Rail Masterplan, April 2007

ROLLING STOCK

Transnet currently owns a fleet of 102 675 freight wagons of which 77 849 are available for service according to the TFR website. Taking into account that the capacity and efficiency of the fleet should be improved if it were replaced with standard gauge wagons, the new fleet could be of the order of 60 000 wagons.

The average replacement cost of a freight wagon could be of the order of R800 000. (from R500 000 for coal wagons to R2 000 000 for sophisticated tankers).

Transnet Freight Rail owns 2 440 locomotives of which 2 106 are available for use according to the TFR website.

As indicated in Annexure 3, the tractive effort of standard gauge locomotives could be substantially higher than narrow gauge locomotives.

Assuming that the NG fleet could be replaced with about 1 500 standard gauge locomotives, the total cost to replace the narrow gauge wagons and locomotives with standard gauge equipment would also be about R100 000m.

With dual gauging the introduction of standard gauge rolling stock could possibly be phased in over time in line with a narrow gauge rolling stock retirement plan.

DISCUSSION

The validity of these assumptions could of course be challenged. In particular, they posit that conversion to a standard gauge railway would inherit the key parameters of a narrow gauge railway. This of course largely nullifies the benefits of conversion.

It is only logic that a real life conversion of gauge from NG to SG would aim at realising the full potential of SG. It would therefore go much further than what was assumed in this annexure:

- Higher axle loads would require formation improvements,
- Higher speeds would require flatter curves,
- Larger rolling stock would require increased track centres in yards.

All of these would require substantial additional investment over and above the basic cost of a straight forward conversion via the dual gauge route.

There will also be other stumbling-blocks such as:

- What to do about the 3kV DC electrification. 3kV DC standard gauge locomotives are not a global standard. So locomotives and electrification should really become part of a gauge-conversion deal. A possible option would be to operate with standard gauge diesel locomotives in 3kV DC areas while 25kV AC is phased in over time.
- The possible loss of railway connectivity with South Africa's neighbouring countries. This may or may not be a problem depending on whether Africa develops a new standard gauge network (and/or a gauge conversion) and if so, whether and/or when it will reach the borders of South Africa. (Refer to Annexure 2 for a summary of the Africa Union's guidelines)

  As long as the dual gauge track continues to exist, rail services to neighbouring countries could continue by means of NG rolling stock.
- Limiting a gauge change to the core network. As long as the dual gauge track continues to exist, rail services to branch lines could continue by means of NG rolling stock. Once dual gauge disappears on the core network, unconverted branch lines will have to rely on transhipping. This is likely to kill them off.

The assumptions in this annexure have nevertheless been used as a basis for analysis, but only as a starting point to determine the most basic cost of a workable conversion.

AFFORDABILITY

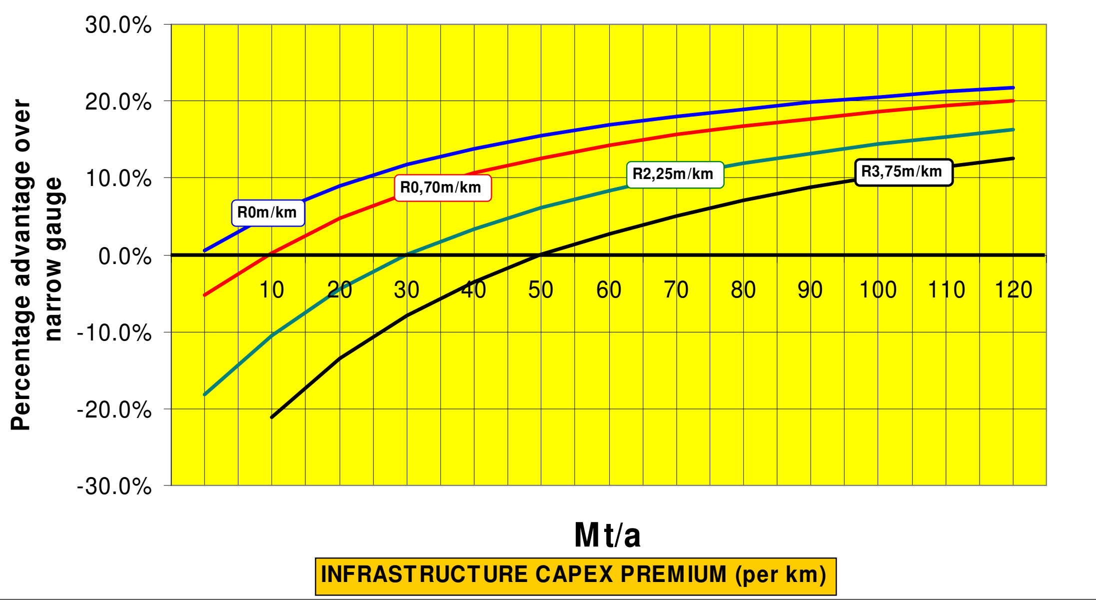
Figure 1 below represents an integrated version of Figures 1 and 2 of Annexure 4.

It illustrates that if a SG line can be established for the same cost as a NG line (nil premium), the advantages of a SG line are positive for all traffic volumes.

When SG requires a capex premium there are minimum traffic requirements for the premium to become affordable. It is shown that a premium of R3,75m per km is only affordable if the traffic exceeds 50 Mt/a.

It is clear that the advantages of SG will not be able to recover the R4m plus per km that will be required to convert a NG line to SG.

FIG. 1 - STANDARD GAUGE UNIT TRANSPORTATION COST ADVANTAGE



CONCLUSION

Changing South Africa's track gauge from narrow to standard could be workable if adequate solutions can be found for the issues mentioned in the above discussion.

Such a conversion will however not be economically viable.

A freight operation can at best afford an infrastructure premium of between R1m and R4m per km before it will neutralise the advantages of standard gauge (see Annexure 4).

A straight forward dual gauge conversion will however cost more than R6m per km.

The two heavy haul lines are the only ones in South Africa with traffic volumes approaching or exceeding 50 Mt/a.

It is clear that gauge conversion in South Africa cannot succeed from an economical point of view.

The advantages of standard gauge railway operations will be achieved best by starting with a new separate and smaller network tailored for a specific purpose(s) and based on underlying economic viability.