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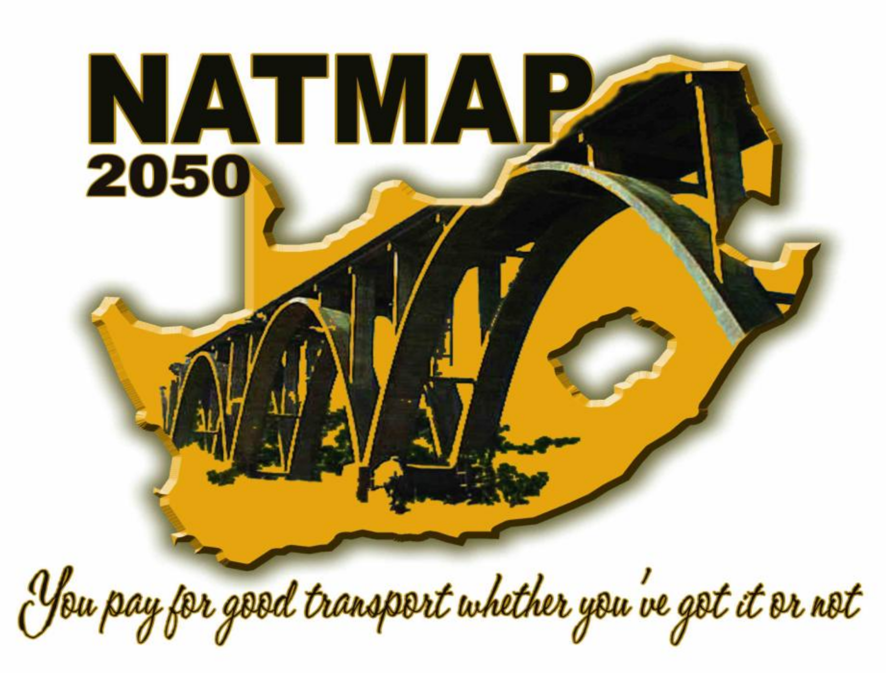
National Transport Master Plan



RAIL WORKING GROUP

PASSENGER RAIL TECHNOLOGY STUDY: PHASE 1 - FRAMEWORK REPORT

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National Transport Master Plan (NATMAP)

Passenger Rail Technology Study

Phase 1: Framework Report

Contents

Executive Summary

Introduction

Broad scope

There exists a considerable investment backlog in passenger railways in South Africa. In addition, there are many fundamental questions regarding the positioning of its passenger rail technology. It was therefore important to identify, by way of this study, firstly opportunities where investment could confidently be initiated in the short term, to get up to speed quickly, and secondly situations where deeper insight was required, or where substantial preparatory work would be needed, to guide medium- to long term interventions.

Problem statement

Passenger railway technology in South Africa has stagnated, service delivery has fallen behind expectations, and competitors have invaded the natural passenger rail market space. Strict interoperability requirements have impeded entry of new technologies. In addition, several rail applications in South Africa need to migrate from narrow gauge track to standard gauge track, to leverage the strengths of contemporary passenger rail technology. There is no precedent for such railway repositioning anywhere. It was therefore necessary for this study to develop a way forward from first principles.

A passenger rail technology framework

This study developed a comprehensive framework for passenger rail technology, from the premise that railways, which are competitive with other transport modes, are sustainable. It reflects the inherent strengths of rail transport, based on heavy axle load, high speed, and coupled vehicles. Passenger rail requires careful positioning in urban settings, because human beings do not make a heavy payload, and speed is relatively low. It naturally comes into its own over longer distances at high speed. Among other, the framework indicates areas where rail is inherently weak, where threats from competitive modes exist, and where alternative guided transport solutions exist.

Application to South Africa

Priority issues

Track gauge underlies several of the present constraints on passenger rail technology, as well as longer-term opportunities and challenges: The framework provides deep insight into this topic, and offers suggestions on how to move forward.

Systemic roadblocks, in particular interoperability constraints, have prevented movement from the status quo. They will need careful evaluation with a view to creating space within which to implement contemporary passenger rail technology solutions.

Findings

Positioning of passenger rail in South Africa is fundamentally constrained by the trains currently operated under the Metrorail and Shosholoza Meyl brands. Their technologies are dated, and have consequently not demanded high performance infrastructure, which is consequently also dated. Metrorail offers a one-size-fits-all solution, which is generally not able to match the performance of contemporary higher capacity, lower cost, and/or faster rail solutions. Shosholoza Meyl is handicapped by limited speed on narrow gauge track, and cannot differentiate itself competitively from offerings by other transport modes.

Potential new investment

Urban heavy rail

There are immediate opportunities for investment in contemporary metro rolling stock, without risk of entering a strategic dead end. This could add capacity to the existing fleet, and possibly replacing existing stock, thereby increasing mission reliability, and making services more attractive. Such opportunities could be exploited when stakeholders are ready, while longer term, more complex, issues in other passenger rail market spaces are addressed in parallel. Such opportunities must however be qualified regarding signalling: Maximum capacity requires closely-matched signalling and train performance characteristics, and contemporary rolling stock could not deliver its full potential under existing signalling systems.

Given the existing investment backlog, and the need to maximize the impact of new investment, the existing basic urban narrow gauge track infrastructure can be considered good for at least another rolling stock generation. After that time, it would be appropriate to revisit the question of track gauge, to assess whether the relative benefits of standard gauge, as well as the state of the supply industry, had changed sufficiently to yield a different answer.

Any new infrastructure-plus-rolling-stock projects, which can operate as standalone entities, or which have the potential to grow into larger networks, should of course be built to preferred international standards of track gauge, body width, platform height, and power supply. This would accelerate introduction of new technology, and concurrently secure the most competitive pricing for such projects.

Urban light rail and alternatives

At the lower end of the capacity scale, urban rail is increasingly exposed to alternative guided transport solutions and competitors. In South Africa, bus rapid transit has already emerged. However, rail fundamentally offers a greener, more permanent mass mobility solution. Contemporary variants such as Light Rail, Light Metro, and Automated Light Metro address the capacity market space below Metro, offering safe, efficient solutions. They warrant attention as South Africa looks to move commuters from road to rail.

Regional rail

Regional rail has the potential to provide a foundation for integrated mass mobility solutions outside the approximately 35km radius in which metro optimizes the trade-off between capacity and speed. It is currently a market space dominated by road in South Africa, because of low rail speed. It is the first level at which standard gauge track would be required, to support speeds in the range 160-200km/h, to yield reasonable journey times over longer distances. In the 40-400km range, regional rail has the potential to serve as backbone for integrated mass mobility solutions, and to provide inter-regional links.

High-speed rail

High-speed rail, i.e. services at a maximum speed of 200km/h, has limited potential in South Africa. This is essentially the ultimate development stage of conventional rail, before it is necessary to provide dedicated infrastructure to advance to the next level, namely ultra-high-speed rail. However, due to South Africa’s narrow-gauge heritage, in particular the large number of small-radius curves, high speed would be feasible on very few routes without substantial reconstruction, including changing to standard gauge track. Nevertheless, a few suggestions have been made in this report.

Ultra-high-speed rail

Ultra-high-speed rail provides service in the 300-400km/h range on dedicated infrastructure. The first potential application would be Gauteng-Durban. However, at this time it seems as if economic viability might be some way off. However, many of South Africa’s economic peers are already in the ultra-high-speed rail field: A proposal has been made regarding developing an understanding of what drives adoption of ultra-high-speed rail in developing economies.

Key recommendations

Examine minimum interoperability requirements carefully, and relax them to the extent necessary, to create space within which migration to contemporary passenger rail solutions can take place.

Deal with the question of narrow track gauge. In the market spaces between metro and ultra-high-speed intercity, progress will in the first instance require accommodation with Transnet Freight Rail, by dual-gauging, re-gauging, or reallocating track. When those options do not meet aspirations or requirements, new construction will need to be considered.

Recognize that rail solutions in general require close matching of infrastructure (curvature, gradients, signalling, and several others) and train (braking, speed, traction, and several others) characteristics, to maximize capacity and minimize journey time.

Consider alternatives to existing steel-wheel-on-steel-rail passenger rail technology, such as rubber-tyred solutions, that allow passenger rail to compete effectively against road competitors over a wide range of capacities.

Physically separate metro and freight operations, to develop fully the potential of urban rail, without interference from incompatible trains.

Consider technologies such as automatic train protection and automatic train operation, to mitigate passenger exposure to undue risk, and to utilize infrastructure and rolling stock more intensely.

Revisit local content and the state of the supply industry, which aspects will need to support effective implementation of contemporary rail solutions in South Africa.

Conclusion

The global railway renaissance has generated a range of attractive, competitive mass mobility solutions that have the potential to restore a meaningful contribution by passenger rail to South Africa.

By comparison with its legacy passenger rail system, both South Africa’s socio-economic challenges, and the available technological solutions, are now vastly different.

When integrated with all other possible challenges and routes, the future national mass mobility solution is likely to lean towards a new departure rather than to an extension of the past. Contemporary passenger rail technology offers competitive rail positioning that addresses different opportunities: Its application must therefore lead to outcomes different from the past. Portions of the legacy may nevertheless be recyclable: Leveraging them will maximize the return on new investment.

However, one should recognize that many constraints impede their adoption, and that overcoming them will pose high challenges. South Africa’s back-to-rail aspiration is achievable if the task is reduced to manageable portions. Clear insight and firm resolve can guide its realization.

NOTE

The Consultant delivered a Preliminary Report dated January 2009. The content of the Preliminary Report has been incorporated into the present report. This Final Report therefore replaces and supersedes the Preliminary Report.

1 Introduction

1.1 Background

Passenger rail in South Africa has drifted far from the role that contemporary rail plays in countries that have founded their mass mobility task on rail. New investment in passenger rail in South Africa has all but stalled. Users even go as far as burning passenger rail assets to vent their frustrations. It is time to reposition passenger rail for competitiveness and sustainability.

The South African railway situation is globally unique. It is an outcome of slicing and dicing a monolithic state railway into a freight component and a unified urban/long distance passenger component. While the freight component is in several respects uncompetitive and in decline[1], passengers have high aspirations and a sympathetic government. From the perspective of this study, one should thus expect the passenger component to embrace contemporary passenger rail solutions.

1.2 Problem statement

An accumulation of reasons has caused passenger railway technology in South Africa to stagnate. Consequently, service delivery has fallen behind expectations, and competitors have invaded the market space that passenger rail should naturally dominate. Legacy infrastructure- and rolling assets still bind the passenger and freight components to one another, impeding development of their respective strengths. Strict interoperability requirements have proved to be a barrier to entry of new technologies. Many rail applications in South Africa need to migrate from narrow gauge track to standard gauge track, to rise to their aspirational and competitiveness challenges by leveraging the strengths of contemporary passenger rail technology. There is no precedent for such fundamental railway repositioning anywhere in the world. It was therefore necessary to develop a way forward from first principles and research findings.

1.3 Objective

The South African Rail Commuter Corporation (SARCC) business strategy states the objective clearly: *Transforming and Positioning Passenger Rail to form the basis of the Integrated Mass Rapid Public Transport Networks in South Africa* (South African Rail, 2008/09). It is a worthy objective: This study therefore set out to provide railway technological insight that could underpin that strategy. It developed a roadmap to identify, examine, and understand how to align the challenges of the existing South African setting with contemporary passenger rail technology, and with sources of such technology. Where such alignment depends on interaction with freight rail, the report set out to examine appropriate interface issues. The Consultant structured the methodology, analysis, findings, and recommendations in this report to provide the Client with high-level insight regarding passenger rail technology issues to:

- Support informed policy decisions,

[1] Many reasons underlie this decline. In principle, they are outside the scope of this study. However, the report recognizes their existence as far as they affect passenger rail technology, and points them out where appropriate.

- If necessary, procure subsequent more detailed studies from local and international consultants, and
- Enable entry to the market for new assets as informed purchaser.

1.4 Study structure

1.4.1 Design

The Consultant proposed to spread the study deliverables over the following four phases:

> **Phase 1**, the subject of this document, is a Framework Report. It outlines the field of study, and canvasses a range of pertinent passenger rail technology questions, as well as their generally accepted contemporary solutions, with reference to the rest of the world, Africa and South Africa. The Framework Report will provide the Client with a broad appreciation of the passenger rail technology landscape early in the study, to draw attention to critical issues, and to decouple the local portion of the study from the possible international participation envisaged in Phase 3.
>
> **Phase 2** was proposed as a Stakeholder Workshop. It was intended to expose stakeholders to the issues identified in the Framework Report, and hence to ensure that all pertinent issues for further attention have been identified, as far as reasonably practical.
>
> **Phase 3** was proposed as development of work packages, together with their terms of reference, to address detailed or specific issues or opportunities requiring further attention. The intention was to procure appropriate and competent local and/or international consultants to undertake the work.
>
> **Phase 4** was proposed as integration of the outcomes of Phases 1, 2, and 3 into a final report, which would contain overall recommendations and conclusions.

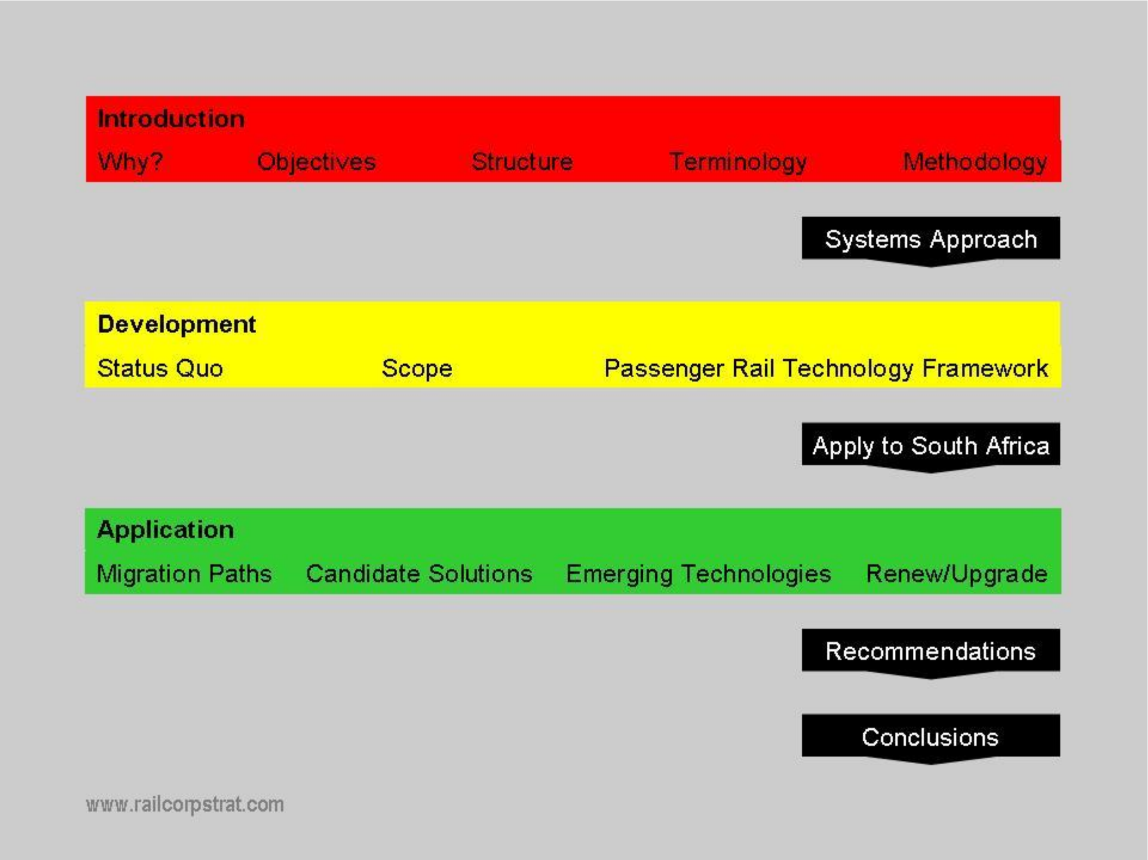
At date of this Report, the Consultant had been mandated to deliver Phase 1 of the Passenger Rail Technology Study.

1.4.2 Funding

South African Rail Commuter Corporation (SARCC), which changed to Passenger Rail Agency of South Africa (PRASA) during this project, funded the study, as a contribution to the development of South Africa's National Transport Master Plan (NATMAP).

1.4.3 Study roadmap

The following diagram illustrates the basic structure of the study. It is intended to give readers a high-level view of the subject matter, to enable them to then to drill down quickly into whatever takes their interest.



1.5 Acronyms, definitions, and terminology

The following acronyms, definitions, and terminology clarify or explain terms used in this Report. Particular railway terms may have different meanings in different countries. Thus, while many South African railway terms generally are aligned with international usage, exceptions do exist. Noting that this Report will reason that South Africa should expose itself to global railway solutions, the objective of this Section is simply to promote the widest possible understanding of this document, rather than to take issue with possible differences. It provides readers with a glossary that is widely understood in the international mass mobility industry.

AAR: Association of American Railroads.

ATP: Automatic Train Protection.

Boundary: The conditions, often vague, always subjectively stipulated, that define a system and set it apart from its environment.

Broad gauge: Railway track laid to a distance of more than 1435mm between rails.

BRT: Bus Rapid Transit.

Capacity: System throughput, usually expressed in passengers per direction per hour or passengers/direction/hour.

Car: A vehicle in a fixed-formation train.

Coach: A trailing (i.e. non-motored) vehicle coupled into a train that is hauled by a locomotive.

Contemporary: Solutions and technologies that leading system integrators currently offer in competitive markets—they range from state-of-the-art to well-proven.

DMU: Diesel multiple unit. See also *Multiple Unit Set*.

EMU: Electric multiple unit. See also *Multiple Unit Set*.

Entropy: A measure of energy expended in a system that does no useful work, which tends to decrease the system's organizational order.

Environment: The context within which a system exists. It is composed of all things external to the system, and it includes everything that may affect the system, or which the system may affect.

Fixed formation train: A train consisting of a specific number of cars (or vehicles), with braking, propulsion, auxiliary, and other equipment distributed over the cars in such a way that they cannot operate separately from one another.

Heavy rail: A steel-wheel-on-steel-rail transportation system that uses relatively heavy vehicles and infrastructure—it has less routing flexibility than Light Rail, as it needs wider curves and does not run in streets.

Interchange: A location where two transport operators meet, perform some kind of exchange, and go on their separate ways again.

Interface: A shared boundary across which two or more interacting systems exchange energy, material or information.

Intermodal: Traffic that uses two or more transport modes between origin and destination.

Interoperability: The ability of diverse systems and organizations to work together. One may use the term in a systems engineering sense, or in the broad sense of recognizing social, political, and organizational factors that affect system-to-system performance.

Interoperate: Two or more systems working together by allowing one another's equipment, such as trains, to operate on one another's infrastructure.

Intraoperability: A property that refers to the ability of particular subsystems to contribute functionality interchangeably to diverse systems or to diverse supra-systems.

Legacy: Something carried over or inherited from a former dispensation.

Light Metro: A light steel-wheel-on-steel-rail transportation system built on completely segregated right of way, where necessary with elevated- and/or underground sections, and signaled- or automated operation.

Light Rail: A transportation system that operates relatively light steel-wheel-on-steel-rail self-propelled vehicles. The technology is basically the same as that of trams, although light rail systems usually operate on segregated rights of way rather than streets for most of their length, and so provide faster service than trams.

Low floor vehicle: A relatively new type of vehicle with floor level at about the same height as street curbs and low level platforms at stops: This makes it easy for people (especially those with impaired mobility, baby carriages, bicycles, and/or shopping bags) to enter and exit safely and swiftly.

LRV: Light rail vehicle.

Metro: A high speed (compared to other transport modes in the same corridor), high capacity, high frequency urban rail system that runs entirely on exclusive tracks on its own dedicated right of way (underground, on elevated structures and/or at grade), usually with level entry platforms.

Migration: The process by which contemporary- or emerging systems, or technologies, displace legacy systems or technologies.

Mobility: Ease of moving about, often specifically meaning access to a vehicle for travel.

Multiple unit set: A fixed-formation train composed of a specific number of cars, with a high proportion of motored axles, usually 50-100%.

Narrow gauge: Railway track laid to a distance of less than 1435mm between rails[2].

Open system: A system in a state of continuous interaction with its environment.

PRASA: Passenger Rail Agency of South Africa.

Rapid transit: See *Metro*.

Regional rail: Rail services between towns and cities, and sometimes between regions, rather than purely linking major population hubs in the way inter-city rail does.

Riding quality: Lateral, vertical, and longitudinal accelerations that determine passenger riding comfort and safety against derailment: They include vibration acceleration, steady lateral acceleration, and jerk.

SARCC: South African Rail Commuter Corporation.

Standard gauge: Railway track laid to a distance of 1435mm between rails.

Subsystem: A major component of a system.

Supra-system: An entity that is composed of a number of component systems organized in interacting relationships.

Sustainability: The ability of a system to maintain itself with no loss of function for extended periods.

[2] In South Africa, the distance is 1067mm. In the rest of Africa, it is mostly 1000mm or 1067mm.

System integrator: An entity that specializes in bringing together component subsystems into a whole, and ensuring that those subsystems function together.

System: A system comprises all elements of interest that have a meaningful relation to one another. One could regard a complete railway as a system. A system may even extend beyond the physical railway, for example to road-based feeder services that support a passenger railway. Sometimes, major elements of a complete railway are also called systems, for example the overhead traction power system, or the signaling system.

TFR: Transnet Freight Rail.

UAR: Union of African Railways.

UIC: International Union of Railways (English), Union Internationale des Chemins de Fer (French).

VAL: Automatic Light Vehicle (English), Vehicule Automatique Legere (French).

Wheelset: Two wheels mounted on an axle. They may be of fixed gauge or variable gauge.

1.6 Study methodology

1.6.1 Significance of the global railway renaissance

A global railway renaissance has advanced and transformed passenger rail technology rapidly over the last two or three decades, across the entire spectrum of passenger rail services, from low-speed urban- to ultra-high-speed intercity. Although outside the terms of reference of this study, the railway renaissance has similarly transformed freight rail technology: Where freight- and passenger rail technology attributes mutually influence one another, this study also recognized relevant aspects of freight rail technology.

Perceptive South Africans are aware of the visible achievements of the global railway renaissance: Through direct exposure, as well as through the media, they have recognized the existence of railways that may be described as Assertive, Progressive, and Enlightened, and some of the attributes that set them apart from railways that may be described as Insecure[3]. By comparison, it is evident that unfulfilled expectations and opportunities exist with regard to passenger rail in South Africa. While there have been sporadic attempts to fulfill these expectations, such as the Metroblitz intercity trains and the New Generation suburban trains in the 1980s, such technologies failed to take root and flourish.

While it is easy to look over the fence at the achievements of passenger rail technology in other countries, admiration and envy cannot lead to understanding of why passenger rail technology in South Africa has fallen behind. A study of passenger railway technology in isolation is thus unlikely to deliver adequately penetrating insight into the

[3] The existence of railways with Assertive, Progressive, Enlightened, and Insecure corporate citizenships was found in research by Van der Meulen and Möller (2008b).

present passenger railway impasse in South Africa: Prima facie, it appears to be as much structural as technological.

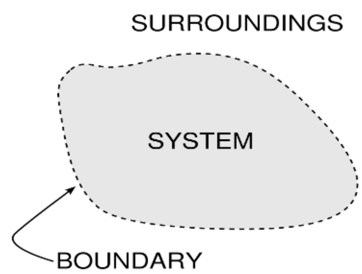
This study therefore set out not only to catalogue and to explain contemporary- and emerging passenger railway technologies, and to match them to opportunities in South Africa. It concurrently delved into why the global railway renaissance has not yet touched passenger rail technology in South Africa: Where appropriate, it points out non-technical impediments. Only in this way, can one interpret and project the significance of the global railway renaissance for South Africa.

1.6.2 The systems approach as an analytic toolset

1.6.2.1 General systems theory

General systems theory is a useful toolset for the study of complex systems in nature, society, and science. Railways and their competitive- and symbiotic transport modes in a specific country setting are a perfect example. The systems approach provides a way to organize and to analyze what may otherwise seem to be an incomprehensible assortment of complex issues. To introduce the approach, note the following attributes of a system:

- It is a dynamic and complex whole.
- It interacts as a structured functional unit.
- Energy, material, and information flow among its various elements.
- Some amount of disorder (or entropy) is present in any system.
- It is situated within an environment.
- Energy, material, and information may also flow from and to the environment.
- It is structured hierarchically: It may consist of sub-systems, and the environment itself may be a supra-system containing several systems.
- One may define the boundary between a system and its environment as narrowly or as widely, as is appropriate for a particular purpose.



The following notion illustrates the energy-, material-, and information flow among the various components of a passenger railway system. Think of a railway, and symbiotic transport modes such as buses and taxis, interworking conveniently with one another under a national public transport smart card dispensation, exchanging passengers at stations or termini, operating rolling stock on their respective infrastructures, and clearing payments to each participant. Such a flow is clearly reflected in the language of railways, in which the terms *interchange* and *interoperate* are of the essence.

1.6.2.2 Types of systems

Systems may be functional or dysfunctional: Work on corporate pathology has contributed valuable insight into the latter condition (Gharajedaghi, 1983): It found that systems adapt to their environment in terms of three models, namely *mechanistic*, *organismic*, and *socio- cultural*, typified in simple terms as follows:

> **Mechanistic systems** are relatively closed. The amount of disorder, or entropy, increases within them over time. Without creative ability to respond to their environment, mechanistic systems must eventually break down. The general condition of passenger railways in South Africa and, for that matter, freight railways too, is symptomatic of decreasing organizational order. It illustrates, in a railway setting, how institutional arrangements have established and entrenched a closed system, leading predictably to an unsustainable outcome.
>
> **Organismic systems** are open to their environment. Their basic limitation is failure to recognize that a social system exists on a higher and more complex level. Their outcome over time is fixed by regulating their structure. The emergence of high-speed intercity trains in Japan, and of heavy haul- and double-stack container trains in the United States, exemplifies changes in technology and liberalization of institutional arrangements, which stimulated changes in railway competiveness. They illustrate, in a railway setting, how rail's competitive strengths, relative to other transport modes, determined equifinal[4] market share outcomes.
>
> **Socio-cultural systems** are also open to their environment. Members create, or recreate, their system structure in terms of a shared vision. While one of several outcomes is possible at the outset, only one ultimately emerges—through the dialectic interaction[5] of opposing though concurrent processes. South Africa's transition from a closed apartheid society to an open democratic society is arguably one of the most striking modern examples of a socio-cultural system in action. It is illustrated, in a railway setting, by structural changes currently underway in Europe's railways: Dialectic interaction among many stakeholders is transforming an assortment of unsustainable, closed, national railways to one of several possible, though presently unpredictable, sustainable outcomes that will rest on dynamic competition among continental-scale infrastructure- and train operators.

Note that, although one system type dominates real settings, elements of one or both of the other system types may also be present.

1.6.2.3 Validity of the systems approach as toolset

The foregoing brief but accurate explanation of several systemic outcomes, in the South African railway setting as well as in the global railway setting, gives confidence that general systems theory is a valid toolset for examining South Africa's passenger railway status quo, and for indicating subsequent remedial interventions.

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[4] *Equifinal* means that the outcome is the same, regardless of the migration path that leads to it.

[5] One can pair the modalities of *dialectic interaction* as integration and differentiation, entropic and neg-entropic, morphostatic and morphogenetic, competition and cooperation, generation and distribution, and creation and recreation. In plain language, *dialectic interaction* tests the truth of opinions, by discussion, regarding the existence or action of opposing social forces.

South Africa’s existing passenger railways seem to meet few stakeholder aspirations, expectations, and requirements. Furthermore, there is no empirical relation, based on recent experience, between investment quantum and market uptake. The country therefore can have no idea what the mass mobility landscape will look like after, say, half a century of high-quality passenger rail transport. Market share- or modal split outcomes projected from the status quo could therefore vary within wide and astounding limits.

To illustrate, displacement of European domestic air transport by high-speed intercity trains could not have been, and was not, predicted as an outcome of Japan’s introduction of its Shinkansen in 1964. Similarly, development of double-stack container trains, which have revolutionized container transport for railways, could not have been, and was not, projected as an outcome of the 1980 United States’ Staggers Act. With perfect hindsight, both outcomes were of course clearly predictable by the systems approach. However, one can predict that a closed system will eventually degenerate into disorder and stop functioning. Similarly, one can predict that the outcome of socio-cultural systemic adaptation, whatever that outcome turns out to be, will be right on the money.

This study will therefore use the systems approach as an analytic toolset, to develop insight into the drivers of passenger rail technology, and to indicate interventions that will support migration to a sustainable outcome for South Africa.

1.6.2.4 Applying the systems approach to a passenger rail technology study in South Africa

Before defining the boundary or boundaries, of the system or systems, relevant to passenger rail technology in South Africa, consider first which systems may be involved:

- Mass mobility systems comprising all transport modes—at municipal-, provincial-, and national level, possibly even at international level—for the people of South Africa and potentially also for its neighbours.
- Competing-, contending-, and/or symbiotic transport modal systems—minibus taxis at municipal level, airlines at national level, rail freight vying for capacity on a shared network at all levels, and so on.
- Rolling stock- and infrastructure systems such as consulting services, financing, operations and maintenance, manufacture and so on, which one could source globally, extend far beyond the borders of South Africa.

Several different system views, and their corresponding system boundaries, can therefore exist, or even co-exist, depending on the topic under consideration and the scope of inquiry. This study will therefore implicitly define ad-hoc boundaries appropriate to the issues under examination.

2 The status quo

2.1 *In South Africa*

2.1.1 Public passenger transport systems

2.1.1.1 Applying the systems approach

Taking a systems view on existing public passenger transport in South Africa shows that many subsystems are present. They include not only the various transport modes, such as buses, taxis, and trains, as well as their respective long-haul and short-haul subsystems, but also a range of similar subsystems replicated across the entire country. Such integration as there is among modes often appears to be spontaneous. It is therefore evident that non-integration of transport modes constitutes a fundamental public transport issue in South Africa.

Spontaneous initiatives to provide service do of course indicate that fundamental economic drivers are alive and well, and should therefore be valued. However, if spontaneous solutions respond to demands that formally integrated solutions could or should meet more efficiently, then it is necessary to revisit the institutional arrangements. Evidence of spontaneous solutions substituting for more efficient solutions, such as the phenomenon of ubiquitous taxis punching above their fighting weight in the national transport task, clearly illustrates that an organismic system is at work: The outcome is contained in the system structure, in this case the existing institutional arrangements that regulate the public passenger transport industry.

Recall that the basic limitation of organismic systems is their failure to recognize that a social system exists on a higher and more complex level. Thus, from the perspective of passenger railway technology, South Africa should revisit the institutional arrangements that allow- or drive implementation of passenger railway technology, to engage the social system in socio-cultural adaptation.

2.1.1.2 Learning from the systems approach

Vibrant systems, including public transport and its passenger rail subset, routinely implement new applications and technologies. The preceding process of consultation among stakeholders exposes decision makers to values and trade-offs among potential users. In South Africa, such dialectical inquiry in respect of passenger rail technology issues, and by implication positioning of passenger rail relative to alternative- or competitive modes, appears circumscribed. This has resulted in an apparent disconnect between global availability of good passenger rail solutions, and their local implementation.

South Africa would do well to flesh out its vision what passenger rail could contribute to the national mass mobility task in an ideal dispensation, and then set about migrating to that vision. While the requisite socio-cultural adaptation process will not necessarily lead to an outcome preferred by sponsors, it will produce a robust outcome.

2.1.1.3 Legacy systems

Railways are long-lived, so their technology status at any time reflects the history that shaped them. Among other, colonialism marked South Africa's railways. They started out on standard gauge, but administrators copped out and changed to narrow gauge when they encountered mountains en route to the interior. Many standard gauge railways, which successfully overcame terrain that is more challenging, bear witness to their mistaken call.

The shortcomings of narrow gauge encumber railway competitiveness and sustainability. This report therefore refers to them frequently. They have been addressed comprehensively in a parallel report on track gauge (National Transport, 2009a). For the convenience of readers, pertinent track gauge issues are explained briefly with respect to the fundamental drivers of passenger railway competitiveness in §4.2.1.5.

There are of course other legacy technologies as well, many of them simply reflecting the time when they were acquired, and others reflecting the inability of uncompetitive railways to exit their downward spiral of unsustainability. One way or another they have also had an incisive influence on the status quo of passenger railway technology in South Africa. The report will mention them as appropriate.

2.1.1.4 Realizing the vision

In countries that have sufficient population to support public passenger rail transport, and South Africa is one of them, rail should provide the national mass mobility backbone. While rail typically requires the highest capital investment, it can deliver high capacity, low cost service in corridors with sufficient traffic volume. For precisely the reason it requires the highest capital investment, it also represents the firmest commitment by the relevant transport authority. That commitment should attract and anchor commercial-, industrial-, and residential development, which should in turn support symbiotic opportunities for lower volume, lower-cost, feeder services by other transport modes. Ideally, seamless through ticketing should also be part of the solution.

The overall vision has already been clearly stated: *Provide safe, reliable, effective, efficient, and fully integrated transport operations and infrastructure which will best meet the needs of freight and passenger customers at improving levels of service and cost in a fashion which supports government strategies for economic and social development whilst being environmentally and economically sustainable* (White Paper, 1996). Facilitating passenger rail's step-by-step contribution to such an integrated transport vision must rest on a dispensation that responds to and supports it.

While institutional arrangements are outside the scope of this study, it does provide a framework for passenger rail technologies that can support whatever passenger rail services South Africa can envision, and its institutional arrangements can facilitate.

2.1.2 Urban rail assets (Metrorail)

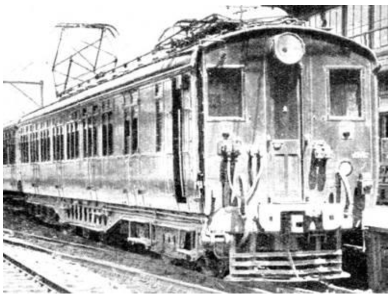
2.1.2.1 Infrastructure

The present PRASA network was created by dividing the former monolithic South African Transport Services railway network between Spoornet and SARCC in 1990. At that time, network elements were assigned to the dominant user. While major portions of their respective networks enjoy exclusive use, there remain shared portions where interoperation between PRASA and TFR is required. No investment in systemic change has taken place since 1990, so all legacy infrastructure characteristics remain today. The only change has been Spoornet's re-branding as Transnet Freight Rail. The inherited interoperability requirement imposes the following constraints on passenger trains:

- Signalling must accommodate trains with the longest headway, as determined by the longest braking distance, namely vacuum-braked freight trains[6], and occasionally vacuum-braked mainline passenger trains. However, high performance multiple-unit passenger trains can support materially shorter braking distances and headways. The latter cannot realize their minimum headway potential on shared routes, which either sacrifices passenger capacity, or increases the length of trains required to deliver a given passenger capacity.
- General freight wagons have an axle load of 20 tonnes, while Class 6E/6E1 locomotives have an axle load of 22 tonnes. The new Class 19E locomotive has an axle load in the 25-26 tonne range. These axle loads are higher than required for passenger stock and passenger routes. To the extent that general freight trains must interoperate on passenger infrastructure, structural and maintenance requirements would be adversely affected.
- TFR's de facto vehicle profile, based on certain steam locomotives (South African Transport, 1980d) imposes the most restrictive dimensions on fixed equipment in the space immediately above rail level. This precludes providing raised guard rails at diamond crossings and slips, which in turn imposes a speed restriction of 30km/h on such special trackwork.

2.1.2.2 Trains

South Africa introduced electric suburban trains, the 1M generation[7], on the Cape Town-Simonstown line in 1928. Their configuration reflected the locomotive hauled suburban stock of the time: One electric motor coach hauling a specified number of coaches simply replaced one steam locomotive hauling a specified number of coaches. The electric motor coaches, which had a driving compartment and an electrical equipment compartment at one end of the vehicle, were in effect small locomotives that also carried some passengers. The trailer coaches had no functionality other than carrying passengers.



[6] TFR has long planned to convert all its freight trains to air brakes, which have significantly shorter braking distances than trains with vacuum brakes. However, it has yet to implement fully its plans in this regard.

[7] Each generation has sub-series, such as 5M2A, but the fundamental generations suffice for the purpose of this report.

The foregoing configuration still holds for Metrorail today, i.e. electric motor coaches hauling a non-associated number of trailer coaches. Trains have at least two motor coaches, one at each end to provide a driving cab[8]. Current train configurations are:

- 6 trailer coaches + 2 motor coaches (25% motored axles)
- 8 trailer coaches + 3 motor coaches (27% motored axles)
- 9 trailer coaches + 3 motor coaches (25% motored axles)
- 10 trailer coaches + 4 motor coaches (29% motored axles)

The proportion of motored axles is not constant, so train performance can vary in the ratio of trailing vehicles to motor coaches. Although the traction motors are fairly sized at ≈230kW, the low proportion of motored axles means that performance must lag contemporary multiple unit trains that typically have 50-100% motored axles. The vacuum braking is not load-weighed, so retardation rate will vary as the passenger load varies. The worst case, namely fully laden trains, determines headway.

Metrorail commuter trains are much longer than most metro trains elsewhere in the world. All other things being equal, throughput capacity is almost directly proportional to train length. It appears that train length was used to compensate for substandard acceleration and deceleration (Van der Voort, 1980). This results in very long stations and peaky passenger flow. The preferred solution nowadays is to use shorter trains at shorter headways, for greater convenience and smoother passenger flow.

No new rolling stock has been built since the mid 1980s. The last was the 5M generation, introduced in the early 1960s, followed by the 6M, 7M, 8M, and 9M New Generation projects that did not achieve large scale fleet deployment. The current 10M upgrade of the 5M generation achieves lower maintenance and better appearance, but even the 10Ms fall short of many contemporary requirements (see §5.5.2.2 for details).

Metrorail trains operate on 3kV dc electrified infrastructure owned predominantly by PRASA. Metrorail's Eastern Cape Region is an exception—services there are operated on 25kV ac electrified infrastructure owned by TFR, who also provides locomotives to haul Metrorail trailer coaches.

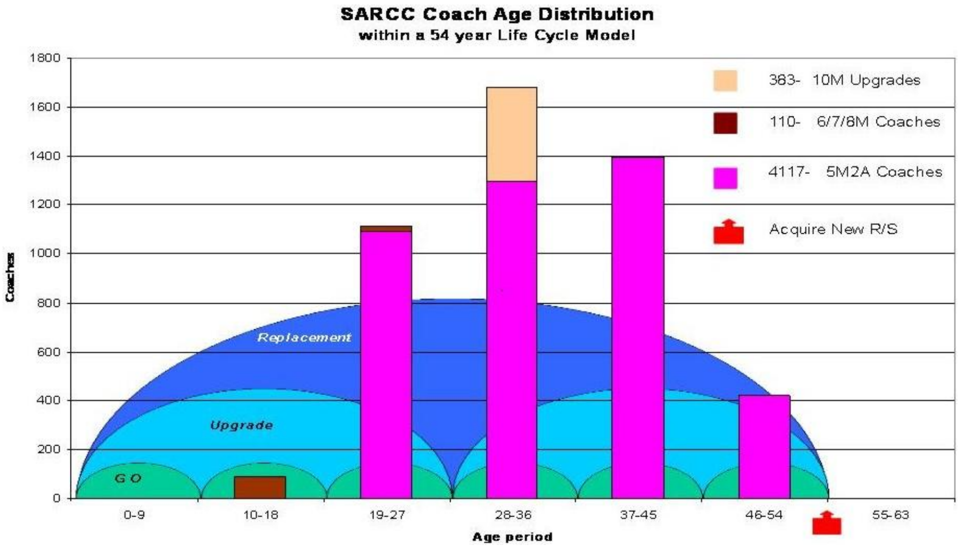
2.1.2.3 Life expectancy

Rolling stock: The current Metrorail rolling stock life cycle plan spans fifty-four years. It comprises three nine-year general overhaul cycles, followed by an upgrade. The cycle is then repeated, after which the vehicles ought to be scrapped. The diagram below depicts the cycle. The 6/7/8M stock represents only a small portion of the fleet, and is therefore excluded from the present discussion.

[8] Formerly, some short trains were worked in push-pull mode, with a motor coach at one end, and a driving trailer at the other end.

The need to keep the vehicles roadworthy drives the general overhaul cycle. Among other, general overhauls restore corrosion damage that can weaken coach structures, posing risks both in normal service where they carry heavy peak loads, and in collisions where they need to protect passengers from injury or death. The illustration at right shows a coach structure that failed under impact. The carbon steel used in 5M stock is susceptible to corrosion, due to ingress of water, or to operation in coastal environments. From the diagram, it is evident that coaches need to be replaced at around 200 per year merely to keep up with life expiry, not to mention additional stock to expand services to and reduce the average age of the fleet. A large problem is clearly approaching.

Nowadays, a fifty-four year life cycle is arguably too long, for the following reasons. First, in a competitive global market that continuously develops new technologies, rolling stock performance keeps rising, while real life cycle costs keep decreasing. An operator that is out of the market cannot keep up with and benefit from technological advances: Over time, such operators become uncompetitive. They then burden the economy in which they are set, through either being unable to maintain equipment, paying over the odds to do so, and either way consuming more energy than they should. Second, in a growing economy, passenger expectations rise. Passengers become dissatisfied with obsolete equipment, and vote with their feet for other public transport modes or for private cars. Third, heavy workshops must be maintained to undertake the overhauls and upgrades: While that might be good for job creation, it could prejudice national competitiveness in a global economy. Taken together, these drivers encourage modal shift in the wrong direction, namely from rail to road.



Contemporary rolling stock uses aluminium or stainless steel structures. They are designed to be maintained in running depots over their entire life cycle. While that cycle is usually shorter than fifty-four years, it may include a mid-life upgrade of power electronics and control systems, because competitive developments in those fields currently render such equipment obsolete before the mechanical equipment has reached the end of its useful life.

Infrastructure: Basic right-of-way is generally sustainable over a long life span: The world's first metro, London Underground, is still going strong after nearly 150 years. Metro speeds are relatively low, so even tight curves are not unduly problematic, other than from a maintenance perspective. Track, and electrification, can be renewed as required. However, signalling and communication equipment has the shorter life cycle associated with electronics- and information technologies. Noting the age of signalling installations in South Africa, much of it would have little or no book value. It generally cannot support optimum performance from contemporary rolling stock, and overlaid automatic train protection would be false economy. As contemporary trains are rolled out, it would be appropriate to replace signalling and communications equipment with new equipment of the same generation.

2.1.3 Long-distance rail assets (Shosholoza Meyl)

2.1.3.1 Infrastructure

Long-distance main line infrastructure is owned exclusively by TFR. Indeed, the Shosholoza Meyl long-distance passenger operation was a brand of Spoornet until April 2008, when it and its rolling assets were transferred to SARCC. This left the long-distance rail network with the dominant operator TFR, and Shosholoza Meyl as a passenger train operator on TFR infrastructure. In this respect, one can draw a parallel with Amtrak in the United States and the Class 1 railroads that provide it with track access outside the Northeast Corridor[9].

Shosholoza Meyl offers services in two classes, Economy and Tourist. Most radiate from Johannesburg, to Cape Town, Bloemfontein, Durban, East London, Kimberley, Komatipoort, Musina, and Port Elizabeth. In addition, there are services between Cape Town and Durban, and between Bloemfontein and Kimberley (Shosholoza Meyl, undated). Key infrastructure aspects of routes on which Shosholoza Meyl operates follow:

Alignment. The alignment of original portions of the abovementioned routes dates from the beginning of main line railways in South Africa, namely the 1880s and 1890s. Some portions, particularly in mountainous terrain, were upgraded from time to time, until the 1950s and 1960s. After that, only Volksrust-Newcastle was upgraded, and the Hex River Tunnel was built, both in the 1980s. Even at that time, commercial high speed was not on the South African railway technology horizon. The Volksrust-Newcastle section thus has many curves in the 700-849m bracket, rated

[9] Amtrak owns the Northeast Corridor, which connects Boston with Washington DC.

by TFR for 90km/h. The Hex River tunnel itself is straight, but it serves a route that has many curves limited to 90km/h or less.

The 90km/h maximum speed of vacuum braked passenger trains has thus left its mark on the speed potential of South Africa's railways. Fortuitously, a few sections passed through comparatively easy terrain, where the builders were able to provide mostly wide curves. These sections are:

- On the Johannesburg-Cape Town route:
  - Dean-Content 228km
  - Modderriver-Houtkraal 181km
  - De Aar-Barnard 123km
  - **Total** **532km**
- On the Johannesburg-Polokwane route:
  - Bon Accord-Eersbewoond 96km
  - Modimolle-Makopane 86km
  - Sandrivier-Polokwane 18km
  - **Total** **200km**

The above sections would be good for 130km/h on the existing 1067mm track gauge, if appropriately maintained. If re-gauged to standard gauge, the sections mentioned on the Johannesburg-Cape Town route would be good for 150-160km/h, and those on the Johannesburg-Polokwane route for 140-150km/h (National Transport, 2009f). Note that the curves within the sections mentioned are not all suitable for higher speeds: It was assumed that any general speed increase would require re-alignment of several isolated[10] low-speed curves, to obtain clear high-speed runs over meaningful distances.

Smaller portions of other routes not mentioned above would also be suitable for speeds higher than those authorized at present. However, unless a meaningful distance is available, the journey time saving might not justify the cost of implementing high-speed over short distances.

Noting that the routes presented here represent the best potential for higher speed in South Africa, one must conclude that higher speed on other existing routes would challenge engineers, and possibly even require new alignments.

Electrification: The routes on which Shosholoza Meyl trains run are all electrified at either 3kV dc or 25kV ac. All currently also support freight trains, so electrification infrastructure should have no difficulty in supplying sufficient power to passenger trains.

[10] Although isolated, they are generally low-speed because a relatively small radius was used to negotiate natural obstacles such as water courses and water sheds. Realigning them may be expensive.

Train authorization: Routes of interest for long distance passenger trains are provided with either centralized traffic control or track warrant control. TFR's freight trains typically run at maximum speeds of 60km/h (for vacuum brakes) or 80km/h (for air brakes).

Where centralized traffic control with colour-light signaling is installed, warning signals were spaced at fixed distances from stop signals in older systems, and notionally at braking distance in later systems. Braking distances can vary materially among different train types: Signals notionally spaced at braking distance were designed for trains with the longest braking distances, usually vacuum-braked freight trains[11]. A maximum braking distance of 1200m has been deemed proper, but where train speed is lower than maximum permissible, for example on up gradients, some signals have been spaced at less than 1200m. In practice, the foregoing arrangement leaves residual risks that are mitigated by a combination of train driver road knowledge, and route- and train-specific instructions. Such mitigation measures are of course fallible.

Track warrant control issues movement authority to a train driver, to a specific point only, by radio. All contingent safety risks are mitigated by train driver road knowledge and route- and train-specific instructions. Once again, such mitigation measures are fallible.

High-speed passenger trains are relatively less sensitive to gradient, so their braking distances are more consistent, whatever the track profile. Nevertheless, signaling designed to TFR's 1200m braking distance does not provide an attractive foundation for high-speed passenger service[12]. At retardation rates that respect passenger comfort, around $1m/s^2$, a 1200m braking distance would limit speed to around 150km/h, while at 200km/h around 2200m braking distance would be required. This aspect should be considered in conjunction with any speed increases contemplated.

Note also that, of the TFR routes on which Shosholoza Meyl trains currently operate, only Johannesburg-Bloemfontein and Johannesburg-Durban are double tracked. The remaining routes are either entirely, or largely, single tracked. Single track can accommodate substantial freight volumes, and usually some passenger traffic as well, if the speed differential between freight and passenger trains is not excessive. If mainlines were to be re-gauged or dual gauged to standard gauge to support higher speed passenger trains[13], the

[11] Note that vacuum brakes numerically dominate TFR's present freight wagon fleet.

[12] For context, note that US infrastructure generally permits speeds up to 127km/h, except in the Northeast Corridor, where 241km/h (150 miles/hour) is permitted. US freight train braking distance is of the order of 2500m, which allows sufficient braking distance for passenger trains running at 127km/h, or even higher if it were permitted.

[13] Cogent reasons exist why standard gauge track would benefit freight traffic , but they are outside the scope of this study.

speed differential between freight and passenger trains would increase dramatically[14]. This would reduce line capacity equally dramatically, even if sophisticated signalling and dynamic scheduling aids were to be used.

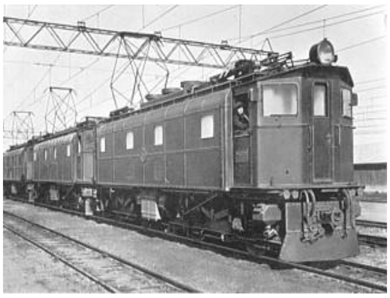
To summarize, South African long-distance passenger rail infrastructure attributes have become tightly entangled with corresponding rolling stock- and train attributes. To upgrade rolling stock performance without corresponding infrastructure upgrading is unlikely to deliver a satisfactory outcome.

2.1.3.2 Trains

As in the case of urban rail, the basic design of long-distance passenger trains in South Africa has not changed much since their inception.

Coaching stock: First, vestibules replaced open balconies, and then steel bodies replaced wooden bodies. Existing vehicles are built of steel, which provides acceptable crashworthiness[15], but requires routine heavy repair to mitigate corrosion. Secondary suspension[16] is still by means of steel springs, whereas good riding quality demands air suspension as is commonplace elsewhere[17]. With limited exceptions, power for passenger amenities (lighting and water raising, but not heating and air conditioning) is drawn from axle-driven generators. Heating is by steam from head-end steam heat vans, which are ineffective on long trains. Air conditioning is a rarity, so comfort and cleanliness suffer. Speed is low, so journey times are long, in turn requiring stops to refill water tanks, which further lengthens journey time. Vacuum-operated tread braking does not support high speed, a factor that is not particularly noticeable now, because equally limited infrastructure masks the issue.

Locomotives: The Class 6E/6E1 workhorse electric locomotives, which dominate the existing Shosholoza Meyl fleet, were conceived as improved performance Class 5E1 locomotives. The Class 5E1s were in turn direct technological descendents of the first Class 1E introduced in 1924, shown at right. The Class 6E/6E1 resistance-controlled starting procedure, series- and parallel connected traction motors, weak



[14] Please note that, other things being equal, heavy freight trains on standard gauge track do not run inherently faster than on narrow gauge track. On the other hand, light freight trains that might run faster on standard gauge, such as in Europe, are not competitive against road transport.

[15] Provided that the structure is not corroded.

[16] Secondary suspension is located between coach bodies and the bogies that run on the rails. It needs to be soft, so that it does not excite unpleasant vibrations in long, lightweight coaches. Soft suspension also gives passengers a good ride.

[17] Air suspension has been used in South Africa—first on the Blue Train in 1972, then on the Metroblitz and New Generation suburban stock in the 1980s.

field “high” speed control, and separately excited regenerative braking, were state-of-the-art 85 years ago[18], but are an anachronism today. Even the Class 7Es on routes electrified at 25kV ac, which use modern solid-state power electronics, are now 30 years old.

Class 6E/6E1 locomotives have a 2250kW power output, and a 110km/h maximum speed. Their mission reliability is now questionable, and they are frequently deployed two in multiple to provide redundancy. During the 40 years since their introduction, passenger locomotives have advanced substantially. For passenger trains that still use locomotives (many contemporary passenger trains are multiple units), power output is in the range 4500-6500kW, and 200km/h capability is taken for granted. Single locomotives typically haul trains, because mission reliability is impeccable, and redundancy is unnecessary.

The Blue Train is a well-known, exemplary exception to the above situation. Setting aside luxury appointments in the present context, it features several contemporary essentials, such as air conditioning, air-operated disc brakes, air suspension with load weighing, on-board electricity generator, tight-lock couplers, and wheelslide control. Its riding quality is exceptionally high, which demonstrates that low-speed, single-deck, trains can work well on narrow gauge track.

2.1.3.3 Life expectancy

Rolling Stock: Existing Shosholoza Meyl coaches were built in the same plant at the same time using the same technology as the 5M commuter coaches. In addition to the technical obsolescence mentioned in §2.1.3.2, their remaining useful life is therefore also threatened by the same corrosion problem. It is therefore opportune to consider whether traditional long distance passenger rail has any role in future mass mobility in South Africa. The reader is referred to §6.6.2 for recommendations in this regard. Locomotive structures are heavy, and corrosion is a lesser problem: Their basic technology is fairly robust, but obsolete, ineffective, and inefficient. Their life could be prolonged if necessary, therefore a decision on locomotives for mainline passenger trains should follow from whatever decision is taken in respect of coaches.

Infrastructure: The situation regarding infrastructure is different, because TFR owns most of it, with Shosholoza Meyl trains operating under an access arrangement. It will therefore be necessary for future regional- and intercity passenger rail positioning to recognize TFR’s plans and strategies, and either go along with them, or diverge where there is no synergy. In principle, right-of-way is sustainable well into the future: However, its relevance to contemporary passenger train technology will likely be the dominant consideration that drives passenger rail infrastructure decisions.

[18] That makes them technological contemporaries of the Model T Ford (1908-1927)!

2.1.4 Expectations

Except for the tourist train market, which necessarily must play in the global league, the status quo largely does not satisfy the expectations of South African rail passengers or, more importantly, prospective passengers who will ultimately nurture the rail industry to take its rightful place in the national mass mobility task. The following reasonable expectations (South African Rail, 2008/09) should inform the way forward regarding selection of appropriate passenger rail technology:

- Safety
- Speed
- Reliability
- Convenience
- Cleanliness
- Affordability

This study recognizes that passenger public transport expectations have already been extensively documented. It therefore takes them as read, and will henceforth take a delivery perspective on passenger rail technology, i.e. what technologies should stakeholders leverage to start transforming the passenger rail system? The ultimate match between expectations and delivery must of course be made through diligent economic analysis.

2.1.5 Opportunity knocks

Passenger rail progress in South Africa has been interrupted for several generations, human and technological. Many of its citizens have no idea what good rail service is, nor what it can contribute to society and to the economy. Rail does not feature significantly in their frame of reference, because a near rail-less environment has informed their perceptions. In the mean time, particularly since economic globalization in the 1990s, contemporary rail solutions, and their supporting technologies, have become highly nuanced. They now reflect rail's aggressive competitiveness in several very specific market spaces. Intense competition throughout the global railway industry has stripped preconceived constraints away, leading to vibrant interaction with societies who are willing to entertain contemporary rail.

By contrast, in the monolithic[19] railways of former times, neither differentiation of solutions nor diversity of suppliers was encouraged. Indeed, the opposite approach was usually imposed, as is clearly visible in the status quo. Hence, passenger railway technology in South Africa is still weighed down by requirements to be backwardly compatible with equipment, practices, and standards that have long ceased to be relevant to contemporary mass mobility. While interoperability, to local standards, over the whole passenger fleet has been rigorously maintained, one crucial, unintended, consequence is that both urban- and long-distance passenger rolling stock fleets are now way off contemporary best practice. Unsurprisingly, the undemanding rolling stock has had the

[19] *Monolithic* in railway context means that all operations, whatever their purpose, technology, market, or other differentiating attribute, were placed in a single entity—one country, one railway.

knock-on effect of failing to stimulate high-performance infrastructure. All told, an entirely predictable closed-system outcome.

Noting the generally high age, obsolete technology, and tired condition of many passenger rail assets, South Africa has never had a more opportune time to transform and position passenger rail to form the basis of integrated mass rapid public transport networks (South African Rail, 2008/09). Refurbishment or replacing with the same again, will not cut it: The country needs to migrate to contemporary passenger rail technology.

2.2 In Africa

2.2.1 Africa, business destination

Time, a respected periodical for contextualizing significant events and world trends, in the cover story of its recent Annual Special Issue, reported on *10 Ideas Changing the World Right Now*. Regarding one of the ten, Africa, *Business Destination*, it said the following (Africa, business, 2009):

- “Africa is becoming a business destination.
- According to OECD, foreign investment overtook foreign aid for the first time.
- The private sector is the key driver.
- Africa offers more opportunity than any place in the world.
- Compare the African growth figures with this year’s forecast for the developed world. Who’s the basket case now?”

Among other, the article mentioned railways. Read on …

2.2.2 North Africa

North Africa already has a substantial standard gauge network, which stretches from Marrakech in Morocco through Algeria to Tunis in Tunisia. Egypt also has a standard gauge network, which stretches from Sallum on its western border with Libya to Rafah on its eastern border with Gaza. Libya is constructing a standard gauge double-track railway along its Mediterranean coast, from Surt to Benghazi. 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, a 6000 route-km coastal railway, designated the UAR’s Corridor North, will link North Africa. In Tunisia, this will require, as a minimum, the following construction. First, fill a missing link of some 70km from the Libyan border to Mélenine. Second, complete some 115 km under construction from Mélenine to Gabès. Third, re-gauge, or dual gauge, some 215km of narrow gauge to standard gauge from Gabès to Tabeditt. Last, construct a missing link of some 35km, across the border, to the standard gauge railhead at Djebel Onk in Algeria (National Transport, 2009c). The potential ultimately to link into the Eurasian standard gauge network through the Middle East, and into the European standard gauge network via the envisioned Gibraltar under sea tunnel and on through the standard gauge network in Spain[20], is attractive.

Four North African cities enjoy urban rail operations—Algiers, Cairo and Tunis with metros, and Alexandria and Tunis with light rail systems. Mainline passenger operations use conventional locomotive-hauled stock. In addition, France and Morocco have signed a framework agreement to build a high-speed rail link from Tangier to Casablanca, to meet a rise in passenger numbers. The arrangement is part of the Moroccan railway master plan, which aims to construct 1500km of high-speed rail lines by 2035, capable of carrying 120 million passengers on two routes—the Tangier-Marrakech-Agadir Atlantic link and the Rabat-Fez-Oujda Maghreb link.

North African railways follow UIC (Eurocentric) standards, to advantage and to disadvantage. While they are able to acquire standard rolling stock from European builders, they concurrently inherit Europe's freight train constraints of low axle load and short trains. The latter attributes handicap railway competitiveness vis-à-vis roads.

2.2.3 Iron ore railways

Heavy duty iron ore railways in Africa carry so much more traffic than ordinary railways that they almost always adopt standard gauge so as to make use of proven off-the-shelf technology. New such lines are looming in Cameroon and Senegal. Gabon is already standard gauge. The Trans Guinean Railway is proposed to be standard gauge. Some standard gauge lines in Liberia are to be restored. A Cape gauge line in Sierra Leone is to be changed to standard gauge (African Union, 2009). South Africa is a notable exception to the foregoing generalization. African heavy-duty railways tend to follow AAR standards, the most appropriate for such service. They offer limited, if any, passenger services.

2.2.4 West Africa

Nigeria's narrow gauge network of about 3 500 km is in poor condition. Some five years ago, it was decided to rebuild the whole network, and change it to standard gauge at the same time. Multi-billion dollar contracts were signed with Chinese contractors in 2006, only to be suspended again in 2008. Progress to date is reported as zero (National Transport, 2009c).

2.2.5 The Common Market for Eastern and Southern Africa (COMESA)

In 2008, governments in East Africa agreed to expedite construction of a standard gauge rail network from Dar es Salaam and Mombasa, through Kenya and Tanzania, to Burundi, Democratic Republic of Congo, Rwanda, Sudan, and Uganda, thereby connecting the countries with the region's first heavy-duty standard gauge line. Among other, the United States Class 1 railroad BNSF is advising the countries on acquisition of locomotives, freight wagons, and related equipment. It was reported that while narrow gauge track is cheaper, standard gauge has a greater haulage capacity and allows higher speeds (Barouski, 2008; National Transport, 2009c).

[20] The Trans-European Transport Network Executive Agency's Priority Project 16, Algeciras-Madrid-Paris, is scheduled to start construction before 2010. Algeciras is near where the northern portal might be.

2.2.6 A new dawn

Many narrow gauge railways in Africa have reached, to a greater or lesser extent, the end of their useful lives. In the light of the massive advances that the global railway renaissance has stimulated, it is unthinkable to now contemplate simply replacing like with like in Africa. The media have reported evidence of a turnaround in the value Africa places on its railways. At face value, their reports leave the impression that the orientation will initially be toward freight traffic, although passenger expectations should also be referenced against examples in North Africa. Nevertheless, evidence of addressing the many issues raised in this report is scant, and evidence of implementation even scanter. South Africa potentially has the critical mass to lead progression from aspiration to implementation, to bring the railway renaissance into Africa.

2.3 Globally

2.3.1 A basic rail orientation

Increasingly, cities and countries around the world are consciously deciding to base mass mobility on integrated transport solutions built on a rail foundation. Some of the key drivers are:

- Already high population densities in some cities.
- Higher population growth rates in developing countries.
- Unbearable traffic problems.
- Urbanization—an increasing proportion of a country’s population will live in cities.
- An increase in intercity travel, arguably caused by polarization of populations into cities.
- Decimation of airlines that compete with high-speed intercity trains.

The quantum and scale of projects currently underway leave no doubt that rail solutions are making a major contribution to the world’s mass mobility needs. The following passenger-oriented project numbers (Industry projects, undated) drive home the point:

- Heavy railways 30
- High-speed railways 42
- Light rail systems 90
- Metros 50

The following two examples are a minute sample that illustrates the settings of the above projects, how they approach key issues, and how they represent the ethos of contemporary rail mass mobility solutions.

2.3.2 Two implementation examples

2.3.2.1 A city—Dublin

Greater Dublin[21] is following an integrated transport strategy, to create a single integrated rail network. It comprises Dublin Luas—a growing light rail network; Dublin Area Rapid Transit (DART)—a broad gauge network administered by Iarnród Éireann (Ireland's national railway); Dublin Suburban Rail (DSR)—a broad gauge network owned and operated by Iarnród Éireann; and Dublin Metro—a heavy rail project in planning. As a side note, Dublin's light rail network has been built to standard gauge, narrower than Irish broad gauge (1600mm).

It is useful to appreciate that integrated does not imply interoperable—Luas is, and Metro will be, two standalone systems, while DART and DSR are interoperable with the rest of Ireland's 1600mm gauge network. Integrated in this context means that passenger convenience requirements, such as service synchronization, interchange between operators, public information, and through ticketing, have been duly developed.

2.3.2.2 A country—Turkey

Turkey is a standard gauge country that had invested little in its railways for almost fifty years (On the, 2009). Some existing assets could well be leveraged into the future, but, overall, substantial new investment was indicated.

Light rail development in Turkish cities has progressed briskly, setting an interesting model of affordable, cost-effective, high-quality public transport for the developing Third World. The latest system to open is the new 16km system in Eskisehir, a rapidly developing industrial city with a population of about 500 000. Initial rolling stock consists of 18 totally low floor trams, 29.5 m long by 2.3 m wide, with five articulated sections. Of a model already is use in Linz, Austria, the trams have a maximum speed of 70 km/h. The fleet is designed to carry an initial ridership projected to reach 110 000 per day (Eskisehir launches, 2005). The following are some highlights of Turkey's urban rail rollout:

- Existing Istanbul regional rail, 30km in the European sector and 44km in the Anatolian sector.
- 1989 Istanbul Light Metro,
- 1992 Istanbul Light Rail,
- 1992 Konya Light Rail,
- 1996 Ankara Light Rail,
- 1997 Ankara Metro,
- 2000 Istanbul Metro,

[21] For context, note that Dublin's population of some 1.7 million is smaller than that of several South African conurbations.

- 2000 Izmir Metro,
- 2002 Bursa Light Rail, and
- 2009 (projected) Adana Light Metro.

Turkey is also implementing high-speed intercity trains. The Ankara-Eskisehir 250km/h new electrified double line opened in 2009, The Eskisehir-Istanbul section is under construction, as are new Ankara-Konya and Ankara-Sivas high speed links. Surveying has started from Istanbul to the Bulgarian border for a 230km/h line. Korea's Hyundai Rotem is delivering interregional trainsets capable of 140km/h (On the, 2009). The Transport Ministry's allocation to rail has increased from 6% in 2002 to 42% in 2008.

Turkey is an interesting case of a country investing substantially in rail to recover quickly ground lost to competitors. The foregoing list of projects spans a mere ten years.

2.4 Positioning passenger rail

2.4.1 A research foundation

It is not easy to perceive any patterns or relations in the above examples of the status quo in South Africa, in Africa, and globally. A much larger sample and appropriate research design is required to glean the insight that underlies strategic positioning of railways. The Consultant has undertaken such research over several years, using multivariate statistics applied to global databases. Some of the key findings with respect to passenger rail are presented next.

2.4.2 Urban systems

In a paper on positioning urban rail systems, *Strategies for sustainable mobility: Urban railways as global corporate citizens* (Van der Meulen & Möller, 2008a), which compared rail systems in 245 cities around the world, the following factors (among other) were presented in detail:

- Factor 1, Positioning Metro Rail.
- Factor 2, Positioning Light Rail.
- Factor 3, Pitching Urban Rail at Developing Economies.
- Factor 4, Pitching Urban Rail at Developed Economies.
- Factor 5, Positioning Railway Technology.

For the present study, note that Positioning Metro Rail and Positioning Light Rail (Factors 1 and 2) emerged as distinct activities. Metro rail and light rail respond to different drivers—the stature of a city drives metro rail, while demand for lower density service drives light rail. The research is ongoing, and deeper insight is expected in due course.

Interestingly, after clustering the 245 cities, those in Turkey emerged in an exclusive cluster. The example in §2.3.2.2 above thus attests to the exceptional nature of the transformation in Turkey's urban railway policy.

Factors 3 and 4 assure the quality of this study, by confirming one's intuitive sense that finding rail technology solutions for South Africa, for example, is different from finding rail technology solutions for Europe, North America, or Japan. Where possible, the Consultant therefore selected reference applications in countries comparable to South Africa. [22]

Factor 4 indicated that light rail aligns with standard solutions, including standard gauge track. The emergence in recent years of proprietary light rail solutions from major system integrators underscores this insight in implementing greenfields urban rail projects.

2.4.3 Regional- and intercity rail systems

In a paper on positioning line-haul rail systems, *Ultimate interoperability: Line-haul railways as global corporate citizens* (Van der Meulen & Möller, 2008b), which compared rail systems in 113 countries around the world, the following factors (among other) were presented in detail:

- Factor 1, Positioning Passenger Rail
- Factor 3, Positioning Freight Rail

Factor 1 indicated that positioning passenger railways focuses on finding a sweet spot among Relative Maximum Speed, Gross National Income, Motorways Percentage, Information Technology Leverage, High-speed Intercity Presence, Economic Freedom, Paved Roads Percentage, Research & Development Level, and Electric Traction. Not only do high gross national income and economic freedom associate with motorways and paved roads, they also associate with advanced passenger railway solutions. The association of motorways and paved roads indicated that railways benefit from road competition, and should therefore not be unduly protected from it. The institutional positioning of rail and road should recognize this finding. It is significant that positioning passenger rail emerged ahead of all other line-haul rail positioning functions.

Factor 3, indicated that positioning freight rail is a function distinct from positioning passenger rail. For the purpose of this study, it is not necessary to explore freight rail positioning, other than to note that it shares no drivers with passenger rail.

The two factors together indicate the contention unleashed by operating freight and passenger trains on the same infrastructure. They explain the intuitive sense that passenger trains in North America, and freight trains in Europe, both on shared infrastructure, have been butting heads with stronger opponents. This issue is unavoidably also part of finding passenger rail technology solutions for South Africa.

The findings in §2.1, §2.2, §2.3, and §2.4 present the status quo in South Africa, in Africa, and globally in a coherent framework. It is now appropriate to unpack passenger rail technology, first in general, and then as it applies to South Africa.

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[22] This was of course not possible in all instances, because developed countries are the source of most railway technology developments.

3 Scope of the study

3.1 A reflection of user requirements

This study considers passenger rail technology subsystems in terms of imposed user requirements. It maintains a high-level perspective, among other to enable stakeholders from diverse backgrounds to develop well-informed positions on railway technology questions. It therefore avoids technical detail, as would be found in a performance specification, as far as possible. However, where such detail is unavoidable, explanatory footnotes provide further explanation. The following topics identify and describe essential passenger rail technology subsystems that distinguish passenger rail technology from other rail technology. While many of them have freight rail counterparts, the following sections emphasize their role in passenger rail. They are presented here to lay a foundation for the competitive technologies that are discussed in §4.

3.2 Inclusions

This study of passenger rail technology strived to maintain a balanced perspective on both infrastructure and rolling stock. The following perspectives were admitted:

- Most passenger rail solutions in the global market are predicated on, in the first instance, supplier standard rolling stock, and increasingly on emerging industry standard rolling stock. This aspect of a total passenger rail solution catches the eye of administrators and users, and leaves first and frequently lasting impressions. Established urban-, regional-, and intercity commuter and/or passenger rolling stock technologies, and the solutions they support, therefore gave direction to this study.

- Other than stations, right-of-way and infrastructure is less visible to users, but are an equally important aspect of a total passenger rail solution. They introduce and fit the rail solution into a local setting. In this respect, they must also satisfy non-users and even assuage opponents, by way of environmental impact study and appropriate mitigation measures. The following aspects are included where appropriate:

    - Right-of-way could well be a major issue, such as when expensive tunnels are required.
    - Passenger trains are relatively light, hence track tends to be a maintenance consideration rather than a fundamental discriminant of solutions. However, particular care needs to be taken of noise and vibration in built-up areas.
    - Interoperability where legacy- or modernized freight railway infrastructure is expected to carry passenger traffic.

3.3 Exclusions

Many aspects other than railway technology, such as user convenience, modal integration, passenger amenities, station facilities, and many more, influence the acceptability and attractiveness of passenger rail. However, they relate to railway general management, not to passenger rail technology per se, and were therefore considered to be outside the scope of this study.

- The institutional arrangements within which passenger railways operate may influence their ability to adapt to stakeholder expectations, through the technological solutions they promote or impede. Nevertheless, for this study, institutional arrangements have been taken as neutral with respect to passenger rail technology, and were therefore considered to be outside the scope of this study.
- Specific routes, which are at present without rail service, or which have rail service that does not meet stakeholder expectations, were excluded because the material presented in this report is sufficiently generic to be applied to any setting.
- Although some people movers[23] use rail guidance, they typically only operate over short distances. People movers were therefore also considered to be outside the scope of this study.

Specific technologies at subsystem level, for example power electronics, are outside the scope of this study. They have become a systems integrator prerogative in the competitive global market, and simply come packaged within an overall solution in much the same way as motor manufacturers package a particular range of technologies in their products. There is thus no longer a consistent technology leader in railways. With new technologies continuously coming onto the market, the leader could be the latest purchaser—e.g. Public Transport Authority of Western Australia led with water-cooled power electronic devices on Perth' Mandurah line, and open access operator NTV in Italy is lead purchaser of Alstom's 360km/h AGV. There was no research and development on their part—they simply happened to be the first customer when a system integrator bid a new technology. The scene has now been set to move into the passenger rail technology framework ...

4 A passenger rail technology framework

4.1 Strategic gap identification

4.1.1 Former times

It is useful to first consider how new technology enters railway systems. In former times, railways:

- Dominated land transport,
- Had not yet developed mature technologies, and
- Had not yet positioned themselves in one of the market spaces that rail dominates[24].

[23] People movers are essentially elevators or lifts that operate horizontally.

[24] Heavy haul, high-speed intercity, heavy intermodal, and urban rail. These applications will be examined in detail in §4.2.

Then, individual railways tended to have equipment custom built to their specifications. To some extent, this state was driven by the necessity to interoperate with previous generations of custom-built equipment, but in many instances, it pandered to the preferences of countries, administrations and authorities, and even officials. Some of those preferences and specifications rested rationally on formal research and development. However, many operators, and even suppliers, simply did not have the wherewithal to undertake research and development. In that milieu, resistance to change also played a significant role.

4.1.2 Recent times

In recent times, governments around the world have expected public enterprises such as railways to deliver real value. Frequently, such railways are exposed to, or measured against, some form of competition, such as competitive transport modes, or even competitive claims on public funds. Many public sector railways have adapted by shifting to more competitive solutions and/or technologies. In this respect, they have moved closer to their private sector counterparts. Concurrently, significant research and development efforts have shifted from sometimes fragmented and opportunistic endeavours by railway administrations, -authorities, and -operators, to routine, well-funded, competitive research by system integrators. One outcome has been industry standard or preferred technological solutions. Many railway solutions, particularly in the rolling stock and signalling fields, which are more transportable than civil infrastructure, thus now come from an ever-consolidating range of system integrators. This is much the same as aircraft and motor vehicles come from an ever-consolidating range of competitive manufacturers. This phenomenon is more pronounced in passenger rail, arguably because mass mobility requirements are less diverse than the logistics requirements that influence freight rail.

4.1.3 Setting course

This Framework Report will examine the competitive strengths that rail's technologies support, and the contemporary passenger rail solutions that exploit them. The Consultant will then apply the findings to the South African passenger rail setting, to identify gaps between existing passenger rail technology, which falls short of stakeholder expectations in many respects, and solutions that can place rail in a commanding position in appropriate market spaces.

4.2 Positioning passenger rail for competitiveness and sustainability

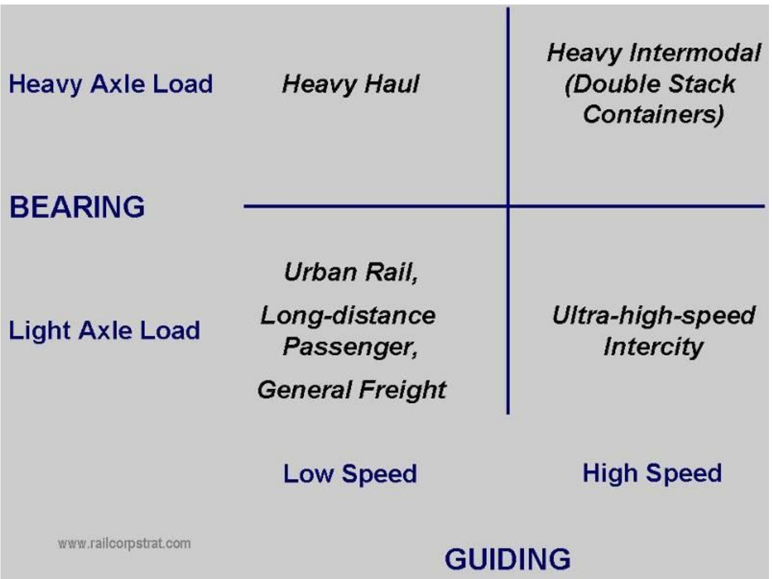
4.2.1 The fundamental drivers of railway competitiveness

4.2.1.1 Distinctions among transport modes

It is useful to consider railway technology from a perspective of degrees-of-freedom-of-movement of the various transport modes. First, some modes possess three degrees of freedom of movement (e.g. aerial- and submarine transport): They offer three-dimensional mobility, but at relatively high cost. Second, some transport modes possess two degrees of freedom of movement (e.g. unguided surface transport such as maritime and road): They trade off reduced mobility against lower cost. Last, guided surface transport modes possess only a single degree of freedom of movement (e.g. railways and maglev): They offer limited mobility, back and forth on a guideway. To the extent that limited mobility reduces value to existing- or potential users, such applications must offer compensating advantages to hold their own against competing transport modes with more degrees of freedom of movement.

4.2.1.2 Railway genetic technologies

Guided surface transport is predicated on a vehicle-guideway pair, which ensures precise application of vertical loads, and secure application of lateral or sideways loads. Conventional steel-wheel-on-steel-rail contact develops vertical and lateral forces, which underpin technologies known as *Bearing* and *Guiding*: They support respectively heavy axle load and high speed. Cross-breaking Bearing and Guiding in the figure at right, yields four rail market spaces. Three of them are intensely competitive—Heavy Haul, High-speed Intercity, and Heavy Intermodal or Double Stack. Railways that participate in them have demonstrated inherent sustainability. One may leverage all four market spaces by linking vehicles into trains, to scale capacity as required, a technology known as *Coupling*. Bearing, Guiding, and Coupling are the three *genetic technologies* that distinguish railways from all other transport modes: Railway competitiveness can be measured by the extent to which railways exploit their genetic technologies[25].



4.2.1.3 One potentially weak market space

Section 4.2.1.2 also defines one potentially weak market space—light axle load in combination with low speed It is exemplified by general freight-, traditional long-distance passenger-, and urban rail applications. Where general freight- and long-distance passenger traffic share infrastructure and operations, their natural speed difference results in contention for line capacity, while their natural riding quality difference results in contention for permissible axle load. Neither traffic type can exploit its full potential without compromising the other, which imposes an opportunity cost that competitive modes do not face[26].

Railways that cannot offer significant advantage over competitive modes struggle for sustainability. Line-haul railways that fail to exploit their genetic technologies are weak,

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[25] One cannot define the three competitive market spaces by hard rules, but the following empirical boundaries fit real railways. Plotting speed on a logarithmic scale, $10^{1.x}$km/h (i.e. 10-99km/h) comfortably accommodates most low speed applications, and $10^{2.x}$km/h (i.e. 100-999km/h) comfortably accommodates most high-speed or ultra-high-speed applications. International Heavy Haul Association Bylaw 4.9 [3] admits permissible axle load of ≥25 tonnes as heavy haul.

[26] It will emerge later that this has been an impediment to development of intercity rail in South Africa, and that the contention will be magnified when railway operators try to exploit different strengths on the same infrastructure.

hence competitors erode their markets: Depending on whether economic-, political-, or social objectives determine their destiny, they are respectively eliminated, protected, or subsidized. This aspect will be developed further when interoperation between freight and passenger trains is addressed in §4.4.7.1. Fortunately, urban rail is the exception that can prove the rule in the light axle load and low speed market space.

4.2.1.4 Urban rail

The criteria by which urban rail is positioned differ from those of line-haul railways in so many respects, that urban rail is virtually a mode distinct from other railway applications[27]. While it resides in the potentially weak market space, it is nevertheless a popular and valuable mass mobility solution in many cities. The Coupling genetic technology makes short average headways possible, by combining vehicles into trains. Such short headways would challenge the autonomous vehicles with which urban rail competes. Urban rail's advantages thus typically relate to total system capacity, by leveraging the output from each headway- or timetable slot. Note that this perspective recognizes all urban rail variants found in practice—heavy rail, light rail, metro, tram, and so on, or any combination of them in a particular city.

Recognize that urban rail's position in the potentially weak market space does expose it to encroachment by alternative guided surface transport systems, which package axle load, headway, and speed differently, to offer alternative benefits. This issue is developed further in §4.5.2.

4.2.1.5 The important role of track gauge

In noting that the Coupling genetic technology redeems urban rail from uncompetitiveness, note also that Coupling is not track gauge dependent. That partially explains why narrow gauge railways operate some of the longest heavy haul trains in the world. One must therefore look for the influence of track gauge on passenger rail technology in the other two genetic technologies, Bearing and Guiding.

Human beings do not make a heavy payload for railways, even under crush load conditions. Noting the determinants of passenger capacity discussed in §4.4.5.2 and §4.4.5.4, passenger train axle load rarely exceeds 18-19 tonnes, because it is simply not possible to get more people into a practically sized railway car or -coach. This is light by contemporary railway standards, and one must therefore conclude that high axle load does not drive passenger rail competitiveness. The remaining genetic technology, Guiding, is highly dependent on track gauge.

Track gauge, through its influence on the Guiding genetic technology, is therefore an important determinant of train speed. This is in turn a fundamental driver of journey time, a key parameter for long distance passenger rail competitiveness. The technicalities of track gauge are addressed in §4.4.5.5: In the context of §4.2.1, note now that track gauge is a fundamental driver of passenger rail competitiveness in the speed-dependent (>130km/h) domain beyond urban rail, i.e. regional rail and high-speed intercity. In the latter applications, standard gauge track has become a minimum requirement.

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[27] It will be shown later that this has important migration advantages for upgrading technology.

4.2.2 Good corporate citizenship

4.2.2.1 Convenience

Several aspects of positioning railways do not fit into neat categories. Convenience is one of them. It is not a competitive advantage per se, but unless operators recognize it as an essential element of their total offering, much of their competitive advantage derived from passenger rail technology could be neutralized. This study therefore takes for granted that the following material automatically includes consideration of users' convenience expectations.

4.2.2.2 Climate change considerations

The rolling resistance of steel-wheel-on-steel-rail is inherently low. Furthermore, coupled rail vehicles follow in one another's slipstreams, so aerodynamic resistance is also low. Rail is therefore an inherently energy-efficient transport mode, offering around 4-to-1 advantage over cars and airliners (National Passenger, 2007b). However, neither regional- nor urban railways have yet leveraged this advantage aggressively (Van der Meulen & Möller, 2008a and 2008b), by comparison with other modes.

For example, bus rapid transit has positioned itself as a green urban transport solution. Proponents reason that it uses less fuel than the private cars and taxis it displaces. While this is true, urban rail ought to claim a similar advantage over BRT, but has not yet done so. Diesel locomotive builders make a similar claim—diesel locomotives use less fuel than diesel driven buses or trucks to perform the same task—also true, but they fail to make the same comparison with electric traction.

Two thrusts are leveraging technology developments that exploit rail's inherent energy efficiency. First, coercion in the form of emissions limits on diesel engines has become assertive. Second, despite the present dip in oil prices, the peak oil spectre is set to drive oil prices upwards in the medium term.

Fortunately, railway equipment suppliers and system integrators have seized the initiative from operators in promoting the green benefits of railways, as they strive for market share. First, they picked low hanging fruit, such as regenerative braking[28], which is now taken for granted. Next came more complex solutions such as ultra-capacitor on board energy storage systems, which are a naturally good fit between electric traction and frequent stops in urban public transport settings.

Recent incisive developments directly address fundamental weaknesses by reducing the resources required to deliver a given transport task. Noting that urban rail is positioned in a potentially weak market space, and by extension reasoning that even regional rail is does not fully exploit rail's axle load and speed potential, system integrators are promoting articulated cars on regional trains. The technology increases axle load, and reduces cost and complexity, by sharing bogies

[28] Regenerative braking minimizes energy consumption by recovering the energy that would otherwise have been dissipated in friction braking. It has a side benefit of minimizing wear and maintenance of friction brakes.

between vehicles as in the picture. Of course, maintenance facilities need to be appropriately equipped to lift an entire train for bogie and wheelset maintenance[29], and high equipment reliability is a key success factor. Car body width is also being increased, to as much as 3,6m[30], to increase floor area to accommodate more passengers and hence to raise axle load, on both commuter and regional trains. Naturally, such big vehicles are not widely interoperable, but their capital- and operating cost savings outweigh constrained interoperability.

Next generation urban and regional trains hold the prospect of almost 50% reduction in energy consumption, derived as follows (Hondius, 2008):

- Permanent magnet traction motors 2%
- Driver aids to balance energy usage and schedule optimization 15%
- Aerodynamically optimized nose ends 12%
- On-board braking energy recovery 20%

Thus while energy consumption cannot reflect rail's genetic technologies[31], it is closely related to those technologies. Now that research and development is primarily in the hands of system integrators, the field is making rapid progress in reducing energy consumption. As climate-change concerns mount, rail's energy efficiency is becoming almost as strong an attraction as the competitive strengths that its genetic technologies provide. Together, they offer a winning combination that can offset disadvantages in rail's weaker low axle load, low speed applications. Railway operators should be willing to upgrade equipment routinely, to take advantage of such technological advances.

4.2.2.3 The security subsystem

Security is not a requirement unique to railways. It applies as much to railways as to any other situation in which people become opportunities for villains to strike. In South Africa, train passengers are additionally at risk because it is not possible to effectively patrol trains without end-to-end access. It is also not workable to interlock door operation with propulsion, which means that it is possible to force doors open and throw passengers out of moving trains. The railway industry has developed a standard security sub-system comprising:

- Access control to stations,
- Video surveillance at stations and on trains,
- Door interlocking to prevent opening while trains are moving at speed,
- Communication between passengers and train driver and between driver and control,

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[29] Train lifting is not an undue imposition—most contemporary maintenance facilities for multiple unit sets are equipped to lift entire trains, so that bogies and major underfloor equipment can be changed quickly.

[30] Copenhagen suburban train sets produced by a Siemens/LHB consortium.

[31] Many transport modes use propulsion and braking systems, so energy consumption cannot be a railway genetic technology.

- Public address from control to passengers on stations and trains, and
- Rapid response personnel.

Although not an element of the abovementioned security sub-system, full width inter-circulation gangways between cars, which have become popular for increasing usable floor space, also allow passengers to avoid empty cars, and facilitate end-to-end access by security personnel.

This solution offers adequate peace of mind to attract potential users. Unless a railway operator meets passengers' minimum security expectations, they will vote with their feet for other transport options: Implementation of contemporary rail technology in unsafe settings will not meet with success.

4.3 Mainstream conventional passenger rail technology solutions

4.3.1 A menu of contemporary solutions

The following sections describe variations that have emerged from the global railway renaissance as mainstream passenger rail technology solutions. They represent a competitive, vibrant industry's best shot at serving the needs of mass passenger mobility, and capturing market share from other modes. Authorities and operators should consider this the menu from which they can order solutions. Specials are of course available, but are likely to command a price premium and thereby miss the competitive advantage that mainstream solutions seek to exploit. Furthermore, specials only perpetuate the competitive disadvantage that requires them in the first instance, thereby ultimately relegating deviant railways to the margins.

Note that the technical system parameters mentioned in §4.3 are indicative, not definitive. Values that are more precise would need to be developed during feasibility study and preliminary design phases for application opportunities that warrant deeper examination. Note also that, on the same track gauge, the boundaries between the mainstream solutions are not rigid, but allow a degree of performance overlap.

4.3.2 Light Rail

4.3.2.1 Evolution

Light Rail evolved from what were formerly trams, and in many instances still runs on former tram tracks. However, contemporary light rail vehicles (LRVs) are technologically advanced; they contribute substantially to a city's transport task, and are attractively styled. They can mingle intimately with pedestrians and motorists, where their presence represents an in-your-face marketing opportunity. On segregated right-of-way, they can make rapid progress. They are quiet, and offer a comfortable ride. State-of-the-art LRVs feature low floors, 300-350mm above rail, over 60-100% of their floor area. They are convenient for shoppers with parcels and parents with children. Some systems provide low-level platforms for level entry, to reduce dwell time.

4.3.2.2 Vehicle design

Contemporary LRVs may use multiple articulation, comprising sections 5-9 meters long: They can therefore easily negotiate curves to a minimum radius of around 25m in existing city streets. They can also adapt to growing ridership by adding units. Total lengths typically range between 20 and 70 meters. The industry rates nominal passenger capacity at four persons per square meter. Depending on seating configuration, body width, and total length, LRV capacity is in the range 150-350 passengers.

Light Rail is generally less restricted in terms of vehicle dimensions than other urban rail applications, except of course in those cities where it needs to pass through narrow passages in historic districts. System integrators therefore offer standard body widths in the range 2.30-2.65 meters. End sections are frequently tapered, to minimize swept area in confined spaces.

Light Rail is a standard gauge application for new systems, with very few exceptions. Former meter gauge light rail routes in some European conurbations have been re-gauged to standard gauge, to foster large-scale integration with neighbouring standard gauge networks. It makes no sense to specify a track gauge other than standard gauge, because it increases price and reduces the global fleet size. A global trade in LRVs is picking up—Konya and Antalya in Turkey opened starter networks with LRVs from respectively Cologne and Nuremberg in Germany. In an interesting international deal, Mulhouse in France ordered its entire fleet at once, but is building the network itself in stages: Five LRVs not immediately required were leased to Melbourne in Australia until 2011 (C2 class, undated).

4.3.2.3 Traction characteristics

Low floor LRVs do not have space to accommodate traction motors between their wheels. Traction motors are therefore overhung outside the wheels. The proportion of motored axles can be as high as required, up to 100%. LRVs can cope with gradients as steep as 8%, thereby making less demand on environment and infrastructure.

4.3.2.4 Infrastructure

Axle loads have traditionally been of the same order as road vehicles, around 8-10 tons: The rationale was that Light Rail could be implemented without major substructure preparation. Of course, installing a guideway in built environment is always a disruptive operation. Note however from §4.2.1, that axle load drives rail competitiveness. It therefore comes as no surprise that buses, with the same axle load but greater mobility, offer serious competition. Light rail axle loads have therefore been creeping up into to the range 10-12 tonnes. Except on legacy infrastructure, this should not pose a structural or financial challenge when contemplating extensions or new applications.

Electrification is typically overhead. It may be trolley wire (contact wire only), which has less visual intrusion but lower speed potential, or catenary (contact wire and messenger wire), which has more visual intrusion but higher speed potential. Attractive alternatives are expected in the near future (see §4.4.7.4).

4.3.2.5 Performance

Maximum speed is typically around 70 km/h, but could reach 90km/h on segregated right-of-way in outlying areas with long station spacings. Average speed depends on the extent to which light rail vehicles must contend for right-of-way. It could be less than

15km/h on shared right-of-way in areas congested by pedestrians and/or road traffic. Depending on distance between stops, it could be as high as 40-45km/h on segregated right of way.

4.3.2.6 Capacity

Light rail vehicles must be driven manually on right of way shared with motorists or pedestrians: Signalling systems simply do not work when people and road vehicles also contend for access. Even in outlying areas on segregated right-of-way, many light rail systems use no signalling other than controlled intersections with road vehicles, to minimize costs. However, un-signaled light rail generally does not exceed 60-70km/h (Van der Voort, 1980). Should a higher speed be indicated, signals would be required, and the application would then tend to the domain of Light Metro (see §4.3.3.1).

It is therefore difficult to give exact capacity numbers, and many systems are rated in passengers per day, rather than passengers per direction per hour. Indicative rates would be 6000-12 000 passengers/direction/hour during peaks, and 30 000-60 000 passengers per day.

Short dwell time at halts is helped by many side doors—typically at least one, frequently two, per articulation unit. It is common practice for regular users to have long-period tickets, and for casual users to validate tickets when boarding. Such honour systems do little ticket checking but have high penalties for fare evasion. Operating light rail vehicles with many doors at street level in South Africa might challenge the ingenuity of fare collectors. In settings where light rail could be a candidate solution, there may be value in exploring the next level, Light Metro, to manage fare collection by means of formal stations.

4.3.2.7 Costing

Costing is of the order of R75 million per kilometer and upwards, for a basic though complete system including rolling stock. It is of course sensitive to many factors. First, situation-specific such as cost of land, extent of segregated right-of-way, extent of elevated and/or underground construction, type of signalization, and complexity and frequency of stations. Second, sharing right of way with say, freeway construction, or combining stations with commercial development, could possibly reduce costs. Third, generic such as funding arrangements and exchange rate. There is no applicable history of light rail construction in South Africa, so overseas prices have been used as a first approximation.

4.3.2.8 Key technical system parameters

Stated values are those typically preferred for new systems: Extensions to legacy systems may follow previous practice.

Maximum speed	70-90km/h, depending on station spacing
Average speed	15-45km/h, depending on right of way
Capacity	5000-10 000 passengers/direction/hour
Track gauge	1435mm
Track configuration	Double
Minimum curve radius	25m

Maximum gradient	8%
Axle load	8-10 tonnes
Control system	Manual driving on sight, or signalized
Power supply	25kV ac

4.3.2.9 Tram-train

Tram-train operation allows LRVs to venture further afield than their traditional city networks. Light rail networks in many cities have potential links, to regional- or national rail heavy rail networks. Such external networks can support LRV access from outlying suburbs into city centres. Of course, the converse, heavy rail vehicles entering city centres via tram routes, is usually not possible because of axle load-, vehicle length-, and vehicle profile constraints.

Driven by competition, a trend to differentiate a new category of rolling stock has emerged in recent years. The 70km/h maximum speed of most LRVs is insufficient for heavy rail lines, so they are typically re-geared for a maximum speed of 100km/h. Heavy rail can also support higher axle load, so tram-train axle load has crept up to 11-12 tonnes. Despite the name, tram-train is thus quite far removed from regular trams.

The essential requirements for tram-train operation are firstly, interoperability with respect to track gauge and overhead power supply and secondly, a modus operandi that recognizes the relatively weak crashworthiness of LRVs by comparison with heavy rail vehicles. Operators employ two methods. First, temporal separation, i.e. operating heavy rail and light rail at different times of the day, say light rail during the day, and freight trains at night. Second, physical separation is achieved by interlocking signals such that there is no possibility of say a derailed heavy rail train crashing into a LRV (Bowen, 2008).

Tram-train is not a passenger rail front-runner in South Africa, because there are no standard gauge light density tracks on the present TFR network. It is therefore mentioned here for completeness only.

4.3.3 Light Metro

4.3.3.1 General description

Light Metro is essentially high-floor Light Rail provided with dedicated right-of-way throughout the system. This enables its full speed potential of 80km/h to be exploited, without contending for right-of-way. It can thus offer average speeds similar to metro, namely around 40-45km/h. Operation is usually automatic (driverless). The high-floor design allows level entry from matched platforms, to minimize station dwell time. The infrastructure may be at grade, as is usual for light rail, but where necessary it is elevated or tunneled, to provide unimpeded access to stations. This yields the following advantages over heavy metro:

- Axle load is lower, so structures are lighter,

- Vehicle profiles are smaller, so structures, particularly tunnels, are smaller,
- Curves are tighter and grades are steeper, which allows greater use of less expensive guideways,
- Stations are smaller and less expensive, and
- Vehicles cost less.

Light Metro therefore typically requires around half the capital cost of a conventional underground metro system, or around R125 million per kilometer. Of course, system capacity is not in the league of heavy metro systems. Light Metro is rated as a medium capacity system—up to 30 000 passengers/hour/direction. It is a comparatively recent development, and all applications have been on standard gauge track. The illustration shows a Guigaro industrial design for Copenhagen.

4.3.3.2 Key technical system parameters

Stated values are those typically preferred for new systems: Extensions to legacy systems may follow previous practice.

Maximum speed	80-90km/h
Average speed	40-45km/h, depending on station spacing
Capacity	30 000 passengers/direction/hour
Track gauge	1435mm
Track configuration	Double
Minimum curve radius	25m
Maximum gradient	8%
Axle load	11-12 tonnes
Control system	Automated
Power supply	25kV ac

4.3.4 Heavy Metro, or simply Metro

4.3.4.1 Origin

Metro is the rail application that delivers highest passenger capacity. The word *metro* features widely in the names of rapid transit systems around the world, including Metrorail in South Africa. A sign with the letter *M* is also widely used to indicate entrances to stations that may otherwise be inconspicuous. Note however, after reading what follows, that the metro connotation in Metrorail could be a misnomer: Once South Africa's passenger rail dispensation has been repositioned to reflect contemporary solutions, it could be appropriate to consider re-branding it.

4.3.4.2 Infrastructure

Metro is one of the oldest passenger railway applications: London's Underground dates from 1863, after which the technology quickly spread to other cities in Europe and then the United States. Such systems have become so entangled in their respective built environments, that it would be unthinkably expensive to change key dimensions such as track gauge and vehicle profile. Some metros are built to unique profiles with extremely small dimensions—see for example the illustration at right of a London Transport train.

Metros are therefore often more restricted regarding vehicle dimensions than other rail applications, particularly those that were established prior to emergent industry standards. Now that globalization is forging a shared vision, there is growing appreciation of the advantages of designs with as many common elements a practicable. Note that while many people associate *metro* with *underground*, this is not necessarily so. Chicago's famed L (for elevated) metro has more elevated track than at grade- or sub-surface track.

Metros can accommodate gradients as steep as 5%, because they have a high proportion of motored axles, up to 100% in some cases. Axle loads are around 16 tonnes.

4.3.4.3 Vehicle design

The above, and other comparable vehicle profiles, can never be a preferred or standard profile, yet the supply industry is ready to build to such unique requirements. By contrast, Mumbai Metro, currently under construction, has even departed from India's uni-gauge policy to embrace standard gauge track (Bhatnagar, 2006). The reasoning was that, for a greenfields project with no interoperability requirements, the most competitive, industry standard or industry preferred, rolling stock would support the optimum overall solution.

System integrators have therefore been careful to design modular vehicle structures, which they can adapt to a variety of vehicle heights and widths: Deviating from preferred or standard[32] vehicle profiles and widths will of course command a price premium. In a world where numerous cities are building or contemplating greenfields metro systems, the wisdom of going with the mainstream is compelling.

Notwithstanding such preferences, it is interesting to note that a plethora of new metros springing up in Asia has vehicle profile widths in the range 3000-3150mm. Appreciate however that tunneling is extremely expensive, and that avoidable tunneling may influence the body width selected.

4.3.4.4 Performance

Metro performance is bounded by acceleration and retardation, typically close to the passenger comfort limit of $1 m/s^2$, and a maximum speed of around 80km/h, which parameters maximize line capacity. This gives an average speed of around 40-45km/h.

[32] That is, where standards do exist.

Metro lines are typically in the range 15-35km in length, which gives end-to-end journey times in the range 20-45 minutes. Individual station-to-station link times are of the order of two minutes.

Acceptable or desirable journey time depends on the socio-economic setting. However, for journeys outside the above range, other options, such as regional trains, with lower passenger density and higher maximum speed, could offer more attractive solutions.

4.3.4.5 Capacity

Minimizing station dwell time contributes to maximizing system capacity. Metro cars therefore have between two and four doors per side, to ensure rapid egress and entry. Double deck coaches cannot discharge and load commuters as rapidly as single deck coaches: The double deck configuration allows no more than two doors per side, and they have to serve a higher passenger count on two decks. Metro systems have therefore converged globally on single deck trains for ultimate passenger capacity.

The industry rates nominal passenger capacity at six persons per square meter of car floor area. A six-car train can therefore carry around 2000 passengers. At 1½ minute headways, this gives a throughput of 80 000 passengers per direction per hour. Actual capacity is of course a function of the headway supported by the signaling system, the train length, manual or automatic train operation, frequency of stops, and so on. For example, Guangzhou Metro, in China, has a capacity of 100 000 passengers per hour per direction.

Entry-level systems convey around 15 000 passengers per direction per hour. The challenge with a new metro system is to pitch it at a growing catchment area, by extending the length of the initial line, adding further lines, usually radially, or developing bus or light rail feeder networks. To give an appreciation of ultimate duty cycle, cities such as Sao Paulo carry more than one million passengers per day per line (Automating Brazil's, 2009). For service of 18 hours per day, the average throughput is almost 28 000 passengers per direction per hour. Metro is thus a robust urban rail application.

4.3.4.6 The enigma of track gauge

Metro trains make comparatively frequent stops. While higher speed may shorten journey time, it also increases headway between trains, and so diminishes capacity. The headway-speed trade-off maximizes capacity at around 80km/h. Metro trains require high acceleration and high retardation to achieve short headways. A high proportion of axles must therefore be motored, but the traction motors themselves are relatively small. They thus fit easily between the wheels of even narrow gauge bogies.

Greenfields metros are nowadays built to standard gauge, whatever the national gauge of the country in which they are built, whether narrow or broad. The advantage of standard gauge is that it can attract competitive bids based on established designs and -production capacity. However, narrow gauge metro sacrifices nothing in performance, because it can accommodate the requisite traction motor size.

The enigma of metro rail is thus that it is the one railway application where narrow gauge track does not impede train performance in any way—vehicle profiles are diverse, single-deck vehicles do not raise stability issues, speed is relatively low in any event, and adequately rated traction motors can fit.

Of course, while metro trains do not intrinsically require standard gauge track, the latter does add value through greater comfort, wider bodies, and importantly, competitive global sourcing. The enigma provides valuable insight to inform future metro investment decisions in South Africa.

4.3.4.7 Costing

As with any urban rail project, costing is essentially situation specific. Land acquisition can be significant. The cost of infrastructure runs around 80% of the investment, and is dependent on location—at grade, elevated, or underground, the cost increasing by rule of thumb in the ratio 1:5:10 respectively.

The Gautrain price tag of around R20 billion would be a fair starting point to estimate the cost of metro construction, and is the only current reference for South Africa. Aside from the higher speed, there are many similarities with a metro system. The speed would be lower, which would allow tighter curves and thereby reduce environmental impact, but signalling for high capacity would be more expensive. For 80km route length, the system cost is R250 million per kilometer.

4.3.4.8 Key technical system parameters

Stated values are those typically preferred for new systems: Extensions to legacy systems may follow previous practice.

Maximum speed	80-90km/h
Average speed	40-45km/h, depending on station spacing
Capacity	15 000-80 000 passengers/direction/hour
Track gauge	1435mm
Track configuration	Double
Minimum curve radius	100m
Maximum gradient	5%
Axle load	15-16 tonnes
Control system	Manual with ATP, or fully automated
Power supply	25kV ac

4.3.5 Regional rail

4.3.5.1 Origin

Operators and system integrators have been able to delineate the regional rail market space more clearly in recent years: Its combination of high speed and high capacity per train have stimulated a commuter market that rippled out in a widening catchment area around large cities. It is thus positioned between metro and high-speed intercity. Regional rail typically offers convenient interchange with metro systems, where they exist, to facilitate easy access from outlying areas to diverse destinations in a city.

4.3.5.2 Trains

Regional trains trace their origins to, and have largely displaced, earlier suburban services, operated by traditional single deck locomotive-hauled coaches or EMUs. Contemporary regional trains are usually double-decked, vehicle gauge permitting. This is possible even within the comparatively low UIC vehicle gauge, although the window band of the upper deck needs to be canted inwards. Double deck coaches have emerged as an economic solution for many regional rail applications.

Double deck stock uses the volume below the normal single-deck floor for lower deck passengers. This means that normal underfloor propulsion-, braking-, and auxiliary equipment must move elsewhere. First generation double deck trains met this challenge by using locomotives—the coaches were plain trailers. Regional trains are usually operated in push-pull mode, with the locomotive at one end, and a trailer with driver's cab at the other. The disadvantage is that the power-to-mass ratio, and hence the acceleration, varies as the number of coaches varies. Nevertheless, braking performance on coaches with air suspension is consistent, regardless of passenger load.

Despite the challenge of finding space for two passenger decks and all propulsion-, braking-, and auxiliary equipment, technological advances, and competition among system integrators, has yielded a new generation of double-deck regional EMUs, now entering the market. Regional trains can now enjoy the consistent performance that characterizes fixed formation trains.

Adaptable entrance levels are emerging on single deck regional stock, to accommodate a range of customer platform heights. Note that entrance level should be specified at time of order, usually not adjustable from station to station. On double deck stock, doors may be configured on the lower level, ideal for low-level platforms, or above the bogies, ideal for high-level platforms.

4.3.5.3 Infrastructure

Regional rail is a synergistic application that frequently shares infrastructure owned by others—for example, the national infrastructure operator in European countries, or one of the freight railroads in North America. It sometimes also uses dedicated infrastructure portions, such as the RER[33] in Paris, which also ultimately link into a national network.

Regional rail thus generally runs at grade, but it may include elevated or underground sections to access city centres. Outside city limits, regional rail typically needs to share infrastructure access with freight traffic and possibly high speed intercity trains as well.

Aspects such as line speed, riding quality, and signalling warrant due consideration. There could be synergy between freight- and regional passenger trains in the context of communication based train control (see §4.4.7.5), which has recently emerged as the preferred system for medium density shared routes in the United States.

Standard gauge track is an essential requirement for full-size double deck trains, due to their comparatively high centre of gravity and, depending on operating regime, their high speed as well.

[33] Réseau Express Régional, or regional express network.

4.3.5.4 Performance

Maximum speed depends on the infrastructure characteristics, but is in the range 120 km/h (on narrow gauge track) to 200km/h on standard gauge track. DMUs are at the low end of the range, while locomotive-hauled trains operate at the upper end of the range. Maximum speed is more important than acceleration and deceleration, because regional trains typically do not run to headways as short as urban rail.

Regional trains typically operate on legacy infrastructure as is, or with low-budget upgrades. System integrators therefore offer active body tilting as an option on regional multiple unit trains. On standard gauge track, body tilting can raise permissible speed in curves by 30-35%. On curvy routes, that can materially reduce running times. See §4.4.5.6 for more information regarding tilting.

4.3.5.5 Capacity

Double deck coaches carry 140-240 people, depending on interior layout, seating configuration, and passenger density. Journey time, and the length of time passengers are willing to stand, also influences the number. Regional trains may be equipped with toilets, to accommodate passenger needs over extended journeys. The number of coaches in a train depends on capacity requirements, and whether it is locomotive-hauled or multiple unit stock.

Headway is dependent on the host railway signalling system.

Practical capacity ranges from 30 000 passengers per hour per direction for single deck stock, to >60 000 passengers per hour per direction for double deck stock.

4.3.5.6 Costing

Costing regional rail projects is a complex exercise. Aside from the basic infrastructure cost, which is highly situation-specific, there can be positive and negative impacts. On the positive side, commercial development of stations and station precincts can increase a system’s revenues, and make fares more accessible. Dramatically reducing travel time can change the course of economic geography development. On the negative side, mitigating environmental impact can be significant where routes pass through ecologically sensitive areas and built-up areas.

To put a number on it, South Africa’s recently proposed greenfields Moloto Rail project, over a distance of some 120km, was estimated to cost ZAR 8-9 billion (National Transport, 2009g). If suitable existing infrastructure is available, only rolling stock, and possibly station platforms as well, will be required. In this case, standard gauge double deck EMU stock costs in the region of R20 million per car

4.3.5.7 Key technical system parameters

Stated values are those typically preferred for new systems: Extensions to legacy systems may follow previous practice.

Maximum speed	160-200km/h
Average speed	110-150km/h, depending on horizontal curvature
Capacity	30 000-60 000 passengers/direction/hour
Track gauge	1435mm

Track configuration	Usually double, could be single
Minimum curve radius	2500-3000m for unrestricted speed
Maximum gradient	2½%
Axle load	17-18 tonnes
Control system	Manual with ATP
Power supply	25kV ac or diesel

4.3.6 High-speed Intercity

4.3.6.1 Origin

High-speed Intercity trains run at 200km/h, perhaps 220km/h (UIC, General definitions, undated). Note that in recent years, as the fastest intercity trains advanced from the mid-200s to the mid-300s km/h, a significant number of high-speed operations stayed at 200km/h. They are now still known as high-speed trains. However, those that advanced above 300km/h have come to be known as ultra-high-speed trains, described in §4.3.7.

It appears that 200-220km/h has become a ceiling for conventional rail on non-dedicated track. A tilting version of such a train is shown at right. Most railway engineers around the world agree that it is only economic and feasible to upgrade a conventional railway to 200km/h or to 225km/h if the original alignment is good (Briginshaw, 2009). Beyond that, there is distinct advantage in building new dedicated infrastructure for ultra-high-speed rail.

See §2.1.3.1, §4.4.2.1, and §4.4.3.2 regarding potential application to South Africa (whose legacy system does not meet the *good original alignment* criterion above).

4.3.6.2 Infrastructure

Contemporary high-speed intercity trains thus run largely on legacy infrastructure that does not justify replacement by, or incorporation in, dedicated high-speed lines. The concept is generally well developed in the western European setting, and China has also implemented similar operations in the last year or two. Note that Europe has had a history of notching up speed regularly, and railways routinely programmed curve widening. However, now that ultra-high-speed has emerged as a distinct market space, regular speed increases on legacy infrastructure appear to have abated.

High-speed infrastructure is usually double tracked and electrified. It is always standard gauge or broad gauge. It usually also includes substantial portions of upgraded legacy routes, but some portions may be on new dedicated right of way. In many instances high-speed trains use existing low speed infrastructure to gain access to stations in city centres. Signalling always includes automatic train protection. Sound barriers are required near to built-up areas.

4.3.6.3 Services

High-speed is invariably associated with quality service—a high level of comfort, frequency and accessibility (UIC, In view of operating, undated). Routes are operated by classical trains hauled by locomotives, or tilting trains in fixed formation (UIC, In view of rolling, undated). A 200km/h capability has come to be taken for granted for such rolling stock.

4.3.6.4 Capacity

Average speed is of the order of 140-150km/h. High-speed intercity is timetable driven, rather than capacity-driven. A realistic maximum frequency would be six trains per hour, with a capacity of say 500 persons per train of single deck coaches. This gives 3000 passengers/direction/hour, which is not remarkable. Given that capacity is relatively lower and journey time relatively longer than ultra-high speed, only countries that have suitable legacy infrastructure, such as the new accession countries of the European Union, are still pursuing the high-speed option.

4.3.6.5 Freight access

High-speed routes evolved out of traditional mixed freight and passenger traffic operations. Although some network operators still allow freight trains to run on high-speed lines, they are severely restricted and at present operate only at night (UIC, In view of operating, undated). Wagons of questionable condition from a general freight pool are regarded as a safety risk on high-speed infrastructure.

4.3.6.6 Costing

High-speed multiple unit trains cost around R20 million per car. A 9-car train for the 500 passengers mentioned in §4.3.6.4 would thus cost around R180 million. Noting that such trains normally run on existing infrastructure that has been routinely upgraded, there should be no infrastructure cost. However, in South Africa this is not the case. To upgrade a line for high speed, around 70% of the existing route distance would need to be rebuilt, at a cost of some R10 million per kilometer for a single track non-electrified line.

4.3.6.7 Key technical system parameters

Stated values are those typically preferred for new systems: Extensions to legacy systems may follow previous practice.

Maximum speed	200km/h
Average speed	140-150km/h
Capacity	3000 passengers/direction/hour
Track gauge	1435mm
Track configuration	Usually double, could be single
Minimum curve radius	3000m* for unrestricted speed
Maximum gradient	2½%
Axle load	20 tonnes (locomotives)
Control system	Manual with ATP
Power supply	25kV ac or diesel

*This radius could be reduced by using trains with body tilting.

4.3.7 Ultra-high-speed Intercity

4.3.7.1 The market space

Since the opening of Japan's Shinkansen in 1964, continuous passenger rail technology development has created the ultra-high-speed intercity market space. It builds on rail's Guiding genetic technology, and leverages that with the Coupling genetic technology, to create capacity. Rail has become the predator in competition for intercity travel, and has made substantial inroads into air travel over distances to 1000km. An example is shown at right.

The market space is bracketed by maximum speed higher than 250km/h, currently to 360km/h technical capability. Typically such routes do not carry freight traffic, but it may develop in the near future (UIC, In view of operating, undated). There have been moves to carry IATA containers between airports in Europe. However, operation of conventional freight wagons is not favoured, and many high-speed lines are built to steep gradients that preclude heavy freight trains. The only freight likely to justify high speed trains is what goes by air at present—i.e. relatively light, urgent, high-value consignments.

Spanish infrastructure manager ADIF announced recently that it will allow freight trains to operate on high-speed lines following a change in policy by the Development Ministry (ADIF allows, 2009). Spain's rail freight market share fell to 2.6% in 2004, making it almost irrelevant in the national freight transport task. It is not yet clear from practical experience whether the development will have positive or negative spin-offs.

4.3.7.2 Rolling stock

Europe's first generation high-speed trains, for speeds of 250km/h and up, were built to individual railway specifications, e.g. France's TGV and Germany's ICE. Following their success and the spread of cross-border high speed train travel, the industry now offers proprietary trains, in much the same way as Boeing and Airbus offer proprietary aircraft (see §4.4.7.3). As in the case of proprietary regional trains, low energy consumption has become a selling point. The European Union's Technical Specifications for Interoperability, which set out to regulate international passenger trains, now regulate many aspects of ultra high speed trains and their operation (see §4.3.8).

4.3.7.3 Performance

Ultra high-speed services have few stops, to minimize journey time. In a biennial survey of scheduled train average speeds above a 150km/h threshold, six countries boasted average speeds higher than 200km/h, from 228km/h in Spain to 279km/h in France (Taylor, 2007). For new, dedicated, high-speed routes, one could expect average speeds in the range 220-280km/h.

4.3.7.4 Infrastructure

The following norms are emerging as standard for ultra-high-speed intercity railways:

- They use standard gauge (or broad gauge[34]) track, without exception.
- Right of way is mostly dedicated, double tracked, and electrified[35]. Such infrastructure can only be justified on high-density routes.
- Gradients can be very steep by traditional railway standards, as much as 4%, to minimize environmental impact and infrastructure cost.
- Sound barriers are provided in built-up areas, to mitigate aerodynamic and running noise.
- Services may use existing conventional, i.e. relatively low speed, infrastructure to gain access to inner city stations, subject of course to the same speed restrictions as normal trains.
- Where through running can minimize journey time over long distances, there is a trend to locate intermediate stations on the outskirts of cities[36]. Over time, such stations would attract development.
- There is a significant trend to link ultra-high-speed networks with international airports, to facilitate convenient global-to-local travel.

From the foregoing bullets it is evident that ultra-high-speed railways are not merely an extension of conventional railways, but that they lift rail's contribution to a country's economic geography to a new level.

4.3.7.5 Capacity

Ultra-high-speed trains can convey around 20 000 passengers per hour per direction. Japan's Tokaido line can run 15 trains/hour, with a capacity of 1323 passengers, while France's TGV Sud-Est can run 20 trains/hour with a capacity of 1090 passengers. Both use double deck cars on some trains, although single-deck cars prevail elsewhere. Aside from economic benefits, ultra-high-speed trains seem to be becoming a must-have as countries develop. The question thus reduces from what is the maximum that a route can convey, to what is the minimum ridership that can support the investment.

4.3.7.6 Costing

Costing ultra high-speed projects is a complex exercise. The basic infrastructure cost, which is highly situation-specific, must account for large-radius horizontal and vertical curves. In all but the easiest terrain, this requires long sections of tunnel or viaduct. Access to, and the cost of, terminals and intermediate stations in existing built environment can be expensive. Where existing lines to the same gauge exist, they can provide valuable access to city centres. This is however not immediately possible in the case of South Africa's narrow track gauge. In addition, there can be positive and negative impacts. On the positive side, development of stations and station precincts can increase a system's revenues, and make fares more accessible. Dramatically reducing travel time

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[34] It is comparatively easy to fit slightly wider wheelsets to standard gauge designs. Siemens' Velaro-Rus for Russian Railways is essentially a standard gauge design fitted with running gear for 1520mm gauge.

[35] State-of-the-art diesel engines are not sufficiently powerful to propel ultra high-speed trains.

[36] For example Lyon TGV on the Paris-Marseilles route, Lille-Europe on the Paris-Brussels route, and Ardennes-Champagne TGV on the Paris-Strasbourg route,

between cities can attract economies of agglomeration. It can also change the course of economic geography development—e.g. the Shinkansen has had a great effect on Japan's business, economy, society, environment, and culture (Okada, 1994). On the negative side, mitigating environmental impact can be significant where routes pass through ecologically sensitive areas and built-up areas.

To put a number on it, the world's most recent proposal, Brazil's São Paulo-Rio de Janeiro ultra high speed project, over a distance of some 550km, is estimated to cost ZAR 80-150 billion (Gevert, 2008). In considering a similar new passenger line from Johannesburg to Durban, the Rail Gauge Working Group estimated the infrastructure cost to be R80 billion (National Transport, 2009f). A fleet of 25 trains at R200 million each would add another R5 billion, for a total of R 85 billion. The first example illustrates the wide range that needs to be reduced before a project can approach financial closure. The second example is in the same ballpark that, in the absence of more detailed analysis, confirms that it is a fair estimate now.

4.3.7.7 Key technical system parameters

Stated values are those typically preferred for new systems: Extensions to legacy systems may follow previous practice.

Maximum speed	360km/h
Average speed	220-280km/h
Capacity	20 000 passengers/direction/hour
Track gauge	1435mm
Track configuration	Double
Minimum curve radius	7000m for unrestricted speed
Maximum gradient	4%
Axle load	17-18 tonnes
Control system	Manual with ATP
Power supply	25kV ac

4.3.8 Emergence of standards

4.3.8.1 A moving target

Having examined the range of mainstream conventional passenger rail technology solutions, it would have been good to consider the standards that have influenced the mainstream. However, one of the realities of the railway renaissance is that technological development has outpaced development of standards. Indeed, the railway renaissance would probably not have happened if standards had had to precede it. Prospects for global standards are thus remote at this time. A country that needs to catch up, such as South Africa, thus confronts a somewhat messy situation. Fortunately it is possible to indicate convergence on supplier-standard and possibly industry-standard passenger rail technology solutions in the following few categories.

4.3.8.2 European influences

The European Union has worked diligently to establish a railway environment that supports international rail transport, creation of an internal market in equipment and services, and that contributes to interoperability of the trans-European high-speed rail system. It has moved away from national- and UIC standards to European Union directives. Its first Directive, 1996/48/EC Annex 1, stated "High Speed train services presuppose excellent compatibility between the characteristics of the infrastructure and those of the rolling stock. Performance levels, safety, quality of service and cost depend upon that compatibility."

Based on experience with implementation, essential requirements in the latest Technical Specifications for Interoperability (TSIs) (European Union, 2008) include safety, reliability and availability, health, environmental protection, and technical compatibility. The scope of TSIs have also been broadened to now include all trains, but "Member States may exclude … metros, trams, and other light rail systems … networks that are functionally separate from the rest of the railway system and intended only for the operation of local, urban, or suburban passenger services, as well as railway undertakings operating solely on these networks." Note that Europe progressed top-down from international services and stopped short of "functionally separate" urban rail systems. This emphasizes the reality already mentioned (see §4.3.4) that existing urban rail systems are a mixed bag in many respects.

While many aspects of the TSIs are proceeding smoothly, the European Rail Traffic Management System (ERTMS), a thrust to achieve open systems signalling (see §4.4.7.5 for more information), is having a rocky ride. It is perceived to be expensive, and uptake has been slow. Nevertheless, Europe, and many other countries, need such a system, and many stakeholders watch progress keenly. So far, the technology has also been applied in China.

Europe is arguably the furthest advanced in the field of standards, but it is working within a socio-cultural system, and the end state is not yet clear, much less implemented. Nevertheless, it already commands a critical mass in railway purchasing power, and is growing faster than others, (Roland Berger, 2008). Hence, it has strong influence on railway standards, particularly regarding passenger applications. Countries that do not have the wherewithal to develop their own standards, or the purchasing power to assert themselves in the global market, should take European standards seriously. However, Europe tends to be a high-price source, so it would be prudent to maintain awareness of other sources.

4.3.8.3 North American influences

North America is arguably the world leader in standardization of freight rail technology. Its AAR standards are widely used by competitive and sustainable railways around the world. In the passenger equipment market, it also builds heavy rail commuter cars, particularly double deck stock to AAR standards, for regional services. However, it no longer has an indigenous urban rail industry, and companies such as Alstom, Bombardier, Hyundai Rotem, Kawasaki, and Siemens have moved in, bringing in European influence and products, particularly in the light rail market space.

Like Europe, functionally separate metro systems need not interoperate, and generally cannot. There is for example no uniform train protection or train stop system (Private communication, 2008). However, an attractive communication-based signalling solution is emerging in the United States (see §4.4.7.5 for more information). It could be the way to go for moderate density services, and can ultimately offer moving block for maximum capacity. Countries that do not have the wherewithal to develop their own standards, or the purchasing power to assert themselves in the global market, should watch this development closely.

4.3.8.4 A way forward

As railways have increasingly shifted from their own specifications to buying what the market offers, a convergence of sorts is taking place. The process is ongoing, but is far from complete. As the supply industry globalized, they responded with industry standard solutions in each market niche. Formal interoperability standards have generally followed rather than led the emergence of each technology mutation. In contemplating passenger railway technology for South Africa, one must look forward to global specifications. Until they materialize, let the buyer beware.

While backwards compatibility and interoperability, and the standards that regulate them, are important, they need to be tempered by opportunities to implement new technologies immediately. It is therefore prudent to position railways such that they can reap the benefits of new technologies whenever such opportunities arise.

4.4 Essential passenger rail technologies

4.4.1 Tapping into the mainstream

This Section identifies and discusses technology issues that mediate between the mainstream solutions described in §4.3, and their migration to South Africa. The purpose is to develop an appreciation of considerations that should inform selection of prospective sources of equipment and rolling stock, or of designs for local manufacture.

4.4.2 Basic infrastructure system parameters

4.4.2.1 The guideway subsystem

Consider the following guideway technology attributes of passenger trains:

- Passenger trains, particularly multiple unit sets and light rail vehicles with a high proportion of motored axles, can negotiate comparatively steep gradients. This ability ensures easy fit with existing built- or natural environment, and minimizes environmental impact and its alter ego, construction cost. It does however render optimally graded passenger infrastructure incompatible with freight trains, which require easy gradients.
- Low speed rail applications can accommodate tight curves: Legacy infrastructure can accommodate even heavy freight trains. However, as speed rises, the minimum curve radius increases approximately with the square[37] of the speed. Raising passenger train speeds beyond

[37] That is, doubling the train speed requires curve radii four times larger.

existing posted curve speed limits on legacy infrastructure therefore soon runs into a wall of curve speed limits.

- Passenger train axle loads are comparatively low. They vary from similar to road vehicles, i.e. around 10 tonnes, to rarely more than 20 tonnes. At such low axle loads, the most serious issue is design of long-span structures. Rail freight traffic is generally uncompetitive, and hence unsustainable, at such low axle loads. Burdening passenger railways with structures that are strong enough to carry heavy freight trains could render them unaffordable.
- Although passenger train axle load may be comparatively low, speed can be relatively high. High-speed passenger track is therefore strong, using heavy rails and heavy sleepers, to keep track geometry within tight limits without undue maintenance outage. While such track may appear suitable for freight traffic, heavy freight trains are generally not welcome, due to the risk of dragging equipment, flat wheels, wheelspin, and worse.

In general, guideway characteristics optimized for passenger trains are not compatible with competitive freight trains. While one should not compromise the safety and integrity of a system by insisting on universal traffic access, it may not always be affordable or possible to segregate freight and passenger traffic. It is therefore important to appreciate that where freight and passenger trains share infrastructure, it compromises one or other, if not both of them. Appreciate that long-distance passenger trains in North America, running on freight-oriented infrastructure, and freight trains in Western Europe, running on passenger-oriented infrastructure, are stepchildren on their respective infrastructures.

4.4.2.2 The energy supply subsystem

The following energy supply technology considerations apply to passenger trains:

- Low-density passenger routes use diesel traction. Contemporary diesel traction offers low emissions, quiet running, and good performance.
- Where traffic density is sufficiently high, the lower cost of electric energy, less the capital and operating costs of electrification infrastructure, may undercut the relatively higher cost of diesel fuel.
- Several system integrators now offer basic rolling stock designs, particularly locomotives and regional multiple unit sets, with a choice of diesel- or electric propulsion (and, sometimes, even both).
- Electricity supply may be continuous, intermittent, or discrete.
- Continuous supply requires conductors running the length of the guideway. An overhead supply typically uses a wire catenary system, but may use a rigid conductor in tunnels, to minimize the size of the tunnel bore.
- Overhead conductors are safe for the public and maintenance workers: They are energized at 25kV ac in modern systems, and 3kV dc (or less) in legacy systems.

- Urban railways can perform adequately on 3kV dc—indeed, many metros run on power supplies as low as 600V dc.

- To the extent that new networks, or extensions to existing networks, would not interoperate with legacy systems, 25kV ac would be the appropriate power supply.

- Alternatively, underground railways may use an electrified third rail, mounted on insulators between- or next to the running rails, where providing sufficient clearance for an overhead conductor is unjustifiably expensive.
- For safety, third rail is generally restricted to no more than 850V. The conductor may be open, with top contact, or shrouded with bottom contact (see photo) to mitigate the risk of electrocution.
- Third rail is more robust against mechanical damage (compare with pantograph hookups in overhead systems), but unsuitable for freight trains, because their power transmission capacity is relatively low.
- Existing intermittent supplies use a segmented, switchable, third rail. Segments are energized sequentially under a train, so that exposed conductor rail is completely safe for workers and public[38]. The solution is expensive, used over short distances where overhead wiring is aesthetically unacceptable.
- See §4.4.7.4 for forthcoming discrete energy supply developments.

4.4.2.3 The signaling- and safety subsystem

Consider the following signaling- and safety technology attributes of passenger trains:

- High acceleration- and retardation rates characterize contemporary passenger trains, particularly multiple units. Passenger comfort limits these rates, usually to no more than $1m/s^2$.
- Maximum speed, and frequency of stops, is aligned with the purpose of the system. Acceleration, deceleration, speed, and stopping frequency can be optimized for passenger capacity[39], or journey time[40].
- Passenger throughput is in both cases also a function of train length, a parameter that strongly influences station design.

[38] The first breakthrough came in Bordeaux, in 2003,

[39] Maximum passenger capacity with relatively frequent stops can be achieved by rapid acceleration and retardation, and relatively low speed.

[40] Minimum journey time with relatively infrequent stops can achieved by moderate acceleration and retardation, and relatively high speed.

- Higher speed requires braking distance to increase approximately with the square of speed[41]. Faster trains thus require more headway than slower trains, and thereby reduce line capacity for a given train length.

- Signalling to support high capacity trains and high-speed trains on the same infrastructure is more complex (and hence more expensive) than signalling for the one or the other.

- It is evident that high capacity- and high-speed passenger railway systems are not easy bedfellows. They should therefore be segregated to the extent possible. The contention between freight- and passenger train signalling requirements is potentially even greater. The contention between freight and passenger trains may be manageable on intercity routes where line capacity might accommodate a small number of high-speed trains: It would likely be unmanageable on a route signaled for high capacity or high speed.

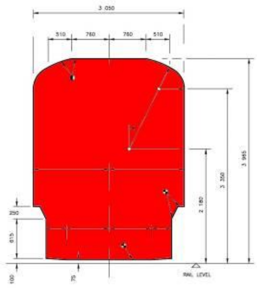
- Contemporary high capacity or high-speed rail systems generally use automatic train protection (ATP) to eliminate human operator error. ATP ensures that trains exceed neither their movement authorities nor their speed authorities, whether permanent or temporary. If a train driver were to exceed his or her authority, then the ATP system would intervene by making a brake application to keep the train within the applicable authority. Under specific conditions, it may make an emergency brake application that brings the train to rest.

- The performance variation among trains should ideally be small, so that an ATP system can quickly discriminate between variation due to differences among individual trains and variation due to train driver error. Contemporary rolling stock features systems to minimize performance variations among trains (see §4.4.4.1).

- It is axiomatic that an ATP system cannot provide full protection where some trains are fitted with ATP and others are not. Ideally, all trains running on a protected route should be appropriately equipped. Compromises are nevertheless possible where, say, occasional freight trains use a passenger-oriented line.

4.4.3 Track-gauge-related infrastructure parameters

4.4.3.1 Platform height and width



Platform dimensions are not necessarily related to track gauge, but they have nevertheless come to be closely associated with track gauge on many narrow gauge railways. In several countries (including South Africa), the comparatively narrow portion below platform level, shown at right, is a critical difference between narrow gauge vehicle profiles and standard gauge (or broad gauge) vehicle profiles. The origin of this feature is not

[41] That is, if speed is doubled, braking distance is approximately quadrupled.

clear, but quite possibly it stemmed from attempts to increase the cubic capacity of freight and passenger vehicles within the constraint of platforms existing at the time. The only possibility to increase vehicle width, without apparent cost[42], was above platform height.

Standard gauge vehicle profiles continue full width down to within 200-400mm of rail level. This allows usably proportioned double-deck passenger coaches and, where applicable, well wagons for double stacked containers. In passenger context, a full-width vehicle profile is frequently associated with low-level platforms for intercity or regional trains. Platforms at or near rail level simply do not constrain vehicle profiles, for either freight- or passenger traffic. Where high- or intermediate level platforms are provided on standard gauge railways, they are sized to accommodate full vehicle body width.

Level entry[43] is important for high-capacity passenger rail systems, because it influences dwell time at stations and hence cycle time, which in turn influence throughput in passengers per hour per direction and fleet size. Therefore, most metro-, light rail-, and even bus rapid transit systems, strive to provide platform and rolling stock floors at the same height.

Intercity- and regional train operators tend to take a more relaxed view on platform height, noting that station dwell time is not a capacity showstopper, and that their existence is in many instances symbiotic with competitive freight trains using the same route.

This reasoning does not lose sight of universal access requirements. Where ideal level entry is not possible, and outside metro environments there are many sites where it is not possible, on-board or on-station wheelchair lifts can ensure compliance.

4.4.3.2 Horizontal alignment

In addition to the obvious impact on new construction, note that if allowable speed were to be increased above present speed on existing (1067mm gauge) intercity lines, the many curves that would then carry speed limits could be candidates for straightening. In many instances this will require land outside the present reserve.

If track gauge were changed to standard gauge, and the speed raised even more, the land required would likely be even more.

If speed were to be increased on existing alignment, many transition curves would need to be made longer, to avoid a perceptible jerk as vehicles enter and leave curves. This may also influence additional land requirements.

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[42] It can only be without cost if one ignores the opportunity cost of not dealing with the root problem. When railways dominated land transport, the opportunity cost was arguably zero. Now that sustainability of narrow gauge railways is under threat, the opportunity cost of not liberating a constrained vehicle profile could be decisive.

[43] That is, platform height and vehicle floor height should be the same.

4.4.3.3 Vertical alignment

The physical size of traction motors, and hence their length, determines their power and tractive effort. Their length in turn is determined by the distance between the wheels of a locomotive into which traction motors must fit. It is shorter on narrow gauge locomotives than on standard gauge locomotives. This means that, all other things being equal, narrow gauge locomotives will have less power and tractive effort than standard gauge locomotives. This issue has been addressed by the Rail Gauge Working Group (National Transport, 2009d). Narrow gauge locomotives for regional trains may therefore have difficulty accommodating adequately sized traction motors. Narrow gauge regional rail services could thus be sensitive to gradients on relatively steeply graded routes[44]. Multiple units could provide more power of course, simply because there can be many more traction motors on a train than on a locomotive.

4.4.3.4 Vertical curvature

Vertical curvature is the radius over a crest or through a sag. If train speed is too high in relation to vertical curvature, passengers may experience the uncomfortable sensation that their internal organs rise or fall. Since 1974, lines in South Africa were built with vertical curves of approximately 10 000m radius. They are good for 200km/h. Lines built prior to 1974 would only be suitable for lower speeds. For example, the existing Pretoria-Johannesburg vertical alignment pushes limits at 150km/h (South African Transport, 1980b).

If re-gauging or dual-gauging to standard gauge is contemplated, the system performance regime will likely change, in which case it will be necessary to revisit vertical curvature. In this sense, vertical curvature is indeed not a function of track gauge, but of changing track gauge.

4.4.3.5 Signal spacing

In principle, track gauge should not affect signal spacing. However, if re-gauging or dual-gauging to standard gauge is contemplated, the system performance regime will likely change due to higher axle load and/or speed, in which case it will be necessary to revisit signal spacing. In this sense, signal spacing is indeed not a function of track gauge, but of changing track gauge.

4.4.4 Basic rolling stock system parameters

4.4.4.1 The train braking- and propulsion subsystem

High traction and braking performance helps to maximize the number of passengers per direction per hour that a rail system can convey through a given corridor, or to minimize the journey time over a long distance. Passenger comfort is a fundamental requirement: Regarding braking and propulsion, it is essential that passengers do not topple over and perhaps injure themselves as trains accelerate and retard. The passenger comfort limit, which is used several times in this document, requires that acceleration and retardation be limited to around $1 m/s^2$.

[44] Note that this explanation applies only to locomotive-hauled regional trains. Traction motors on multiple unit stock are comparatively small (around 200kW), and although high- and ultra high speed multiple units use more powerful traction motors (around 600kW), narrow gauge track does not support such speeds.

While performance variance among trains may be tolerable in a low capacity, lightly stressed system, consistent train performance is a fundamental requirement for high capacity and high-speed systems. High performance rolling stock manages passenger comfort and performance variation by means of the following design features:

- Fixed formation trains, usually multiple unit sets, narrow the performance variation among individual trains[45], so that variation in performance attributable to variation in train composition cannot challenge train drivers.

- Load weighing ascertains the passenger load in each car, and feeds it back to the braking and propulsion control system. The latter increases or decreases braking- and tractive effort in proportion to passenger load, so that acceleration and retardation are constant, irrespective of whether a train is empty or full. It typically associates with air springs, which also offer good riding and self-leveling.

- A high proportion of motored axles supports consistent high acceleration, by diluting the effect of wheelslip at any particular axle.

- Wheelslide- and wheelslip control systems enhance adhesion utilization, and give consistent acceleration and retardation irrespective of rail- and weather conditions[46].

Where so equipped, automatic train protection systems (see §4.4.2.3) and automatic train operation systems (§4.4.7.6) can leverage system capacity even more, the more predictably trains perform.

4.4.4.2 The passenger capacity subsystem

Several rolling stock features facilitate high passenger capacity:

- Station dwell time is a significant determinant of cycle time, particularly for high capacity systems[47]. The number of doors per car side, their width, and their opening- and closing speed, determine the rate at which passengers can enter or leave. Cars frequently have at least two doors per side, but as many as four are not unknown.
- Level entry from platform to car floor encourages people to move quickly, and does not impede special needs passengers. Self-leveling air suspension keeps floor height within a close tolerance despite variation in passenger load.

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[45] The performance of locomotive-hauled trains, where the number of coaches could vary, and of motor coach trains, where the ratio of trailer coaches to motor coaches could vary, depends on train composition.

[46] Motorists know the functionality as anti-lock braking (ABS) and traction control system (TCS), although railways were there many years before road vehicles.

[47] The longer the cycle time, the longer the end-to-end time, and the more rolling stock is required to deliver a given capacity.

- Full width inter-circulation gangways between cars increase usable floor space, and allow passengers to spread more evenly throughout a train, yielding a capacity increase per train of around 11%.

- Floor area determines how many seated passengers and standees a car can accommodate. It is influenced by vehicle profile width and car length. To the extent that it is possible to choose, one should maximize vehicle length and width[48].

- Double-deck coaches offer an alternative way to increase floor area. Their configuration renders it difficult to provide more than two doors per side. Their prime application is therefore regional services, over longer distances with fewer intermediate stops, where dwell time is not a significant driver of cycle time.

This report does not discuss seating density and the ratio of seated passengers to standees. The operator or owner should select this ratio depending on where in the market it wishes to position the service offering.

4.4.4.3 The ambience subsystem

Research has found that, as Economic Freedom and Gross National Income advance, passengers' expectations of public transport rise (Van der Meulen & Möller, 2006). From a passenger rail technology perspective, the following two fields[49] address passengers' rising expectations:

- Heating, ventilation, and air conditioning (HVAC) have almost come to be taken for granted in all economies, because they diminish the hassle of using public transport. Furthermore, air conditioning provides filtered air to exclude dust stirred up by turbulence around moving trains. This helps to keep coach interiors clean—an item in SARCC's mission (South African Rail, 2008/09). It is significant that railways increasingly use white or other light colour to finish their trains—it makes a clear statement about their cleanliness.

- Noise, vibration, and harshness (NVH) is the other area where substantial progress and market uptake is evident. In Europe, trains are expected to beat cars in this regard, to lure motorists onto trains. At least in the interior, their trains are silent, vibration-free, and equipment works smoothly. In a competitive market, and with an eye on the likely advances in passengers' expectations over the economic life of rolling stock, there is no justification for accepting NVH in new rolling stock.

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[48] Note that one must sometimes trade off width and length against each other. Where small-radius curves are present, a longer car might need to be narrower, particularly where platforms are involved.

[49] Note that HVAC and NVH are not track gauge dependent.

Contemporary passenger rolling stock designs provide a foundation for proper attention to HVAC and NVH. In particular, non-opening windows[50], sliding plug doors, and full-profile inter-car shrouds, which isolate passengers from external dust and noise, are taken for granted.

4.4.5 Track-gauge-related rolling stock parameters

4.4.5.1 Riding quality

The most significant determinants of riding quality are vibration and impact of the vehicles, i.e. the lateral, vertical, and longitudinal acceleration felt by passengers. Note that, subjectively, perceived riding quality is also influenced by heating, ventilation, and air conditioning (HVAC), and noise, vibration, and harshness (NVH), which aspects are dealt with in §4.4.4.3. Riding quality depends on vehicle and track attributes: From a vehicle perspective, it is influenced by suspension characteristics, structural stiffness, and coupling arrangements, as the following contemporary good practices for passenger stock explain:

- Air springs support desirable characteristics. They are essential on metro stock, which must accommodate the large mass variation between empty cars and a frequently indeterminate crush load. They are also valuable on long-distance stock, to prevent bogie vibrations from exciting irritating body bending vibrations.

- Slack-free drawgear and inter-car connectors between the vehicles of a multiple unit set minimize longitudinal disturbances.

As an example of good riding quality on narrow gauge, South Africans need look no further than the Blue Train. Even the technology of 37 years ago provides riding quality that is highly regarded by any standards.

Note that the foregoing applies to the natural domain of narrow gauge passenger trains, i.e. single deck and low speed. Outside those parameters, standard gauge is required to extend riding quality to double deck trains at the highest levels of speed, fro example France's TGV Duplex double deck design that runs at 300km/h between Paris and Lyon.

4.4.5.2 Vehicle profile

Vehicle profile is defined by the height and width of a railway vehicle. It relates railway vehicles to fixed structures through which they pass. They are therefore also known as loading gauge or kinetic envelope[51]. The profile may be rounded or shaped at the top and bottom corners. The global urban rail setting still requires many diverse vehicle profiles. Suppliers align profiles as best they can in a competitive setting, but many legacy systems remain that have peculiar though rigid requirements.

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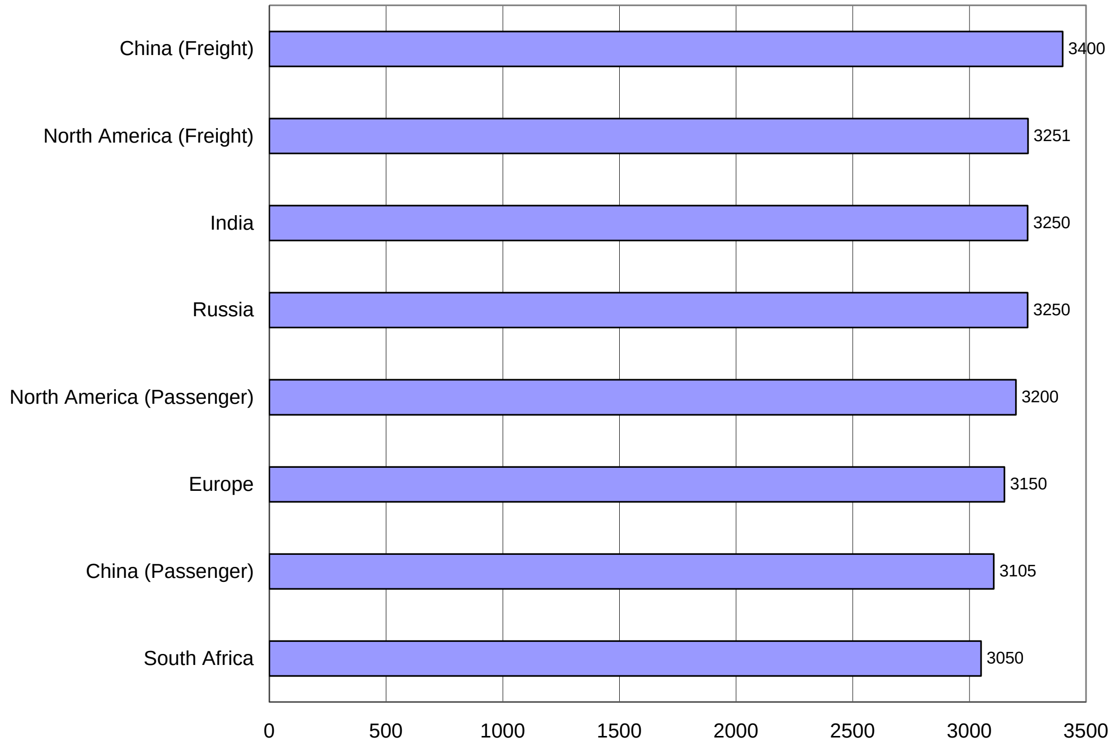
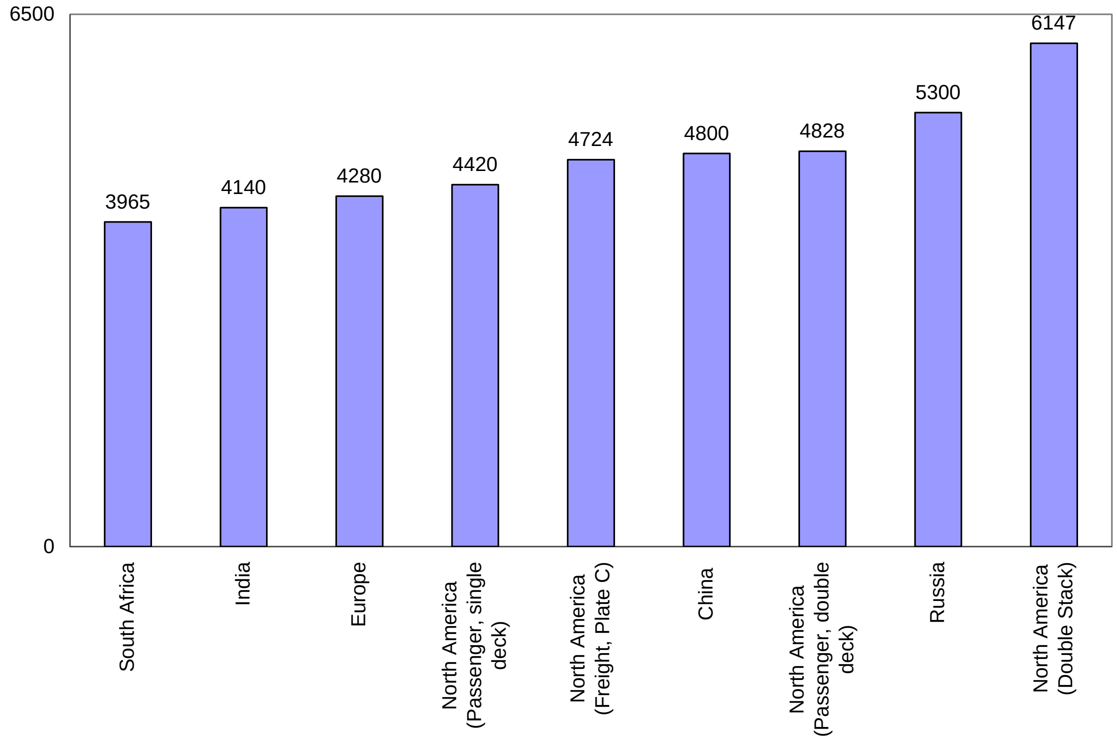
[50] In low- and moderate speed applications, it is customary to provide small hopper windows that passengers may open for emergency ventilation.

[51] Railways in some countries take into account the movement of trains on their suspensions to determine what is known as a kinetic envelope. The kinetic envelope plus clearance then determines the minimum dimensions of fixed structures. This approach can optimally utilize limited clearance. However, the recommendation in this Section is wide enough to obviate the need for such refinement.

Regarding height, the critical passenger rail technology question, is whether it permits double decking. It is generally possible to accommodate two full-height passenger decks on standard gauge track. Double decking has already been implemented on narrow gauge—in South Africa circa 1936, and in Japan in 1989. The latter applications both squeezed two decks into their respective single-deck vehicle profiles. The South African design arranged the seats longitudinally: In the double deck section, the lower deck walkway was under the upper deck seats, and the upper deck walkways were above the lower level seats. It did not progress beyond a single prototype. Japanese designs typically provide double deck cars for additional seating in green cars, their superior class. Squeezing two decks into a single deck profile means that many passengers have to stoop to move about the double deck section. These two examples are provided for completeness, and to illustrate that double deck coaches are not workable on narrow gauge.

Regarding width, the UIC series *Energy Efficiency Technologies for Railways* lists wide-body stock (Wide body, undated) as having the potential to decrease energy consumption by >10%, through increasing the floor area and thereby being able to carry more passengers in a given train length. See also §4.2.2.2 in this regard. The diagrams show the widths (horizontal bars) and heights (vertical bars) for South Africa and the globally significant heavyweights.





A country that contemplates changing track gauge would miss the point if it changed only gauge but retained a constrained vehicle profile[52]. It should rethink the basis on which it determines platform height and width, with a view to maximizing the allowable vehicle profile while it changes gauge.

For a relatively small change, to a minimum height of 4420mm, and to a minimum width of 3250mm, South Africa could position itself to acquire rolling stock designs, or actual vehicles, from a wide variety of sources, in almost any country. A recommendation is made in this regard (see §6.2.2).

4.4.5.3 Track centre distance

A change in vehicle width is not a simple matter. The impact on track centre distances on main lines and in yards, and the location of clearance marks at converging tracks, are but two of the issues.

4.4.5.4 Vehicle length

Metro vehicles: Metros usually operate within confined rights of way, which introduce small-radius curves on parts of the system. Tight curves may require a narrower body due to throw to the outside of curves, and offset to the inside of curves. In such situations, it is necessary to tradeoff vehicle length against vehicle width. Therefore, few metro cars are longer than 20-22 meters.

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[52] The maximum vehicle profile width may be a nominal value. In curves, the throw of the ends to the outside, and the offset of the centre to the inside, usually require vehicle bodies to be slightly narrower.

Mainline vehicles: Standard-gauge mainline passenger vehicles tend to be longer than narrow gauge vehicles. Standard North American passenger coaches are 25,9m (85'0") or 26,2m (86'0") long, depending on bogie centre distance. European coaches can be as long as 26.4m. Few narrow-gauge passenger vehicles are materially longer than 20-21m.

The number of narrow gauge coaches required for a given capacity is therefore likely to be higher than for standard gauge coaches. Railway vehicles have a direct cost component, whatever their length, in respect of brake gear, drawgear, and running gear. Passenger vehicles have additional direct cost components in respect of inter-vehicle connections, end- and side doors, passenger information systems, toilets, and so on. Hence, unduly short coaches drive costs up.

4.4.5.5 Speed and stability

The height of the centre-of-gravity of a loaded railway vehicle, relative to track gauge, influences its stability—with respect to rolling motion on straight track, and with respect to overturning on curved track. The height of a coach, and hence its centre of gravity, is determined by the size of people that it must convey, and by the dimensions of running gear such as wheels and bogies. People and running gear do not scale down for narrow track gauge, so the centre of gravity height stays the same whatever the track gauge. To maintain the same safety against overturning and unstable running, speed must be reduced for narrow gauge trains.

Allowable speed is also determined by the interaction of track quality and vehicle suspension. Both can be specially prepared and rigorously maintained. South Africa set the world narrow gauge speed record of 245km/h in 1978. It also operated the Metroblitz service between Pretoria and Johannesburg at 160km/h in the early 1980s. Both were of short duration on specially fettled track: It is questionable whether such speeds could be sustainable with commercial grade track maintenance.

Australia's QR Tilt Train[53] is also an interesting application. It features a maximum speed of 160km/h, on 1067mm track gauge. However, its average speed from Brisbane to Rockhampton is 78km/h, and from Rockhampton to Cairns it is 69km/h. Even South Africa's Premier Classe maintains an average speed of 63km/h between Johannesburg and Cape Town, or 70% of its maximum speed of 90km/h. High-speed trains typically average 70-80% of their maximum speed. One would therefore expect the Tilt Train to average around 120km/h. The only conclusion must be that the QR Tilt Train does not run long distances at 160 km/h—apparently only on a few specially fettled sections, more between Brisbane and Rockhampton than between Rockhampton and Cairns.

Japan's 1067mm gauge fast trains run at a maximum speed of 130km/h. It is interesting to note that Japan's second prototype Gauge Change Train (shown at right), designed to run on both narrow gauge (1067mm) and standard gauge (1435mm) has a maximum speed of 130km/h on narrow gauge and 270km/h on standard

[53] Tilting trains are examined in more detail in §4.4.5.6.

gauge (Gauge change, undated)[54].

It therefore evident that 130km/h should be considered the maximum commercially sustainable speed on 1067mm gauge.

4.4.5.6 Body tilting

When trains pass through curves, passengers experience lateral, or sideways, acceleration towards the outside of a curve. It can become uncomfortable, and may make it difficult for passengers and service personnel to move around, if it exceeds $1m/s^2$. The outer rail in a curve is therefore usually raised, or superelevated, to compensate for the lateral acceleration, so that the train leans to the inside of a curve, much as a motorcyclist leans into a curve. Slower trains using the line, which need less superelevation, compromise and limit the amount of superelevation that a builder or maintainer can apply.

Body tilting, which tilts a railway vehicle body inwards on its bogies in a curve, to counteract the lateral acceleration felt by passengers, can increase speed through curves. Ultimately, safety against overturning limits the amount of tilt. On standard gauge railways that speed may be up to 35% higher than for conventional trains (New Pendolino, undated). However, as mentioned in §4.4.3.4, the centre of gravity height of a railway vehicle stays the same whatever the track gauge, and the factor of safety against overturning is less on narrow gauge. The amount by which a train can safely tilt on narrow gauge track allows a speed some 10% higher than for non-tilting stock (South African Transport, 1980a). On 90-100km/h mainlines, that could provide around 10km/h higher speed through curves, which is hardly worth the extra cost and complexity of providing and maintaining tilting equipment. On branch lines with allowable curve speed in the range 30-60km/h, the gain would be 3-6km/h, which is arguably not worth pursuing at all.

Experience in Sweden has shown that new generation trains without tilting capability, but with higher rates of acceleration and deceleration, can maintain the same timings as earlier generations of tilting trains with lower rates of acceleration and deceleration (Briginshaw, 2008). One should expect the gain from higher performance over tilting capability to be more pronounced on narrow gauge railways.

In Japan, tilting trains are deployed on some regional services on 1067mm track gauge. Their pendular mechanism allows the vehicle body to swing outwards from a high virtual pivot point, with pneumatic assistance. The maximum amount of tilt is smaller than for standard gauge, as explained above.

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[54] The question of applicability of gauge change trains to South Africa will inevitably arise. The Railway Gauge Working Group (National Transport … , 2009g) examined a high-speed railway line between Gauteng and Durban, and among other found that certain portions of the route may need to be designed for comparatively low speed due to the ruggedness of the terrain. It is conceivable that high-speed deviations could be built to standard gauge in easy terrain, while the line would converge on the existing narrow gauge line in rugged terrain. The train could change gauge as required, and even use narrow gauge to access existing termini and stops en route. Japan's gauge change train project started in 1994, and is now on its second prototype, with a third expected in 2010. Its availability and reliability track record is still in the making. Gauge changing is done by driving the train through a gauge changer at 10km/h, which would lengthen journey time if undertaken too frequently. Overall, this notion will probably not sustain much enthusiasm.

Japanese tilting technology was exported to Australia for QR's Tilt Train in 1998. One of the trains derailed in 2004, due to it entering a curve too fast, apparently due to the driver being disoriented with respect to where the train was, or distracted (Cairns Tilt, undated). The derailment scene is shown at right. Following the derailment, the speed of all tilt trains was limited to 100km/h until the cause had been established and remedial intervention implemented. After track upgrades and installation of automatic train protection, among other to ensure compliance with curve speed restrictions, the service was restored to 160km/h in 2007.

The Tilt Train derailment surfaces the concept of critical curve speed, i.e. the speed at which any train, whether tilting or not[55] can negotiate a curve without overturning, albeit with passenger discomfort and fright, and possibly injury. For a maximum train speed of 160km/h, curves under 900-1000m radius pose the risk of an inattentive driver exceeding the critical curve speed and derailing the train (South African Transport, 1980c). QR's 160km/h Tilt Train derailed on a curve with a posted limit of only 60km/h. Existing South African mainlines have many curves of less than 1000m radius, leaving no margin for error at such speed. At a maximum speed of 130km/h, the radius for critical curve speed reduces to 550-600m, which passes many more mainline curves as safe. Nevertheless, noting the Australian experience, it would not be prudent to implement tilting trains on existing main lines without ATP.

All told, the case for raising maximum commercial train speeds to higher than 130km/h on narrow gauge incurs rapidly diminishing running time gains for materially higher risk, and concomitant cost of mitigating it. The attractiveness of contemplating higher speeds on existing alignment and -track gauge recedes the more one analyses the concomitant issues.

4.4.6 Matching infrastructure- and rolling stock parameters

For many transport modes, high user diversity makes it unworkable to match infrastructure parameters with individual user parameters. The result is usually a one-size-fits-all solution, such as roads that must accommodate vehicles ranging from non-motorized transport to heavy interlinks[56]. By contrast, rail infrastructure users are relatively less diverse than users of infrastructure of other transport modes. With rail it is workable, and frequently desirable, to closely match infrastructure and rolling stock parameters. Note the specialization of heavy haul-, high-speed intercity-, heavy intermodal-, and urban railway applications, each of which each has an optimum infrastructure/rolling stock match. Then compare them with, for example, segregated truck lanes, bus- and high occupancy vehicle lanes, and haul roads for dump trucks and road-trains: While such specialized matching is only applied in extreme road transport situations, some would question its value in naturally enhancing the competitiveness of rail transport.

[55] Note that as a train approaches overturning speed in a curve, body tilting is of no value in preventing overturning—it only influences passenger comfort.

[56] This situation underlies the unfair user charge controversy, where trucks allegedly pay lower licence- and toll fees than cars in proportion to the degradation they cause.

Competitive and sustainable rail is not a one-size-fits-all mode. Infrastructure and rolling stock parameters need to be matched closely. Where compromises are made from time to time, the consequent sub-optimization needs to be identified and accounted.

4.4.7 Significant new global developments

4.4.7.1 Dedicated freight- and passenger corridors

From §4.2.1, it is evident that freight rail and passenger rail exploit the strengths of rail's genetic technologies in different ways. Indeed, research has revealed that Positioning Freight Rail and Positioning Passenger Rail are two mutually exclusive determinants of railway corporate citizenship (Van der Meulen & Möller, 2008b). Further confirmation of this finding is becoming increasingly visible around the world, as the following examples illustrate:

- Europe's line haul railways are strongly passenger oriented, almost to the exclusion of freight service. The European Commission has therefore launched a process to establish a European rail network for competitive freight (European Commission, 2008). The modalities are still being resolved, but the outcome seems likely to resemble the Ukrainian solution in Bullet 4 below.
- The United States situation is opposite—its railroads are strongly freight oriented, and its long-distance passenger rail agency, Amtrak, has had to rely on an annual federal appropriation (National Passenger, 2007a). However, the United States is currently experiencing an urban rail renaissance, much of it on dedicated light rail infrastructure (Transit ridership, 2009).
- India recently launched construction of its 1279km Eastern Dedicated Freight Corridor (DFC) from Ludhiana to Sonnagar, the world's first separation between parallel freight- and passenger infrastructure. Thirty-tonne axle load and 100km/h maximum speed distinguish DFC infrastructure from the existing network. It is set to be followed by the 1483km Western DFC (Dedicated Freight, 2009) from Delhi to Mumbai. India is also considering high-speed intercity in the Delhi-Mumbai corridor, and possibly other corridors as well (Planned high-speed, undated). If the Delhi-Mumbai high-speed project goes ahead, India will have separate conventional passenger-, dedicated freight-, and high-speed infrastructures, in the same corridor.
- Ukraine has designated several major intercity routes as dedicated passenger lines to permit operation of 200km/h trains. It is investing in infrastructure works to enable freight traffic to be diverted to other lines (Segregation for, 2008).

Appreciate that emerging technologies reflect the setting in which they were conceived, developed, and implemented. Ultimately, they become battle-proven solutions that migrate to other settings. Ideally, one should thus consider freight rail and passenger rail as virtually separate, non-interoperable transport modes. Future railway development opportunities would do well either to separate

passenger and freight traffic completely or, where affordability and/or traffic volume do not allow, to recognize that requiring freight and passenger trains to interoperate on shared infrastructure compromises competitiveness of both.

4.4.7.2 Proprietary trains

Under globalization, railway system integrators have consolidated (and eliminated duplicate) research-, design-, and production capacity, to form competitive, excellent sources of systems, subsystems, and equipment. The processes resembled those that took place earlier in the aircraft- and automotive industries[57]. The suppliers have become more powerful than their former national railway clients, while the latter have become fragmented. Fragmentation followed vertical separation, where that was introduced, or parallel competition, where that emerged. Rather than competing to meet the specifications of many individual customers, system integrators now offer preferred or standard platforms or vehicles, which they deploy to compete for a share of the global railway market. The following non-exhaustive list of competitive offerings, mainly from Europe, which commands the largest market, illustrates the point:

Proprietary urban train brands:

In light rail:

- Alstom Citadis,
- Bombardier Flexity, and
- Siemens Combino.

In metro rail:

- Alstom Metropolis,
- Bombardier Movia, and
- Siemens Metro.

Proprietary mainline- and regional train brands:

- Alstom Pendolino (tilting), Coradia,
- Bombardier Talent,
- Siemens Desiro, Viaggio, Venturio, and
- Stadler Flirt.

Proprietary ultra high-speed trains for dedicated lines:

The European Union's Technical Specifications for Interoperability (TSIs) initially addressed high speed intercity trains, because they have the greatest medium-term potential for international services. Trains built to these standards have also had commercial success outside Europe (e.g. Korea's KTX). It is thus interesting that

[57] And many other industries for that matter, too.

Kawasaki sees a global market outside Japan (New 350km/h, 2008). The following are current examples that comply (or will comply) with the TSIs:

- Alstom AGV (Automotrice Grande Vitesse),
- Bombardier Zefiro (carbody in UIC or wide profile),
- Kawasaki efSET (Environmentally Friendly Super Express Train) (UIC body width), and
- Siemens Velaro (two body widths), Venturio.

These trains have been developed speculatively by the respective system integrators, in a way similar to development of commercial aircraft by Airbus and Boeing. Just as airlines cannot afford to develop their own aircraft, railway operators can no longer afford to develop their own trains. Expect Hyundai Rotem of Korea, which has developed high-speed trains for the Korean domestic market, to join the international fray in due course.

4.4.7.3 Intraoperability

Intraoperability addresses the question of reusability, or sharing, of train subsystems across a wide range of products built by several system integrators, to increase standardization and reduce costs. To illustrate, there is no reason why a plug door on an Alstom metro train should not be functionally interchangeable with one on a Bombardier or a Siemens train, or why a metro train in Mumbai should have plug doors that are not functionally interchangeable with those in Shenzhen, and so on. Of course, several suppliers could manufacture modular doors, to ensure competition. System integrators should thus compete for integrated solutions, not for lower tier subsystems such as doors, pantographs, pneumatics, and the many other subsystems that make up a train.

This process will concentrate supplier centres of excellence even further, and will affect countries that aspire to build indigenous rolling stock. The following two European Union projects, paraphrased from Railway Gauge Working Group (2009d), represent significant efforts in this field:

- The MODTRAIN (for Innovative Modular Vehicle Concepts for an Integrated European Railway System) project started in 2004 for four years. It set out to define and prove the necessary functional, electrical, and mechanical interfaces and validation procedures to deliver a range of interchangeable modules, to form the basis for the next generation of fixed-formation passenger trains and universal locomotives capable of 200 km/h or more. The sponsors hoped ultimately to embrace all rolling stock likely to operate over both the high-speed and conventional interoperable networks across Europe. The project embraced running gear, control and monitoring system, on-board power system, man-machine and train-to-train interfaces. The concept of modularity aimed 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 fulfilled the objectives of increased railway competitiveness and interoperability.

- The Modular Urban Guided Rail System project, or MODUrban, brought together all major rail industry suppliers and all major rail operators in Europe. The main target of the project was to design, develop, and test 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. 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 mitigate the risk of new rolling stock and subsystems being built from unproven prototype sub-assemblies.

4.4.7.4 Discrete energy supply

The cost of distributing energy to trains is a significant component of total infrastructure cost in urban railway applications. The cost of electrification infrastructure is crucial for marginal rail applications, such as Light Rail. Indeed, arch competitor bus rapid transit, which avoids the cost of overhead electrification, marshals this argument as a selling point.

Until recently, technology has not supported economic storage of traction energy on board trains. Energy supplies have therefore had to be continuous, either overhead wire or third rail, perhaps with lineside equipment to recover energy regenerated during braking. Development of ultra-capacitors, which can economically store sufficient energy on board, has made it possible to recover braking energy and reuse it during acceleration. Only the modest energy consumption to overcome resistance to motion between stops needs an external supply. There are prospects of inductive energy transfer topping up on board energy storage during station dwell time, which will eliminate electrification infrastructure, and its associated costs, between stations. This technology is expected to enter the light guided surface transport market in 2013-2014 (Private communication, 2009). It augurs well for city rail, which has frequent stops, and which is more energy efficient than road-based competitors such as BRT[58].

4.4.7.5 Communication based train control

Communication based train control, also know as transmission-based train control has evolved over several years, primarily in Europe and the United States. It comes in incremental levels of functionality, which railways can overlay on existing signalling systems, or use as stand-alone systems. Such systems enforce movement authorities and permanent or temporary speed restrictions, and protect maintenance worksites from incursion by trains.

The European Rail Traffic Management System (ERTMS) comprises two subsystems, the European Train Control System (ETCS), a standard for on-board train control, and GSM-R, a standard for mobile communications for railway usage. ETCS determines train position by means of balises[59] placed between the rails. The overall system

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[58] Discrete- or inductive power supply can potentially reduce the cost to supply electricity to trains. On the one hand, this may negate one of the advantages of BRT, which avoids the cost of electrification required by light rail. On the other hand, liberating BRT from diesel engines, also using inductive energy transfer and ultra capacitor storage, could make it an even more formidable competitor against light rail.

[59] Gautrain will also determine train position by means of balises.

architecture reflects the high-density, passenger-oriented services operated by most European railways. It is perceived to be expensive, and uptake has been slow.

The United States' Positive Train Control (PTC) system was developed to be effective and affordable on freight-oriented railways with lower train densities than in Europe. Its architecture allows for minimal dependency on, or elimination of, expensive lineside equipment. It determines accurate train position by means of differential GPS, supplemented by tachometer, gyro, accelerometers, track databases, and sensor fusion/map-matching algorithms. The four US Class 1 railroads, BNSF, CSX, Norfolk Southern, and Union Pacific, have had PTC systems under development for several years (Drapa et al., 2007).

A head-on collision in California on 12 September 2008, between a double deck regional passenger train and a freight train, finally stirred up political action. On 16 October 2008, President Bush signed the Rail Safety Improvement Act (Rail Safety, 2008), which requires the implementation of interoperable[60] positive train control systems for Class I freight- and passenger rail carriers by December 31, 2015. It also authorized $250 million in federal grants, to support development and installation of positive train control.

Both systems eliminate the risk of human error in manually operated railway systems. The functionality should be duly considered as part of proposals to materially raise the speed of trains, or to change the speed mix on a route by increasing the speed of some trains.

4.4.7.6 Automatic train operation

This report refers to automatic train operation, so it is appropriate to examine the technology. An automatic train operation system does what its name says, through control of acceleration and braking, including terminal braking at specified station-stop positions, using operating management information and location information received from lineside equipment. It uses an onboard database containing line data to control train acceleration and braking to suit relevant conditions, such as curves and gradients, between and at each station. Balises enable interlocking control between the train doors and platform gates.

Automatic train operation is sometimes known as driverless operation, although a driver or attendant may be present. In some systems, the driver or attendant may operate the train in emergencies at low speed. Where union influence is strong, the driver may press a button to start the train at each station.

Increasingly, new metro- and light metro systems are being built with automatic train operation, and existing systems are being converted from manual operation to automatic

[60] In this context, interoperability means *the ability to control locomotives of the host railroad and tenant railroad to communicate with and respond to the positive train control system, including uninterrupted movements over property boundaries.*

operation. The following are some key benefits (Driverless metros, undated; Van der Voort, 1980):

- Expenditure for staff is lower. However, service and security personnel are common in automated systems.
- Trains can be shorter and run more frequently, without increasing expenditure for staff.
- Train operators are easily able to vary the service frequency to meet unexpected demands.
- Despite common psychological concerns, driverless metros are safer than traditional metros. None of them has ever had a serious accident.
- Intruder detection systems can be more effective than humans in stopping the trains if someone is on the tracks.
- Energy- and maintenance costs are reduced because trains are driven to an optimum specification.
- An operator or train driver does not need to change ends at terminal stations, so turn back time can be almost zero (a train returns immediately after passengers have alighted), reducing the number of train sets needed for given capacity.
- Shorter reaction time reduces headway by ≈10% compared to manual driving. Alternatively, a three-aspect system could give the headway of a four-aspect system.
- Elimination of collisions allows reduced vehicle end strength, resulting in lower vehicle tare and lower energy consumption.

In conjunction with the platform screen doors commonly, but not always, used with automatic train operation, the following benefits also accrue (Platform screen, undated):

- People cannot fall- or jump onto the tracks,
- Trains enter stations at higher speed,
- Draught and air pressure variations caused by trains in tunnels are reduced,
- Platforms are quieter and cleaner,
- Stations can be air-conditioned at lower cost in hot climates, and
- People cannot throw rubbish on tracks, creating a cleaner environment and preventing fires.

Of course, screen doors also represent one more set of moving parts to be maintained.

4.4.7.7 Industrial design

Attractive exterior- and interior design attracts users to trains. Studios such as Italdesign/ Guigaro, Pininfarina, and Porsche Design have become active in the railway industry. Some system integrators also maintain in-house industrial design studios—Bombardier's

Gautrain design is a striking local example. Draughtspersons do not need to design trains.

4.5 Alternative guided surface transport technologies

4.5.1 Alternatives to steel-wheel-on-steel-rail

Following the systems approach, contemporary public passenger transport is a complex competitive system in several respects: It competes for public funds against other creditable claims, transport modes compete against each other at all levels from local to national, and system integrators compete against one another with continuously improving solutions. Guided transport solutions range from bus rapid transit and light rail, to trains that can cover 1000km in three hours. System integrators have developed a wide range of highly nuanced solutions, and transport authorities have become spoilt for choice.

However, reference to §4.2 shows that the railway mode also competes in market spaces where it is potentially weak, namely those that have low axle load and low speed. In a competitive setting where organismic adaptation is present, one can confidently predict that such market spaces will attract alternative solutions from predators.

Predators can offer attractive solutions in particular situations. A study of passenger railway technology would therefore be incomplete without developing an awareness of competitors who may encroach on marginal railway positions. The following solutions are described in sufficient detail to develop that awareness.

4.5.2 Rubber-tyred solutions

4.5.2.1 Heavy Metro

Rubber-tyred heavy metro originated in Paris after World War II. While other drivers also influenced the development, at that time conventional electric traction did not support the high adhesion, and hence high acceleration, of which rubber tyres are capable. Appreciate nevertheless that passenger comfort criteria, discussed in §4.4.4.1, ultimately limit acceleration and deceleration, whatever the propulsion and braking arrangements.

Rubber-tyred heavy metros customarily retain flanged steel wheels (like a conventional steel-wheel-on-steel-rail system), to guide vehicles through turnouts, to provide a suitable braking surface, and to provide emergency guidance in the case of a flat tyre. The system is therefore relatively complex. Furthermore, for the same transport task, rubber-tyres consume more energy than steel tyres. The additional energy is dissipated as heat, which in turn needs special ventilation measures in underground applications.

With the advent of solid-state power electronics in the 1970s, it became possible for steel–wheel-on-steel-rail systems to economically and reliably achieve acceleration and retardation right up to the passenger comfort limit. Since then, the disadvantages of rubber tyres worked against them. However, advancing automatic train operation, which works best with highly consistent performance, has seen renewed interest in rubber-tyred metro. In Paris, Line 1, which was steel–wheel-on-steel-rail, changed to the rubber tyred format in preparation for automatic train operation (ATO), and Line 14, a new ATO line that was built to the rubber tyred format, are examples.

4.5.2.2 Automated Light Metro—VAL

Light automated vehicles (VAL and other brands), a non-rail, rubber-tyred, guided solution is encroaching on the domain of low-to-medium capacity steel-wheel-on-steel-rail systems in urban areas. In this respect, it bears comparison with bus rapid transit. Both solutions target rail's weak low axle-load, low speed, market space. VAL axle loads are of the same order as heavy road vehicles, and, unsurprisingly, of the same order as BRT.

VAL's rubber tyres run on plain concrete or steel runways, with upstands at the sides to guide trains. The Taipei system is illustrated at right. The next generation will replace the side upstands with guidance by a single centre rail. Its rubber tyres run quietly, a valuable attribute on elevated guideways. Like any rubber-tyred solution, it can also handle steeper gradients than steel-wheel-on-steel-rail.

VAL cleverly repackaged guided surface transport's essential Bearing and Guiding genetic technologies, to deliver a competitive solution despite the higher energy consumption of its the rubber tyres. It is an automated (driverless) system, which offers short headway, short trains, and near instantaneous turnaround at terminal stations. Automatic operation eliminates the possibility of collisions, thereby relieving the lightweight structure of onerous crashworthiness requirements, and offsetting the relatively higher energy consumption.

In so repackaging basic railway functionality, VAL sharpened operating efficiency to offer capacity between light rail and metro for small cities. It is also priced between light rail and metro systems.

The prospect of ultra-capacitors and inductive energy transfer, mentioned in §4.4.7.4, is making rubber-tyred competitors such as VAL an even more attractive solution for the urban rail environment—eliminating lineside electrification and replacing it with recharge during station dwell time could make the next generation Neoval a killer application in urban guided transport.

VAL can convey up to 30 000 passengers/hour/direction. At the other end of the scale, it is suitable for small cities. For example, Rennes, the smallest city in France with a metro (population less than 400 000), uses the VAL system.

Siemens has acquired the VAL system from its originator, Matra, which suggests that the technology has matured to mainstream urban transport status. Woosan in Korea recently offered a similar solution.

4.5.3 Monorail

Monorails have found application in a limited number of urban applications, mostly in Japan. For orientation, it is necessary to distinguish between people-mover grade and transit grade monorail applications. Many South Africans know only the Nasrec monorail—a people-mover system. This study considers only transit grade monorails.

Japan is into large-scale monorails[61], and is the only country that has developed standards for transit grade monorail systems. Noteworthy at the level of this study, is that the standards require flat floors in the passenger space, with running gear below (this is a major difference compared with amusement park applications). Above floor level, they therefore resemble conventional single deck commuter cars. Monorails generally have rubber tyres, and therefore inherit all the associated advantages and disadvantages. They are quiet, which makes them attractive for the elevated applications that are their natural habitat. They can also accommodate comparatively steep gradients. Although they are less energy efficient than steel-wheel-on-steel-rail, they generally run on open guideways, hence the additional energy consumed does not lead to heating issues.

Monorail's footprint on existing built environment is small. It is therefore relatively easier to implement than surface- or subsurface guided transport. There would arguably be fewer disturbances of existing services, which can contribute substantially to total construction cost. Monorail stations also integrate relatively easily inside shopping malls and other buildings. The eminent domain of monorails is thus situations in which they need to thread their way through previously well-developed settings, as reference to most photos of transit grade monorails will confirm.

Axle load is in the range 10-11 tonnes (Kennedy, undated). It is thus in the same league as BRT, Light Rail, and VAL. See bogie photo. Maximum speed is in the range 50-70km/h. Guideways can be complex, because cant in curves must be built into the beam. Monorail offers a medium-capacity of 15 000 passengers/hour/direction (Siemens H-Bahn, undated). From their key parameters, the closest conventional rail alternative would be Light Rail: It is self evident that the cost premium of substantial elevated structures can only be justified where at-grade alignment is simply not economically viable.

Monorail's eminent domain is Japan, where high population density and prior development place a premium on space for new transport corridors. It adapts well to applications such as orbital routes, with intermodal connections to existing radial urban rail lines, which are coming into vogue. Mumbai's recently awarded contract for a 19.5km monorail with 18 stations, including interchanges with existing suburban rail services and the future metro network, is a fitting example (Mumbai monorail, 2009).

Interestingly, the world's busiest monorail, a 24km network with six stations that conveys 150 000 passengers per day, is at Disney World in the United States. Note that Bombardier has entered the monorail market through a series of acquisitions, among other Disney's technology, which suggests that the technology has matured to mainstream urban transport status. Built environment in South Africa is not yet so dense that monorail is an indicated mass mobility solution, so it is not considered further in this report.

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[61] Monorails use several fundamentally diverse technologies: Straddle (vehicles on top of the guideway beam) and suspended (vehicles under the guideway beam), mainly rubber or sometimes steel tyres, and enclosed or open guideways. The material in this section assumes straddle monorails, the most common transit grade application.

4.5.4 Maglev

Maglev technology has been on the horizon for several decades. It has recently shown potential as the following timeline indicates:

- A Transrapid[62] maglev system already links Shanghai Pudong Airport with Longyang Road station in Pudong. The 430km/h service can cover the 30km distance in 7 minutes. However, farebox revenue appears unable to cover costs. Plans for a similar system in Munich were cancelled in 2008, due to unaffordable cost escalation (Lew, 2008). To be viable in the 400+km/h speed range, maglev would need to beat other modes of guided surface transport on total life cycle cost, with due regard for value of people’s time and applicable externalities.

- Urban maglev might be next. Korea's first commercial magnetic levitation train line will be built at Incheon International Airport by 2012 (Korea’s first, 2007). It will operate at a speed of 110km/h. A company in China is also developing maglev for urban transport, to a maximum speed of 120km/h (China develops, 2009). At such low speeds, maglev could likely only compete on project life cycle cost: One of maglev’s advantages is contactless bearing and guiding, therefore infrastructure maintenance is low.

- Over a longer distance, namely the 420km from Tokyo to Nagoya and Osaka, Japan’s maglev Chūō Shinkansen now appears set for completion by 2025 (Chūō Shinkansen, undated). Initial research and development commenced in the 1970s, so maglev has been long in coming in a technologically advanced country.

Monorail proponents consider maglev to be a subset of monorail, and indeed there is a superficial resemblance. However, their case is tenuous, because although the German Transrapid system looks like a straddle monorail system, the vertical load is borne by widely spaced levitation magnets, so the vertical guidance is essentially similar to the two rails of a conventional railway. The Japanese system in no way resembles a monorail, and if one must have an analogy, it is closer to the channel guideway used by rubber-tyred metro and VAL.

It is possible that peak oil- and climate change considerations could affect air travel in the near future. That event might stimulate maglev as an alternative solution for high-speed medium- to long distance ground travel. Indeed, an airline initiated the original maglev research in Japan. However, although maglev is an attractive alternative to air travel over appropriate distances, it has not yet been able to establish a decisive speed advantage over conventional rail. The current maglev speed record is 581km/h, set by

[62] Transrapid International is a German joint company of Siemens and ThyssenKrupp.

JR-Maglev in Japan in 2003. The current rail speed record is 575km/h, set by SNCF in France in 2007. Maglev energy consumption is marginally lower than rail at the same speed (Magnetic levitation, undated), while next generation ultra high-speed trains such as Alstom's AGV feature permanent magnet traction motors to reduce energy consumption. Over the years, maglev and rail have competed neck and neck: A maglev breakthrough into rail's domain will need a distinct advantage over rail.

Noting that energy consumption rises exponentially with speed, maglev will approach the same energy consumption as aircraft if it aspires to close the gap between its present speed and the speed of commercial airliners. Furthermore, commercial airliners fly in thinner air at high altitude with less drag, and are therefore inherently more energy efficient than high-speed surface guided transport. However, aircraft use finite fossil fuel sources, whereas maglev does have the potential to tap renewable sources. When peak oil does bite, airliners on long overland routes would seem to be maglev's natural prey.

Testing on Transrapid's Emsland track is set to cease end June 2009. After 37 years, the 31km Shanghai-Pudong airport link is the world's only commercial high-speed maglev. Over the same period, 9400km of high-speed railway have been commissioned, with a further 8300km under construction. The outcome speaks for itself (Tests to, 2009). Within the time horizon of addressing the challenges of South Africa's passenger rail technology, it does not seem worthwhile to do more than maintain a low-level awareness of maglev technology. The topic is therefore not addressed further in this report.

4.5.5 Bus rapid transit

Comparison of BRT and Light Rail seems to deliver close outcomes. This is no surprise, because they use similar axle loads—indeed both modes reputedly make little or no imposition on existing substructures—and their vehicles have comparable capacity. In practice, implementation of either mode involves substantial disruption and reconstruction. The debate thus tends to reduce to qualitative aspects such as:

- Quality: The goal of BRT systems is to approach the service quality of a rail commuter system, while still enjoying the cost savings of bus commuter system.
- Headway: Both modes combine or couple (see §4.2.1.2) vehicles to reduce average headway, and to increase capacity.
- Perceived image and ability to influence property values positively: Rail is a more effective catalyst for commercial and residential growth than bus in this regard.
- Capacity potential: Even bi-articulated buses at 270 passengers still trail light rail vehicle capacity by around 100 passengers.
- Land take: On open routes, busways are wider than light rail reserves; in confined areas, bus swept area is greater than light rail.
- Environmental impact: Using current technology, a diesel-powered BRT solution is less environmentally friendly than an electrically-powered light rail system of the same capacity.
- Energy source and -efficiency: Partial or complete electrification of BRT attracts the same cost penalty as light rail. The use of ultra

capacitors, to avoid electrification between stations, could apply to both.

- Priority over other road users: Both are driven on sight, and require authorities to make the same choices to resolve contention with other road users.
- Convenience: Both can offer low floor designs or level entry.
- Fare collection: BRT systems, particularly in South America, enforce proof of payment. Light rail might take a leaf out of their book.

Regarding capacity, BRT on a single lane trails light rail on a single track approximately in proportion to the number of passengers per unit, to give an entry level of around 7500 passengers per direction per hour. By virtue of its two degrees of freedom of movement (see §4.2.1.1), BRT can exploit further options, not usually provided on light rail systems, such as passing at stations and express routes (equivalent to double track rail with crossovers). Transmilenio BRT in Bogotá raises capacity to 40 000 passengers per direction per hour in this way, of course with correspondingly large land take.

It thus comes as no surprise that light rail axle load is creeping up, and that enhancements such as automated light rail and VAL are emerging to increase competitive distance from BRT. Automatic light rail and VAL employ technology to raise capacity, asset utilization, and efficiency to a higher level, which BRT is not likely to match. In the final analysis, BRT and light rail are feeding from the same trough. The trade-offs and decisions appear to be situation-specific. Applying the systems approach, it could well be institutional arrangements rather than technology that drives selection one way or the other.

4.5.6 Application potential

Although steel-wheel-on-steel-rail passenger technology has distinct competitive advantages in specific market spaces, alternative guided surface transport technologies have advanced to the stage where they can offer attractive, competitive solutions in settings where rail does not fully exploit its genetic technologies. Authorities and other stakeholders should therefore not ignore such alternative technologies. This study will address their application prospects: If appropriate, it will suggest considerations that should inform policy formulation for South Africa that will allow migration to the most appropriate technologies for each application.

One should look carefully at cities such as Dubai, that apply a wide range of guided surface transport solutions (metro, light rail, and monorail), presumably because they have the strategic freedom to do so. Of course, alternative systems may appear attractive at entry-level traffic volumes, but planners need to consider growth prospects as well.

4.6 Peripheral rail applications

Having explored the drivers of railway competitiveness and sustainability, it is now opportune to lay to rest a few misperceptions about rail's potential contribution to society. Some stakeholders imagine that there is scope for light, road-based, vehicles to provide passenger service on light density lines. They have floated examples such as rail buses, and mini-buses, on flanged steel wheels. Three fatal flaws in the reasoning are immediately evident:

- Road vehicle axle load is low, so such vehicles do not exploit the potential of rail's Bearing genetic technology.
- Speed is low, so such vehicles do not exploit the potential of rail's Guiding genetic technology.
- Road vehicles are not sufficiently strong to be coupled into trains, so such vehicles cannot exploit the potential of rail's Coupling genetic technology.

Road-based vehicles thus have the handicap of a single degree of freedom of movement, without being able to offset it by leveraging any of rail's genetic technologies. Light, slow, single rail vehicles do not address contemporary commuter expectations. A few single trams have survived in the former USSR and its satellites: The Consultant has observed forlorn examples in Khabarovsk, Prague, and Vladivostok, which contribute little to the transport task in socio-economic conditions that have rapidly developed a preference for private cars.

The further obstacle of homologating such vehicles with rail safety requirements, now commonplace in many countries, put the final nail in the coffin of peripheral rail applications.

4.7 The African Union recommendations

This study recognizes, and is entirely consistent with, the Draft Recommendations adopted by the Johannesburg Professional Conference of the African Union on 21 November 2007 (African Union, 2008). In particular, Recommendations 1 and 4, quoted below, relate to the terms of reference of this study[63].

> "1 That Member States carry out significant technical improvements on existing metric tracks, in order to enhance their technical operating performances;
>
> 4 For new railway lines, encourage the construction of tracks with standard gauges, in order to bring African railway transport in line with the development perspective."

The recommendations reflect the reality that standard gauge track offers significant advantages over narrow gauge track. The challenge for South Africa, and the rest of sub-Saharan Africa, is to find a way of implementing the recommendations, to leverage rail's strengths, at affordable cost.

Evidently, it is unaffordable and impractical to implement an across-the-board gauge conversion in a short time: This study therefore, among other, explores ways of migrating from the present track gauges to standard gauge, within the bounds of affordability and practicality.

[63] The six other draft recommendations are sound, but do not relate specifically to passenger rail technology.

4.8 Relations between technology and funding

As passenger rail technology develops apace, relations among technology suppliers and technology purchasers are acquiring a distinct character. Authorities may be wary of purchasing high technology equipment, because they are averse to the risks associated with maintaining it. System integrators may be equally averse to selling the same equipment to operators who may not be able to maintain it properly, and getting their reputation sullied in the process. Arrangements such as full maintenance leases can work around these questions, but investors who fund them are reluctant to commit to equipment that has limited alternative application: A 3kV dc narrow gauge train incurs more risk than a 25kV ac standard gauge train, because the former cannot be readily redeployed elsewhere if a relationship fails, whereas the latter can. One can expand this elementary concept to include construction, operations, maintenance, and ultimately a complete turnkey package.

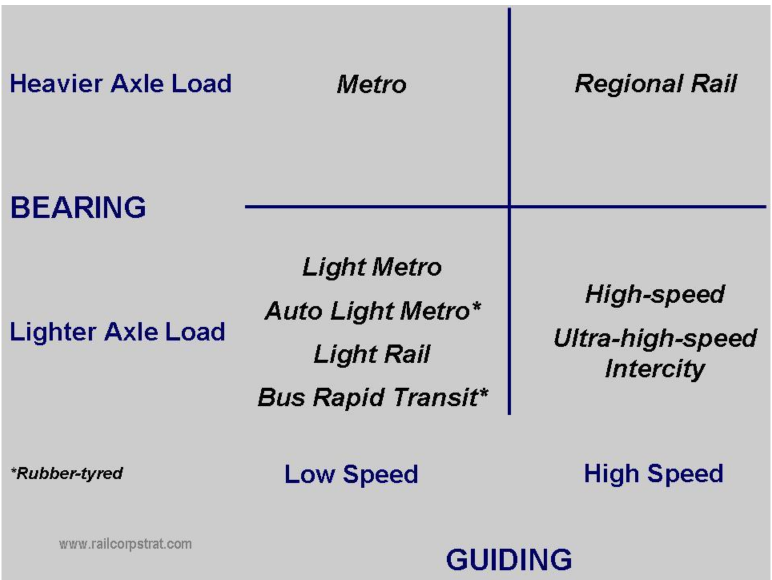
Underlying such arrangements is an implicit relation between funding and railway technology. It requires agreement on a performance specification and the risk or reward of under- or over performing. Whatever the modalities, it requires willing participation by all parties. Institutional arrangements can promote or impede particular solution outcomes. The systems approach is a competent indicator of outcomes. Assuming that mechanistic system adaptation will be history, leaves organismic- and socio-cultural adaptation. Organismic adaptation is rule or regulation driven, and the outcome is inevitably contained in that regulation: It may take long to get to the equifinal outcome, and may even lead to a stalemate. Socio-cultural adaptation can be convoluted, but it can involve all stakeholders to make positive progress to a meaningful outcome. As South Africa goes about realizing its passenger rail technology aspirations, it will need to pragmatically harness the power of appropriate systemic adaptation.

5 Applying the framework to South Africa

5.1 A general direction

5.1.1 Positioning passenger rail for sustainability

In passenger rail context, service delivery means "meeting passengers' needs in terms of speed, safety, convenience, and reliability" (South African Rail, 2008/09). To achieve such service delivery, South Africa will need to consider significant incremental investment in existing passenger rail systems, as well as investment in new railway opportunities, to align its railways with the market spaces that contemporary rail's genetic technologies strongly support. To easily visualize how these market spaces relate to one



another, the diagram on the next page zooms in the genetic technologies discussed in §4.2.1.2 on passenger rail, showing the mainstream conventional passenger rail technology solutions from §4.3, as well as two close competitors from the alternative guided surface transport technologies from §4.5. To the extent that passenger rail operations need to share, or could with mutual benefit share, infrastructure used by freight trains, such investment and repositioning would be required for freight railways as well.

The high quality mass mobility to which South Africa aspires, and the shift from road to rail that will help drive it, will only be achieved by positioning railways in the market spaces that they naturally dominate.

5.1.2 A prognosis on Transnet Freight Rail

It is axiomatic that Transnet should be considered a foundation stakeholder in repositioning long distance passenger rail technology in South Africa. Although it is no longer in the passenger rail business, its rail infrastructure and access thereto, will inextricably be part of intercity- and regional passenger service delivery in the short and medium term.

Because the National Transport Master Plan (NATMAP) needs to estimate the potential contribution of rail to the aggregate national transport task to 2050, it requires a fair estimate of how the national rail network and its traffic will develop over the intervening period. This study develops an approach with which to address the contribution of passenger rail technology. However, it cannot lose sight of the cross impact of freight rail technology. Although outside its scope, this study therefore takes the following high-level view on the state of freight railways, and then indicates where caution is required with respect to investing in new- or upgraded passenger rail technology.

Transnet Freight Rail operates a narrow gauge (1067mm) network. Narrow gauge state-of-the-art supports neither best practice heavy axle load, nor industry leading high-speed. From §4.2.1.2, it is therefore evident that trains on TFR infrastructure are excluded from the High-speed Intercity and Heavy Intermodal (double stack container) market spaces. TFR does operate two routes in the Heavy Haul market space. However, noting the space limitations on narrow gauge traction motors and its comparatively low axle load, it must pay over the odds for locomotives and wagons. TFR is thus not strongly positioned to exploit the three line-haul market spaces that underpin the global railway renaissance. Its low domestic market share, and coal and iron-ore exports that are lagging global competitors, suggests that it faces an insecure future.

TFR's ability to collaborate on future long distance passenger rail technology interventions rests on fragile freight rail positioning. Its ability to relate meaningfully to passenger rail plans should be considered with circumspection.

5.1.3 The basic approach

From the Status Quo analysis (§2), and the Passenger Rail Technology Framework (§4), it is evident that, viewed from a technology perspective, passenger railways in South Africa have fallen behind contemporary practice. Essentially, the country has had only one urban, and one long distance, passenger rail solution since inception of its passenger railways. By contrast, a wide range of attractive passenger rail solutions, which embody competitive technologies, is currently available virtually off-the-shelf in the global market.

Recognizing that the life cycles of many rolling assets have expired, and that the shortcomings of narrow track gauge have been exposed, it is now opportune to break the old mould and migrate to a new dispensation. Note nevertheless that, with due care, some infrastructure can be made to last longer, particularly when other built environment has become established around a railway. For example, it is usually difficult, or expensive, to augment or to re-route railway infrastructure in cities.

The general approach should thus be to renew or upgrade those assets that can enhance competitiveness and sustainability, and to recycle as far as practicable, those that are associated with valuable rights-of-way.

5.2 Migration paths toward contemporary technology solutions

5.2.1 Taking a view on interoperability

5.2.1.1 Learning from the systems approach

South Africa's passenger railway systems have been almost completely closed for many years: The essential technologies of the bulk of the fleet, which date from the early 1900s, are the predictable outcome of mechanistic adaptation. Recall from §2.1.5 that while interoperability, to local standards, over the whole passenger fleet has been rigorously maintained, one crucial, unintended, consequence is that both urban- and long-distance passenger rolling stock fleets are now way off contemporary best practice. Instead of being able, routinely to acquire attractive passenger rail technology solutions in the global market, South Africa's passenger railways have become technological stragglers[64] outside the global railway renaissance.

It is unrealistic to imagine changing South Africa's entire passenger rail system in a single intervention. The pragmatic alternative is to do so piecemeal, as funds and other constraints allow. There is a need to open interaction among railway systems and their environment, to elevate and to enlarge the system, to move from mechanistic- to organismic- and to socio-cultural adaptation. If pragmatic, piecemeal adaptation is the way to go, it is appropriate now to examine the ramifications of interoperability. Piecemeal adaptation rests on setting aside interoperability requirements in certain situations. If this requirement is not entertained, no meaningful renewal and upgrading will be possible.

5.2.1.2 Interchanging and interoperating

When passengers *interchange* at designated locations, they change on foot among urban- and long distance transport modes, such as private car, taxi, bus, bus rapid transit, light rail, heavy rail, regional rail, intercity rail, and even air. They understand that interoperation between different modes is out of the question, and therefore interchange

[64] To be fair, one should recognize that the Blue Train and the New Generation commuter trains did introduce advanced technologies. Unfortunately, they could not muster the requisite critical mass to sustain ongoing change.

willingly, even on foot. Where necessary, of course, provision is made for the mobility-impaired.

When trains *interoperate*, passengers remain in the train from origin to destination. While interoperation is undoubtedly more convenient than interchange, railway stakeholders should weigh the value of that convenience, against the opportunity cost of technological stagnation. Railways in South Africa, both freight and passenger, have become ensnared in a position from which it is difficult to acquire rolling stock with which to respond to market opportunities in real time. The opportunity cost of a national transport service provider failing to support economic activity on demand must be detrimental to all.

Sacrificing interoperating by train, for interchanging on foot as shown at right, allows each transport mode to develop technologically at its own pace. This perspective applies equally to the various passenger rail applications, such as urban rail, regional rail, high-speed intercity, and ultra high-speed intercity. Separating them into sub-systems or sub-networks allows the respective systemic technologies to advance by smaller, more virile building blocks.

It is noteworthy that countries with a progressive attitude to rail-based mass mobility no longer regard interoperability within urban rail systems, and between urban rail systems and regional- and national rail systems, as a non-negotiable requirement. Indeed, adopting a pragmatic stance on interchangeability and interoperability has allowed them to lead or follow closely the development trajectory of passenger rail technology in the global railway renaissance.

Stakeholders now need to grant passenger rail in South Africa sufficient space to open its systems to the most appropriate rail technology for each market space, and allow the industry to develop from there and to flourish.

5.2.1.3 Challenging existing precepts

Relentless change has become an integral part of the global railway renaissance. Competing system integrators increasingly differentiate their offerings, to exploit ever rising user expectations (Van der Meulen & Möller, 2006). The range of passenger rail solutions on offer has consequently increased dramatically in recent years. For steel-wheel-on-steel rail applications, traditional long distance services have mutated into regional-, high-speed-, and ultra high-speed services; suburban heavy rail services have mutated into metro- and regional- services; and tram services have mutated into light rail-, tram-train-, and light metro services. Other than standard gauge track and 25kV ac overhead electrification, each mutation is neither interoperable with any other, nor required to be interoperable. Then come the rubber-tyred variants …

Even within the standard gauge/25kV ac ideal, interoperability still challenges railway operators on many counts—narrow- or wide bodies, control systems specified for long- or short trains; high-, low, or zero platform heights; heavy- or light axle load, minimum curve radius, maximum speed, installed power, and many more. However, pragmatic, progressive transport authorities have learned to deploy each mutation to extract the competitive advantage built in by the system integrator. Within this milieu, interoperability between freight- and passenger trains, on shared infrastructure, is a particularly unwelcome imposition on both operators. It can only be made workable by a cooperative, mature relation among the parties.

In South Africa, where rail passenger transport is perceived to fit poorly with stakeholder expectations, it is necessary to introduce new technologies to move with the times. In so doing, one must challenge and set aside pre-existing one-size-fits-all interoperability precepts. The most compelling reason to do so is that the existing set of interoperability precepts will not be superseded by another set, but by several sets, one for each application. If that seems like a high barrier to entry into contemporary passenger rail solutions, consider the opportunity cost of foregoing the opportunity to change by insisting on interoperability as a first requirement. It will simply entrench the legacy from the past, and snuff out rail's potential contribution to the nation's mass passenger transport task.

Interoperability therefore needs to be negotiable. Not without limits, but diligently, recognizing that system integrators also have a strong interest in limiting the extent of product diversity. Interoperability should therefore be considered case-by-case, with a view to implementing the best solutions that contemporary rail can offer.

5.2.2 Matching subsystems

5.2.2.1 Urban infrastructure

South Africa's existing urban rail infrastructure, in particular its valuable right of way, is entangled in the built environment and the communities it serves. The departure point for future development should therefore be to leave well alone as far as possible, to minimize the cost of redevelopment, and to leverage the maximum benefit from new investment.

To the extent that contemporary metro trains can substantially improve speed, safety, convenience, reliability, comfort, and capacity, over their intended route distances, there is every reason to redevelop existing infrastructure rather than contemplate new. In this regard, South African cities are no different from their counterparts around the world. While examples of abandoned mainline railways do exist, abandoned urban railways are rare—cities grow more and more attached to them.

Some minor improvements should be implemented, primarily to raise base speed above 30km/h on special trackwork such as crossovers, diamond crossings, and slips. Some are placed to facilitate freight operations, and others are restricted for interoperability with steam locomotives[65]. A recommendation is made in this regard (see §6.5).

5.2.2.2 Intercity and regional infrastructure

South Africa's existing long-distance rail infrastructure presents a much bigger challenge than its urban rail counterpart. Lines that were built with no curve speed restrictions for

[65] Steam locomotives are an anachronism that one should no longer allow or consider on urban mass mobility routes.

the 90km/h passenger trains of the time, are immediately overwhelmed by curve speed restrictions when the permissible line speed is raised to 100km/h or more.

Beyond 130km/h, standard gauge track is required in any event. Unless it is possible to build new alignment, it will require sharing track with TFR. This may be parallel with existing tracks, similar to Gautrain and Metrorail between Hatfield and Pretoria. Note however that, if standard gauge track needs to follow the same curve radii as narrow gauge track, it will be subject to similar curve speed restrictions. This will indeed be the case for Gautrain between Pretoria and Hatfield.

5.2.2.3 Train authorization: Capacity versus speed

From §2.1.3.1 and §4.4.2.3, it is evident that there is contention between the requirements of firstly high capacity and high-speed passenger train authorization systems, and secondly between freight- and mainline passenger train authorization systems. The first category would ideally be addressed by segmenting passenger services such that metro operations run on dedicated infrastructure. All other trains would then default into the second category[66]. A recommendation is made in this regard (see §6.3.4). The second case would represent mainlines to be re-gauged or dual-gauged to standard gauge, to support higher speed passenger trains. They will either be impeded by existing signalling systems, or technology such as additional signal aspects, or communication based train control, would need to be provided to mitigate the impediment

Communication-based train control could be of value to South Africa, particularly on intercity and regional routes, where there would likely be sharing of infrastructure, between passenger trains running at higher speeds than at present, and freight trains. The United States systems (referred to in § 4.4.7.5) for intermixing freight and passenger trains in relatively light density traffic could be useful for similar mixed working in South Africa. They originated in a comparable environment having a mixed bag of legacy systems, over which a system was laid to enforce movement- and speed authorities.

It is not possible to realize the full performance potential of contemporary trains on existing rail networks—urban, regional, and intercity. In particular, train speed and braking performance need to be matched by the signalling system, so that headway can be minimized. This requires, as a minimum, matched upgrading of rolling stock and signalling, possibly on a route-by-route basis.

5.2.3 Sourcing passenger rail technology

5.2.3.1 The influence of the railway renaissance and globalization

The last large-series (5M generation) suburban coaches[67] purchased new in South Africa, in the mid-1980s, were built to design concepts that originated in the 1920s. Mainline coaches have a similar heritage. Between then and now, passenger rail technology has developed and diversified, to provide competitive solutions in the market spaces

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[66] Note that there is potentially a third case, namely ultra high-speed trains on dedicated infrastructure. The requisite matching is implicit in the dedication.

[67] This excludes the 6M, 7M, 8M, and 9M generations, which laid the foundation for further series builds, which did not materialize.

described in §4.3. The market and the industry from which South Africa must source new passenger rail equipment and services to join the contemporary passenger rail mainstream has changed beyond recognition. The railway renaissance and economic globalization have fundamentally reshaped the railway supply industry. The remainder of §5.2.3 examines issues regarding migrating into that mainstream.

In this context, technology subsumes the sum total of what makes a railway work over its intended life cycle. It includes intellectual property, from system conception down to the smallest component or operation, as well as designs, hardware and software, construction and manufacturing, operations and maintenance, and their integration—everything that constitutes a turnkey contract to conceive, plan, build, and run a railway[68].

Global centres of excellence, supported by intense, industry-funded, research and development, have emerged to supply high-value-added specialist components and subsystems, such as bogies, power electronics, signalling, and many more, into the global market. The process has transferred competitive advantage from purchasers to system integrators. This means that a high level of sub-systems- and possibly even systems design will need to be imported. South Africa needs to recognize the challenges, and opportunities, of migrating to contemporary passenger rail technology that is aligned with robust industry-preferred or industry-standard solutions. Local participation must inevitably look different from what it did when South Africa last implemented new railway technology.

5.2.3.2 Global sourcing

In addition to the established suppliers and system integrators in Europe, Japan, and North America, Asian mainland suppliers are also making their mark as global suppliers.

- Korea's Hyundai Rotem has already established a global business focused on high-speed and urban rail technology, and has successfully entered markets in Europe and the United States.

- China is still a net recipient in large-scale technology transfer deals with system integrators in developed countries. However, it has also started supplying equipment and services into the global market, and is building a reputation for low technology items such as coaches and wagons in developing markets.

- India is accelerating its railway development. It is setting up technology transfer arrangements, and facilities for rolling stock manufacture. It is also pursuing export markets with indigenous technology. The width of its vehicle profile is the same as that in North America, and it has adopted AAR practices for its heavy freight corridors.

- Russia builds railways to its own standards, but aspires to use [unspecified] international standards (Lukov, 2009). It still has a huge backlog of domestic requirements, so it is likely to be a net importer

[68] Of course, existing railway operators may be interested in only a subset of this scope to, say, expand capacity or renew assets, but they are mentioned here for completeness.

from the global market for some years. However, it is already active in railway construction outside Russia. The width of its vehicle profile is the same as that in North America.

By planning diligently, South Africa could position itself to acquire railway equipment from competitive global sources.

5.2.3.3 Possible stumbling blocks

Being owned by TFR, mainline railways in South Africa are freight-oriented, and likely to remain so for some while. However, many of TFR's existing freight operations are at best marginally competitive against road. From §4.2 it is evident that heavy axle load characterizes competitive freight railways: One should therefore expect wagon axle load to increase as freight rail fights back. If some suitable shared routes were changed to standard gauge, or dual-gauged, useful line capacity utilization synergy could develop between freight traffic and high-speed passenger traffic. However, it is likely to be a North-American oriented axle-load-driven outcome rather than a European-oriented speed-driven outcome.

Competitive freight wagons typically use three-piece bogies with no primary suspension, and maintenance standards on freight-oriented standard gauge railways may be somewhat lower than those on passenger-oriented railways, though not unsafe. European freight wagons use primary suspension on good track, but axle load is comparatively low and competitiveness therefore wanting. While high-speed rolling stock tends to originate in Europe[69], competitive freight rail technology originates in the United States.

While United States' rolling stock has seen minimal service in Europe (because it is too heavy and too bulky), some European rolling stock or technology has famously failed to satisfy expectations on track shared with freight trains in the United States. The following examples illustrate:

- 1961 Krauss Maffei ML-4000 locomotives (German)
- 1973 ANF Turbotrains (French),
- 1977 CC21000-series monomotor-bogie locomotives (French), and
- 1979 Superliner bogies (German)

To give balance, other designs have actually worked well, namely:

- 1978-1988 Amtrak AEM-7 locomotives (Swedish),
- 1988 Talgo pendular tilting train (Spanish), and
- 2002-2009 New Jersey Transit ALP-46 locomotives (German)

[69] Other than Taiwan, Japanese technology has not made much headway in high-speed railways outside Japan

The point is raised here, because South Africa's pursuit of passenger trains poses it an unusual track quality challenge. Saudi Arabia is at present building new lines for a mix of heavy freight and fast passenger trains, and will be the first to experience the outcome. The global railway industry is watching with interest. South Africa should pay particular attention.

5.2.3.4 South Africa's procurement leverage

South Africa is a small player in the global rail market. In a recent study (Roland Berger, 2008), Africa and the Middle East combined contributed only some 4½% of total market potential. This grouping included substantial spending by Saudi Arabia and the United Arab Emirates, leaving the South African share of the global market probably around 1%. For perspective, Europe leads the global market potential with 29%: Passenger operations dominate that market, so it is unsurprising that Europe's purchasing power exerts strong influence on global passenger rail technology. This is also reflected in its rail supplier research spend of Euros 1 billion per year (UNIFE, undated). For perspective, the latter spend is in the league of TFR's annual revenue (Transnet, 2008). Then comes spending on railway research in China, India, Japan, North America, and Russia, to mention the heavyweights.

As South Africa implements its passenger rail vision, it may initially need or want to enter particular market spaces with small fleet quantities. It would have more leverage if it could piggyback on orders by other railways (not an unusual occurrence nowadays), or even acquire second hand rolling stock, particularly trailing stock. Other high-technology equipment—signalling, automatic fare collection, and so on, has a relatively short half-life—which is good from the perspective of keeping up to date, but requires careful management to actually do so.

South Africa has no alternative but to consider it a rail technology taker. It needs to position itself in a workable systemic relation with potential suppliers, both global and local. In organismic system terms, one should recognize that well-intended requirements might bring unintended consequences. In recent years South Africa has found itself in an intractable position regarding rolling stock acquisition as requirements have contracted the solution space. Elevating the relationship to socio-cultural, to admit all stakeholder perspectives, could restore fluidity.

5.2.3.5 Maximizing life-cycle value

Before setting course on a new passenger rail technology dispensation, it will be prudent to revisit South Africa's local participation mix, to ensure that local content perspectives support rather than impede implementation. The following drivers are pertinent:

- Contemporary aluminium and stainless steel bodies, which require investment in sophisticated facilities, have become the domain of specialist suppliers. The extent of local manufacture would depend on fleet commitments and production volumes. As systems integrators segment products to target specific market niches, sales of a particular item in a specific market tend to decrease.
- Manufacture of railway equipment has become a specialized business in a competitive global market. High technology in small packages,

for example propulsion- and signalling systems, has become concentrated in global centres of excellence. Only technologically advanced countries manufacture it, the rest import it.

- Contemporary trains are maintained over their entire life cycle in the same depot that performs running maintenance[70]. Some components may require a mid-life refurbishment, which is also possible with normal equipment at a running depot, with assistance from specialized subcontractors.
- Contemporary equipment is low maintenance, e.g. aluminium or stainless steel car bodies do not need periodic heavy repair. This therefore also eliminates the need for heavy repair facilities.
- Maintenance of high technology equipment requires highly skilled maintainers: There is a global trend to outsource this function to original equipment manufacturers or specialist maintainers.
- In the foregoing milieu, where even completely assembled EMU cars are delivered by air on occasion, the maximum local manufacture in a developing country might be modest assembly of large components such as body sub-assemblies. Even then, local manufacture would face aggressive competition from Asian builders.
- The local content portion during project development is likely to comprise largely infrastructure design**,** -construction, or –reconstruction, and assembly of trains. One may consider the Gautrain model a prototype, and the extent of local vehicle assembly or building will depend on the fleet size in prospect.

The following bullets explain how local participants could leverage the foregoing drivers:

- Greenfields projects run at around 60-80% infrastructure construction cost and 20-40% rolling stock and signalling cost. Infrastructure spend is by nature largely local, so the lion's share should remain accessible to local participation. The ratios for brownfields projects would depend on the scope.
- Maintenance would likely represent a major element of local participation, and if properly structured, could stimulate emergence of competitive maintenance suppliers.
- There could thus be a shift in emphasis from rolling stock manufacturing to construction and services, such as operations, maintenance, information technology, legal services, property management, and so on.
- Regional- and urban rail compete with modes that rely largely on imported equipment—buses, BRT, cars, and taxis. The latter modes

[70] Some specialized maintenance functions may be outsourced to off-site contractors on a unit exchange basis.

enjoy quick response to new technologies, and hold relatively low risk to suppliers. Local content of railway rolling stock is promoted in many countries, but it should not impose high risk to suppliers.

- If passenger rail were positioned to shoulder its rightful share of the South African transport task, the size of the railway industry, both in market presence and in value added, should grow significantly larger than at present. While redistributing the mix might require some incumbents to adapt, an expanding rail equipment market should take such change on board without undue disruption, and create higher aggregate value for all participants.

Stakeholders should consider the passenger rail system over its whole life cycle, to identify all opportunities to add value through local participation.

Life-cycle-spend is the other side of life-cycle-cost. The need to manage expenditure associated with owning an asset over its life cycle is widely understood. However, in the context of migrating to a new passenger rail technology dispensation, it makes sense to look at life cycle spend as well. Cash flows to recipients of life cycle spend are what really count when assessing total impact.

5.2.4 Changing track gauge from narrow to standard

5.2.4.1 Techniques

This section addresses the scenario that South Africa does change some, or all, of its track gauge. Change would realistically take place over several years, introducing the possibility of break of gauge within South Africa. The Railway Gauge Working Group (National Transport, 2009a) addressed the issue from a general perspective. What follows addresses some passenger-specific aspects of changing track gauge opportunistically and piecemeal.

No change is the natural *do nothing* option. Passengers would interchange between one train and another, in the same way that they interchange between trains and other transport modes. This option will probably be unavoidable as gauge change rolls out, or as new routes are introduced. It could even be temporary at any given location.

Dual-gauge track requires complex trackwork, and even more challenging on electrified lines, because contact wire stagger cannot reference the centerlines of both tracks. Dual gauge occurs mainly in Australia, on track worked by diesel locomotives, so electrification is a non-issue there. It is generally not used over long distances, because of its complexity—the longest known route is the 120km from Northam to Perth in Western Australia. The reference distance from track to platform face for two different vehicle profiles is also not a trivial issue—see §5.2.4.2.

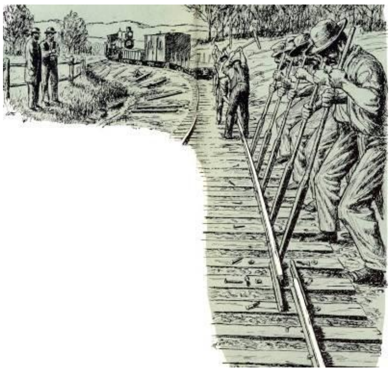
Gauge-adjustable wheelsets have found favour for passenger train applications. They can easily co-exist with electrification, because they support normal contact wire stagger. They are heavier than fixed-gauge bogies by about a tonne, and more expensive too. The following examples could be of interest to South Africa:

- The Talgo system from Spain, which changes gauge automatically at low speed, is particularly attractive: It can be built with a single wheelset configuration, which is thus less complex than a gauge-changing bogie, which is nevertheless also possible. It is generally used on electrified track, although diesel versions also exist. An example is shown in §4.4.5.5.
- Japan has developed an EMU Gauge Change Train to interoperate between 1067mm and 1435mm track gauges—the same situation as South Africa will likely need to address. Using Talgo technology, it is the only design possibly close to commercial availability. After completion of testing in Japan and at Pueblo in the US, the commercial outcome is at present not yet evident.
- System integrator CAF, also from Spain, envisions universal trains for Europe, for unrestricted interoperability among 1668mm (Iberian), 1520mm (CIS countries), and 1435mm (standard) track gauges; as well as 25kV 50Hz ac, 15kV 16⅔Hz ac, 3kV dc, and 1,5kV dc traction power supply. The photograph shows its prototype.

Re-gauge-, or build track to standard gauge is the most desirable option. In South Africa, it would require that a fleet of standard gauge rolling stock be made available up front, as with Gautrain.

Techniques for dealing with either progressive or instantaneous migration to standard gauge are available. There is no reason in principle why South Africa should not contemplate changing track gauge where it offers compelling advantages. The cost and logistics of doing so are matters for careful consideration.

5.2.4.2 Implementation



Implementing track gauge change can range from straightforward to complex, depending on the initial situation and ultimate objective.

Early railways fixed their rails to timber sleepers by means of spikes. The gauge unification of 18 000 kilometers of track in the southern United States, from 5 feet to 4 feet 9 inches[71], was accomplished over two days in 1886 (The days, undated). The gauge was narrowed, so existing sleepers could be retained: New inner spikes were pre-placed, and the outer spikes simply repositioned

[71] The 4 feet 9 inches gauge was a consensus value, but it was of course not standard gauge. The final reduction to 4 feet 8½ inches (1435mm) was accomplished some years later in the course of normal track maintenance, after the value of interoperability with the northern states had been appreciated.

as only one rail was moved over the two days. The principle is illustrated at right above. Rolling stock wheelset gauge was both pre-changed and changed concurrently.

Such gauge changing still takes place—see the illustration at right, which shows track being converted from 914mm gauge to standard gauge in Peru in 2008. End-to-end conversion is imminently feasible when standard gauge invades narrow gauge territory, particularly if electrification and signalling are not at issue.

The ability to change track gauge quickly depends on the amount of gauge difference, and the length and type of sleepers. If the gauge must be widened, as would be the case in South Africa, the United States example would not work, because short sleepers would need to be replaced by long ones. Contemporary concrete sleepers have recesses that locate the rail, and are thus manufactured for a particular track gauge. It is also unlikely that existing rolling stock could be quickly adapted from narrow gauge to standard gauge. The 368mm difference would require completely new bogies on coaches and locomotives[72], which would likely be prohibitively expensive.

In the 1880s, the United States gauge unification would not have involved much signalling or special trackwork, and what was involved was simply screwed or spiked onto timber sleepers. With some foresight, it could well have been on the side where the rail was not moved. Nowadays, signalling track circuits, and points machines, would also be involved.

Vehicle profile was also not an issue then, because low-level platforms were (and still are) used. The slight offset due to moving one rail only could not cause difficulty with platform gaps.

The amount by which the South African vehicle profile exceeds the track gauge is 991.5mm on each side[73]. For standard gauge vehicles, this can range from 857.5mm (e.g. UIC body width) to 907.5mm (e.g. AAR, as well as Indian and Russian, body widths). Narrow gauge vehicle bodies thus project more outside the track than would standard gauge vehicles. If track gauge were changed, the track would need to be slewed at platforms to maintain platform gaps. This could raise issues regarding distances between adjacent tracks.

Dual-gauging eliminates most of the issues raised above. Suitable sleepers, concrete, steel, or wood, with provision for two (or more) track gauges, may be pre-placed in preparation for laying the third rail quickly thereafter. However, the abovementioned platform gap issue would remain.

Motive power can be a confounding issue. Gauge change is comparatively easy with diesel traction, because only the track is involved. However, it is comparatively difficult

[72] Coaches, locomotives, and motor coaches use single-piece bogie frames, which are not easily adaptable to a large track gauge increase.

[73] Profile width 3050mm minus track gauge 1067mm = 1983 mm, or 991.5mm per side.

with electric traction, particularly if a railway wishes to follow the sensible path of installing 25kV ac electrification at the same time as standardizing track gauge.

Thorough planning and preparation is a critical element of changing track gauge. For a passenger railway, it would be valuable to ask passengers' indulgence to interchange on foot during a gauge change, and to keep standard gauge infrastructure and operations separate and non-interoperable as far as possible.

5.2.4.3 Recycling infrastructure

When planning to implement the various mainstream trains described in §4.3, infrastructure can represent a major component of the cost of providing rail service, particularly for higher speed, standard track gauge, and low-density traffic. How does one obtain appropriate infrastructure? A useful guide is that, for passenger rail to become sustainable, it will need to leverage rail's genetic technologies. One should therefore expect passenger trains to become faster and heavier[74]. The following bullets start with what exists right now, and lists the further rational options to leverage existing infrastructure before contemplating new infrastructure.

- Recycle track—new trains run on existing track*.
- Recycle formation—new trains run on new track* on existing formation.
- Recycle right-of-way—new trains run on new track on new formation on existing right of way*. This option admits possible change in horizontal- and vertical alignment. Note that it might require acquisition of additional land, to increase horizontal curve radius, and to make deeper cuts and higher fills to increase vertical curve radius, both to raise speed.
- Build new infrastructure on new right-of-way. This would apply to new routes such as ultra high-speed lines, missing links to enhance the utility of the network, and lines to reach out to communities that need to be included in the rail network.
- In practice, a blend of all four options will probably emerge.

*New- or upgraded signaling could be required in many instances, to match the performance of faster and heavier trains, with higher acceleration- and retardation rates, to infrastructure attributes.

5.3 Candidate contemporary passenger rail solutions

5.3.1 Developing a short list

The following passenger rail applications, drawn from §4.3 *Mainstream conventional passenger rail technology solutions*, and §4.5 *Alternative guided surface transport technologies*, appear worthy of appearing on a short list for consideration in South

[74]They are unlikely to become longer, because South Africa's passenger trains are already among the longest in the world—arguably because they are inherently uncompetitive and hence increased train length was the only way out.

Africa. The approach is generic, with a view to applying some of them to specific routes and corridors in South Africa in §5.5 as requested by the client.

5.3.2 Urban solutions

5.3.2.1 Light Rail

Light Rail does not currently exist in South Africa. It is in principle competitive with bus rapid transit, but offers environmental advantages and a permanence anchor for surrounding development. A decision to implement BRT should not be made without first evaluating light rail as a credible alternative.

5.3.2.2 Light Metro

Light Metro raises light rail performance into the capacity domain of existing Metrorail operations, by segregating right of way and providing signalling. It is typically also automated. One should consider it as a way of providing rail service to corridors that are marginal by PRASA's Priority B criteria (South African Rail, 2006), and may even be viable for Priority C and Priority A in some instances.

5.3.2.3 Automated Light Metro

Automated Light Metro is a close competitor for Light Metro[75]. The essential difference is that automated light metro uses the higher and more consistent adhesion of rubber tyres to reduce headway. Hence it can perform a given transport task with fewer resources. The decisive test would be to compare them back to back on a specific project. Prior experience with either could drive decisions, but South Africa has experience of neither.

5.3.2.4 Metro

Metro, or heavy metro, should feature prominently in South Africa's major cities and -conurbations, i.e. those that currently have their own passenger rail infrastructure, Durban, Gauteng, and Western Cape. A radius of 25-35km from each city centre would include most suitable catchment areas.

These long-established routes have already supported development in their catchment areas for many years. Their right-of-way represents valuable corridors on which to build attractive services with contemporary high performance rolling stock and train authorization systems. Noting that contemporary metro can raise capacity by a factor of three or more compared to existing systems, it could accommodate considerable growth on existing corridors, or support extension of service to wider catchment areas without requiring additional tracks for common routes where they approach city centres, or both.

Recall from §4.3.4.6 that metro rail is the one railway application where narrow gauge track does not impede train performance in any way. This report therefore does not recommend that there is any compulsion to change to standard gauge, but does recognize that standard gauge track can add value through greater comfort, wider bodies, greater energy efficiency, and importantly, competitive

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[75] The Consultant recognizes that the terminology might be confusing, and hopefully the industry will make the necessary distinctions in due course.

global sourcing. These factors should drive a preference for standard gauge on new routes.

5.3.3 Mainline solutions

5.3.3.1 Regional rail

In contrast to the niche indicated for metro, South Africa's major conurbations also contain substantial population pockets further afield. Attractive commuter rail service to such communities would require higher speed than metro, to give a reasonable journey time, but probably a lower frequency.

Regional rail should ideally run on standard gauge track, and would need access to city centres. The Gautrain solution between Hatfield and Pretoria, shoehorning a double track standard gauge route into a reserve previously used by a double track narrow gauge route, could be a model for similar schemes elsewhere.

Given sufficient demand and access to suitable infrastructure, regional rail could make a significant contribution to South Africa's mass mobility task.

5.3.3.2 High-speed intercity

From §4.3.6.1, it is evident that high-speed intercity (200km/h) is a natural development, and ultimate stage, of good basic standard gauge infrastructure that has been routinely upgraded over time. South Africa simply does not have such infrastructure. As mentioned in §5.4.4 and §5.5.1.5, there may exceptionally be opportunities in portions of the Durban-Cape Town corridor.

Standard gauge is an essential requirement for high-speed intercity. In most corridors other than Durban-Cape Town, this would mean re-gauging existing track, and by implication sharing it with freight traffic. This would not be a happy mix. If a new line were to be built for passenger service, it would be sensible to exploit state-of-the-art and build it as an ultra-high-speed line.

5.3.3.3 Ultra high speed

An ultra-high-speed rail service may one day be viable between Gauteng and Durban, as a first application in South Africa. The Rail Gauge Working Group has considered it as a case study (National Transport, 2009f), and found that the requisite traffic is not likely to materialize in the next 10 or even 20 years. The Steering Committee requested that the Consultant examine this application, and further findings are contained in §5.5.1.3.

5.4 Emerging contemporary passenger railway technology applications

5.4.1 Opportunities to join the global mainstream

Three significant passenger rail proposals have emerged in South Africa in recent times, of which one is currently being implemented. Collectively they have shown that revisiting established passenger rail technology precepts can lead to opportunities to join the global mainstream. The rationale behind each of the three proposals provides valuable insight for guiding further application of contemporary passenger rail technology in South Africa.

5.4.2 Gautrain

The Gautrain Rapid Rail Link is the first project to modernize passenger railways in South Africa. Currently under construction, it set out to exploit the attractive features of contemporary passenger trains, and the performance advantages of standard gauge, to attract motorists off congested roads. Its significance lies in:

- Introducing contemporary passenger trains to South Africa.
- Re-introducing standard gauge track to South Africa.
- Giving progressive objectives a higher priority than interoperability with legacy systems.
- Exemplifying the type of integrated public transport solution that can be had by competitive bidding against a performance specification.
- Realizing a public-private partnership, to leverages the know-how of a private sector concessionaire off the authority of a provincial government.
- Providing a transport solution that is already influencing the spatial development pattern of Gauteng, even before it commences operation.

The Gautrain project has demonstrated that it is possible to plant contemporary passenger rail solutions in South Africa. Given the political will to find a way through the inevitable obstacle course, it has proved workable to package funding and technology into a project that is set to have a profound positive influence on many aspects of Gauteng's economic and social fabric.

5.4.3 Moloto Rail

Moloto Rail proposes to deploy a contemporary standard gauge regional rail solution, as described in §4.3.5. It proposes to reduce journey time for commuters in a corridor that is currently served by a bus service that is considered less safe than it should be. Its significance lies in:

- A standard gauge solution outperforming baseline narrow gauge solutions, including—
    - Shorter journey time,
    - Lower capital investment,
    - Lower life-cycle cost,
- Rail providing a more attractive public transport offering than road,
- Good strategic positioning for future capacity growth and network extension, and
- Demonstrating that an industry-standard rail mass mobility solution can fit easily in the South African public transport setting.

See also §5.5.1.2 for potential further development of the Moloto corridor.

The Moloto Rail project demonstrates that industry-preferred solutions, developed and battle-proven in competitive markets elsewhere, can also provide winning mass mobility solutions for South Africa. It also illustrates the advantage of exploring solutions outside the present South African passenger rail technology paradigm, by allowing exposure to the rich variety of competitive rail solutions available in the global market.

5.4.4 Mthatha-Port Elizabeth High-speed Link

The Eastern Cape Province Mthatha-Port Elizabeth High-speed Link proposes to deploy 200km/h standard gauge passenger trains, by recycling moribund branch lines and constructing new key links, to provide fast, high quality service along an east-west axis (Van der Meulen, 2008). The proposal is based on recycling existing infrastructure in one of the primary High Priority Intra Provincial Corridors (South African Rail, undated) to the maximum possible extent, adding new links where necessary, and re-gauging track for high-speed operation. Its significance lies in:

- Reducing route distance of legacy infrastructure from 820km to 590km by building selected route cutoffs,
- Redeveloping old branch line alignments by steepening gradients and easing curves for passenger-only operation,
- Redeveloping existing main line alignments by easing curves to increase speed,
- Re-gauging track to standard gauge,
- Dual-gauging if and where necessary, and
- Raising maximum speed to 200km/h, possibly with tilting trains, to achieve 4½ hour Port Elizabeth-Mthatha journey time.

The proposal is currently under consideration by the government of Eastern Cape Province (Kei Rail, 2009).

The proposal represents a last stand for particular moribund branch lines. Their founding purpose has long been realized, and aggressive competitors have marginalized them. If it proves economically viable, their right of way can be recycled to restore them to the contemporary mass mobility milieu. If not, nature must eventually take them back.

5.5 Renewing and upgrading passenger railway technology

5.5.1 Selected route studies

5.5.1.1 Rationale

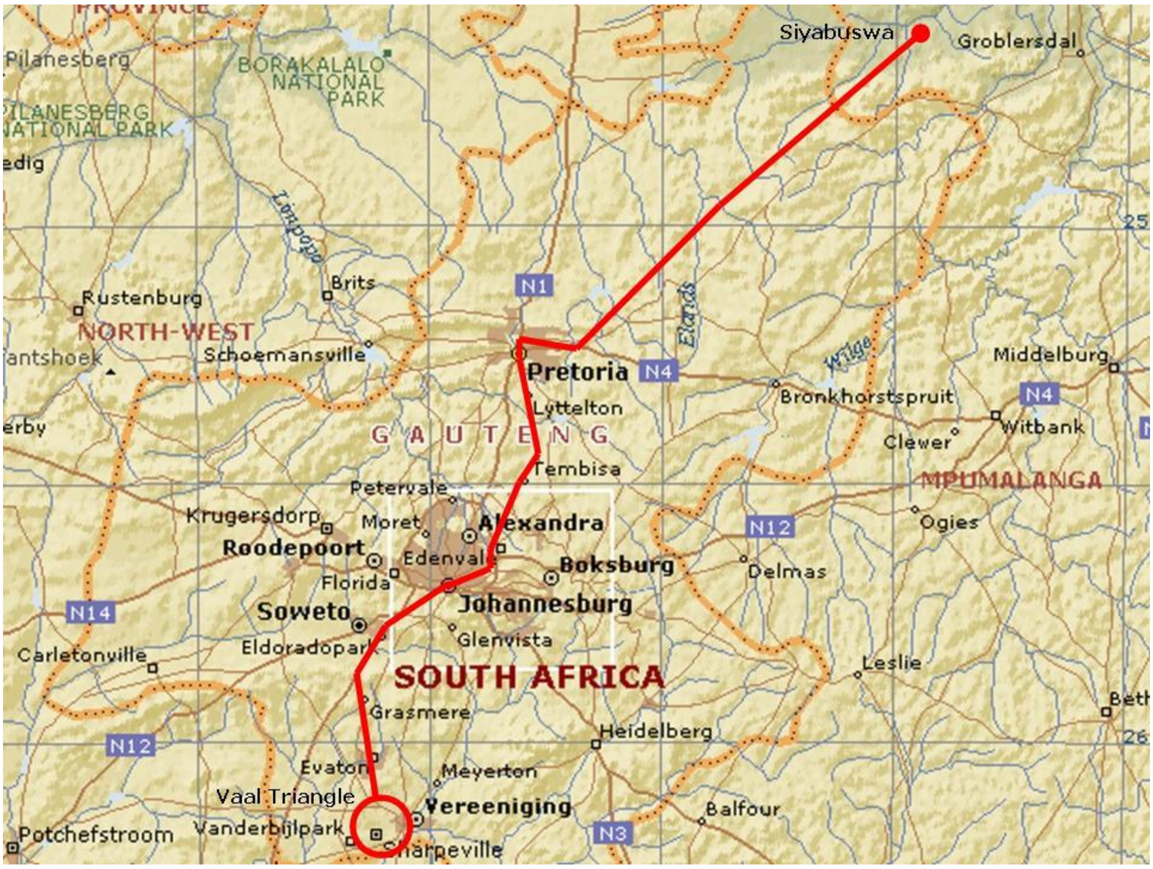
This section applies selected mainstream conventional passenger rail technology solutions from §4.3 to selected networks or routes in South Africa, to discuss and to illustrate their potential application. The selection was agreed between the Steering committee and the Consultant, to achieve a balance between situations that provide generic insight and those that address current questions.

Appreciate that numerate analysis, with actual traffic statistics and real economic and financial data is not within the scope of this study. What follows are therefore high-level scenario-style illustrations of how one might approach contemporary rail solutions for South Africa. More comprehensive insight would require deeper analysis.

5.5.1.2 Gauteng Regional Rail

Gauteng Province has approximately the same dimensions north-south as east-west, namely 200km. Existing rail transport corridors cover the province fairly extensively, as does the road mode. The dominant Strategic Public Transport Network axis is oriented roughly north-north-east to south-south-west across the province, with subsidiary east-west and radial axes. Road corridors are congested, and rail corridors are slow. The current Gauteng Freeway Improvement Project should relieve congestion, and the Gautrain will speed up rail on a small core network. However, from a province-wide mass mobility perspective, transit in Gauteng will still not be rapid.

In common with other provinces, Metrorail 5M/10M stock underpins Gauteng regional- and urban rail services. By comparison with contemporary global practice, it offers less than metro capacity on short hauls, and is slower than regional rail on long hauls. Shosholoza Meyl is relevant to the extent that people in Gauteng need to interchange with it for destinations outside Gauteng, and vice versa.



By integrating the passenger rail technology framework in §4, and its application to South Africa in §5, it is possible to synthesize the following scenario around the Moloto Rail project, which offers the prospect of anchoring rapid rail mass transit in Gauteng. The following are key elements (see map above):

- From the north, extend standard gauge Moloto Rail to establish a regional rail spine,
- From Koedoespoort westwards to Hercules; interchange with Metrorail, and with light rail on recycled right of way to Hartebeespoort Dam,
- From Hercules southwards via Belle Ombre to Pretoria; interchange with Gautrain, Metrorail, and Shosholoza Meyl,
- From Pretoria southwards parallel with PRASA to Olifantsfontein; interchange with Metrorail,
- From Olifantsfontein through Tembisa to Modderfontein, interchange with Gautrain,
- From Modderfontein along N3, enter Johannesburg via Bezuidenhout Valley to Johannesburg/Park Station; interchange with Gautrain, Metrorail, and Shosholoza Meyl,
- Exit Johannesburg/Park Station southwards through Crown Mines and follow to N1 to Midannandale, picking up Midway, interchange with Midway-Oberholzer,
- From Midannandale southwards parallel with existing line to Sebokeng; interchange with Houtheuwel-Potchefstroom-Klerksdorp,
- From Sebokeng to the Vaal Triangle area; terminal loop to pick up all potential stops, and simultaneously turn trains for the return journey; interchange with Metrorail.

Realizing the scenario would contribute the following benefits:

- Provide an opportunity to tap into the Priority A corridors in southern Gauteng (South African Rail, 2006).
- Provide a backbone service round which to integrate all existing Metrorail services, and to segment them if and when necessary to roll out new technology in manageable chunks.
- Provide a backbone service round which to integrate future shorter distance rail services, metro, light metro, and light rail.
- Minimize environmental impact and/or construction cost by running, where possible, parallel with existing rail routes, parallel to freeways, or through relatively underdeveloped terrain.
- Enhance viability of Moloto Rail, by extending utilization of rolling stock that might otherwise have been underutilized between morning and evening peaks.
- Simplify interchange at the northern terminus of Gautrain. Gauteng Regional Rail would need a linear route through Pretoria: It could therefore be sensible to extend Gautrain from Hatfield to

Koedoespoort, rather than link Moloto Rail with Gautrain at Hatfield[76].

Station	Cumulative Distance, km	Link Time, minutes	Dwell Time, minutes	Schedule Time, minutes	Interchanges
Siyabuswa	0	0	0	0	
Intermediate	49	26	1	27	
Mamelodi	98	26	1	27	
Koedoespoort	110	7	1	8	Metrorail Greenview
Hercules	122	6	1	7	Metrorail Hammanskraal, Mabopane, Rustenburg; Light Rail Hartebeespoort Dam
Pretoria	127	3	1	4	Gautrain Hatfield, Park; Metrorail Germiston, Saulsville
Olifantsfontein	152	14	1	15	Metrorail Germiston, Pretoria
Tembisa	156	2	1	3	
Modderfontein	169	7	1	8	Gautrain OR Tambo, Sandton
Johannesburg	191	12	1	13	Gautrain Pretoria; Metrorail East Rand, Soweto, West Rand; Shosholoza Meyl all directions
Nasrec	201	5	1	6	
Kliptown	212	6	1	7	Metrorail Oberholzer
Midannandale	222	5	1	6	
Sebokeng	249	15	1	16	Potentially to Klerksdorp
Vaal Triangle	**260**	6	0	6	Metrorail Germiston
Average Distance, km	20				
Average Running Speed,	112				
Cumulative Time, minutes		**140**	**13**	**153**	

- Kick-start standard gauge: Establish a critical-mass network, which could anchor rail development, and leverage existing infrastructure.
- Invert the status quo, in which narrow gauge dominates, to standard gauge dominates.
- Allow metro naturally to contribute high-capacity solutions—few destinations are further away from the standard gauge regional backbone than the ideal 25-35km.
- Revitalize a 35km portion of the disused Hercules-Magaliesburg branch line, from Hercules Station[77] to the Hartebeespoort Dam

[76] Gautrain is built to the small United Kingdom vehicle profile, whereas Moloto Rail, the Gauteng Regional Rail, and all other future projects, should be built to one of the larger international profiles discussed in this report.

[77] Hercules Station is a key junction in the Pretoria area, where mainlines to Musina and Komatipoort meet. It is on the Pretoria Ring. Metrorail services to Mabopane pass through it, and Moloto rail will likely pass by it.

vicinity, by converting it to light rail. Substantial development is taking place along the Pretoria-Hartebeespoort Dam corridor: This TFR right-of-way is ideally positioned to support sustainable mass mobility, but is currently an eyesore and a nuisance to developers and residents. One could recycle the existing formation by clearing overgrowth, removing existing narrow gauge sleepers, cleaning and augmenting ballast, laying rails on standard gauge sleepers, and securing the right of way. With luck, the existing light branch line rails could be re-used. An obsolete line need not be abandoned, but could be made relevant by implementing appropriate contemporary passenger rail technology, and recasting it from a mixed-use line to a dedicated passenger line.

- Support maximum speed in the range 160-200km/h[78]. Infrastructure design and performance requirements would inform the exact number.
- Support short journey times, for example Pretoria-Johannesburg ≈40 minutes.
- Support high capacity. Performance requirements would inform the exact number. If demand were sufficient, 7–coach double deck trains, with 1600 passengers, at five-minute headway, could move nearly 20 000 passengers per hour.

Note that the foregoing sections sketch a scenario by which to relate contemporary passenger rail to a major conurbation, and thereby to illustrate possible contributions that it could make. The outcome presented examined neither actual nor projected passenger flows, made no attempt at optimizing station spacing and other variables, and undertook no economic analysis, as they were outside the scope of this study.

Note that this scenario does not address interoperability with existing rail operations, because if that were a prime requirement, one could not envision such a scenario. By setting aside an inappropriate constraint, it is evident that competitive contemporary rail can take the high ground, from which it can naturally lead integrated mass transport for Gauteng.

5.5.1.3 The Gauteng-eThekwini Primary Corridor

From a passenger rail technology perspective, this route should be the prime candidate for fast rail service in South Africa. The Rail Gauge Working Group (RGWG) examined the topography and passenger volumes in the Gauteng-eThekwini Corridor, and concluded that a high-speed passenger service might be feasible between Durban and Gauteng in the distant future (National Transport, 2009f). Noting ambivalence in the RGWG report regarding operating speed, this section will tease out some difference between high-speed and ultra-high-speed over the route, and then add some supplementary perspectives

[78] If this proposal attracts interest, it may be advisable to revisit the maximum speed for the original Moloto Rail portion of the route.

Lowest cost infrastructure would have steep gradients, with the tightest curves that a standard gauge tilting train could negotiate, to minimize environmental impact and construction cost. Commercially marketed tilting trains, e.g. Alstom's Pendolino, and Siemens' Venturio concept, are designed for 250km/h. They would complete the distance in an estimated running time of 3.8 hours. The alternative is a standard gauge ultra-high-speed 360km/h train, which gives an estimated running time of 2.7 hours. Both train types would accept the same steep gradients, but commercially available ultra-high-speed trains do not tilt. Curves would therefore need to be wider than for tilting trains, alternatively a non-tilting train would run slower than a tilting train through curves speed-limited by natural obstacles such as mountains. Larger vertical curve radius would also increase infrastructure cost for the faster train.

What is it worth to save 1.1 hours on a trip to Durban? Whichever way such a decision might go, there is no legacy infrastructure available that could influence it. So the entire route would be greenfields infrastructure. Commitment to the first alternative will likely eliminate the second alternative for a generation or two, so it is important to understand the drivers.

The notion of railways promoting development does not have much currency nowadays. However, there is general recognition that the benefits of high-speed- and ultra-high-speed railways extend beyond conventional cost-benefit analysis into the domain of agglomeration effects. After 45 years of Shinkansen service, Japan's economic geography has changed remarkably, and few will argue that the change was not positive.

High-speed and ultra-high-speed railways are being mooted, signed up, or constructed in several of South Africa's economic peer countries, namely Argentina, Brazil, China, India, Morocco, Russia, and. Turkey[79]. The global economic downturn has upset some of them, but the fundamentals are there for all to see.

Experience elsewhere in the world indicates that competitive ultra-high-speed rail should almost completely displace air transport over the 670km distance between Gauteng and Durban. This phenomenon should have a knock on effect on airport capacity—smaller airports could be provided, or existing ones expanded more slowly, and the saving attributed to rail. Rail links with airports allow international travelers to transfer quickly to domestic destinations. How relevant are existing city-centre stations to the needs of prospective travelers? One needs to recognize a much wider catchment area, and consider service to multiple destinations, which air cannot do.

South Africa needs to develop an understanding of what drives decisions to implement fast rail services in developing economies and, when the time is right, seize the convergence between an advancing opportunity, and its understanding of the drivers of such a decision. Failing to hit that nexus at the right time could jeopardize its competitiveness vis-à-vis its economic peers.

[79] Gross National Incomes in USD per capita for 2007 are: Argentina 5818, Russia 5780, Turkey 5400, South Africa 4708, Brazil 3261, Morocco 1916, China 1696, and India 798.

5.5.1.4 The Gauteng-Cape Town Primary Corridor

The Johannesburg-Cape Town rail distance is 1519km. From §2.1.3.1, a fair amount of the route has relatively large-radius curves, so re-aligning for ultra-high-speed trains would be relatively easy over these portions. The remainder is topographically easy, except the portion through the mountains that barricade Cape Town from the northeast to the Indian Ocean. An ultra-high-speed train on standard gauge with a 360km/h maximum speed would give a running time of 6 hours. Several questions arise:

- Allowing, say, three hours for transit at the ends and stops en route, would a door-to-door journey time by rail of around 9 hours compete with air?
- The route is largely single-tracked, and it is also likely to carry some freight traffic. Would passenger traffic be sufficient to justify adding a second line?
- While large sections of the existing alignment could be re-aligned for ultra-high-speed, would it be workable to do so under normal traffic, or would it be necessary to build a completely new line[80] (generally near the existing line to minimize environmental impact)?
- If freight trains had to share the route with ultra-high-speed passenger trains, to help cover the cost of reconstruction or upgrading, would the resulting operation be safe?
- Would interoperability considerations require retention of the existing line for narrow gauge freight trains to access the Western Cape[81], and would such a scenario be workable?

Now that the infrastructure and performance attributes of the various contemporary train types have been specified in §4.3, it could be insightful to undertake a desk study on the modalities of changing gauge and increasing line speed to Cape Town. Noting the outcome in respect to Gauteng-Durban, one may well find that the notion fades away.

5.5.1.5 Durban-Mthatha/East London/Port Elizabeth-Cape Town

This route is one of the primary High Priority Intra Provincial Corridors (South African Rail, undated). Its rail presence, the so-called Cape-Natal Railway, never fully materialized—the Mthatha-Kokstad portion is missing to this day. Rail is at a serious disadvantage to competitors on this route. Its infrastructure is longest by far[82], and passes through uninterrupted rugged terrain. Existing portions, constructed in the early 1900s, are steep (2½-3%) and curvy (limited to 30-60km/h), which relegates average speed to the same league as maritime transport. East-west road freight is generally of diverse origin-destination and lading, and of high value, so one should expect it to remain on the N2 route. Containers and liquid fuel typically move by sea. Given rail's disadvantages in

[80] The recently opened high-speed double line from Ankara to Eskisehir in Turkey was built close to the existing single-track line.

[81] Noting that the Sishen-Saldanha line is currently being extensively upgraded to raise capacity, it is likely to remain on narrow gauge for a generation or more. It could provide narrow gauge access into the Western Cape via the Saldanha-Kalbaskraal-Kraaifontein line.

[82] Rail 2431km, road 1755km, sea 1586km, air 1342km.

terms of distance and transit time, it is unlikely to capture traffic currently on sea. Thus, if the route supports rail at all, it remains beholden to passenger trains.

Noting the existence of a proposal for a Mthatha-Port Elizabeth High-speed Link in §5.5.4, this section concerns the remaining portion. For passenger trains, the most workable option would be to dedicate the line from Cape Town to George to passenger trains only, following the Mthatha-Port Elizabeth model, and recycling infrastructure by:

- Redeveloping old branch line alignments by steepening gradients and easing curves for passenger-only operation,
- Re-gauging track to standard gauge,
- Dual-gauging if and where necessary, and
- Raising maximum speed, to 200km/h, possibly with tilting trains, to achieve a four-hour Cape Town-George journey time.

As in the case of Mthatha-Port Elizabeth, it could be worth constructing a new link of some 45km from Protem (an offshoot of the Eerste River-Bredasdorp branch) to Swellendam (on the Worcester-George line). This would avoid the detour through Tulbagh Kloof, and revitalize the moribund railway through the touristy areas of Sir Lowry's Pass, Elgin, and the Overberg, before joining the Worcester-George line at Swellendam. Total estimated Cape Town-George distance would be 520km (slightly shorter than the estimated 590km for Mthatha-Port Elizabeth. The route is curvy, except for 15km near straight between Albertinia and the aptly-named Reisiesbaan station.

George-Port Elizabeth by rail is 516km, inland through mountainous terrain, against 343km on the N2 road. High-speed rail over that distance could not beat a bus or car at normal speed on a good road, so it seems pointless to contemplate improving passenger rail on that sector.

Note that this rail proposal runs parallel to the N2 road, and that airlines do the George-Cape Town flight inside an hour. Stakeholders should recognize that passenger rail would be severely challenged to come up with a winning solution. If it cannot rise to that challenge, rail service in that corridor is likely to become extinct.

5.5.1.6 The eThekwini North-South Corridor

eThekwini is remarkably compact by comparison with South Africa's other conurbations with urban rail. Taking the Priority A corridors from the SARCC National Railplan Consolidated Report, it is evident that the Umlazi-CBD and Kwa Mashu-CBD routes are within ideal metro distance of 25-35km. Journey time at an average speed of 45km/h should be acceptable at 40 minutes.

Noting from §5.3.2.4 that contemporary metro can raise capacity by a factor of three or more compared to existing systems, it should be possible to extract substantially more capacity from existing right of way, provided that signalling can support the requisite short headway. This should accommodate growth on existing corridors, or support extension of service to wider catchment areas without requiring additional tracks as the common route approaches the CBD.

It is noted that there is concern regarding high passenger density and its associated risk in incidents and accidents. This could also contribute to capacity per train being somewhat lower than in several other countries. When re-signalling a metro route for higher capacity with matching new rolling stock, the incremental cost, if any, for ATP is likely to be much less than sacrificing passenger capacity to mitigate risk. A recommendation is made in this regard (see §6.2.4).

Services further north and south pose an interesting challenge. Stanger and Kelso are approximately 65km from the CBD, so contemporary metro trains, for a journey time of 1½ hours, would be unacceptably slow. The routes are low priority, so it would be difficult to make a case for standard gauge track to raise speed. TFR may one day re-gauge the North Coast line to Richards Bay, and commuter services could presumably share the facility. However, a re-gauged South Coast line is a remote possibility. Arguably, the most rational solution would be re-gearing a portion of a new, contemporary narrow gauge metro fleet for 130km/h maximum speed, for North- and South Coast regional services. Such trains would be able to interoperate with normal metro stock, at the same speed, on lines signaled for high capacity with relatively minor disruption. Of course, some infrastructure work would be required for 130km/h running outside the metro area.

5.5.1.7 Gauteng-Bloemfontein

The rail distance from Johannesburg to Bloemfontein is 405km. Using existing infrastructure and rolling stock, the best timing one could expect is 6-6½ hours. The best Shosholoza Meyl schedules are in this range, some extending to around 7 hours, depending on number of stops. Any delays, or allowance for delays, would lengthen the schedule. Any material improvement would require a different rail technology solution, as explained below.

The Johannesburg-Vereeniging-Kroonstad section has many curves in the 700-849m bracket, rated by TFR for 90km/h. South of Kroonstad the situation improves slightly over the following sections.

o	Bosrand-Eensgevonden	205km
o	Houtenbeck-Bloemfontein	68km
o	**Total**	**273km**

These sections would be good for up to 130km/h on the existing 1067mm track gauge, if appropriately maintained. Note that the curves within the abovementioned sections are not all suitable for higher speeds: It was assumed that any general speed increase would require re-alignment of several isolated[83] low-speed curves, to obtain clear high-speed runs over meaningful distances.

However, if re-gauged to standard gauge, the 1250-1450m radius curves in the abovementioned sections would still only be good for around 140km/h, which would not provide decisive advantage over 1067mm track gauge. Raising speed to 140km/h where

[83] Although isolated, they are generally low-speed because a relatively small radius was used to negotiate natural obstacles such as water courses and water sheds. Realigning them may be expensive.

possible would reduce the journey time by almost 1½ hour, to 4½-5 hours, which is unlikely to change rail's competitive ranking relative to air or road.

It is therefore evident that the legacy curve radii on this route cannot support sufficient benefit to justify simply changing to standard gauge track. For rail to improve its competitive position, it needs to run at substantially higher speed than at present. This would require increasing curve radii to match the maximum speed envisaged (entry level 160km/h, possibly 200km/h). This would in turn involve substantial deviation works, in addition to the cost of changing to standard gauge (or to dual gauge). By the same reasoning, retaining narrow gauge but increasing curve radii for 130km/h would also involve substantial capital expenditure without materially increasing rail's competitive position.

To exploit the speed potential of standard gauge track, consider the scenario of constructing a new standard gauge route[84], with appropriate curve radii, to extend the Gauteng Regional Rail scenario in §5.5.1.2 southwards to Bloemfontein, as shown on the map below. Johannesburg-Vereeniging would take 37 minutes: At the same average

speed, the remaining distance to Bloemfontein could take 3 hours. At 200km/h maximum speed, Johannesburg-Bloemfontein would be possible in three hours; at 160km/h maximum speed, it would take around 3½ hours. Such timings could induce the

[84] The synergy between passenger traffic and TFR on the Johannesburg-Bloemfontein route might be limited, unless it also found a need for standard gauge. The 1% ruling gradient is among TFR's flattest on its core network, so it is unlikely to need a new alignment to flatten gradients. One reason it might need standard gauge is if it developed substantial container traffic, and wanted to implement double stacking.

modal shift to rail that government seeks, from both road and air. Concurrently, it would stimulate wider benefits such as agglomeration effects, reduced greenhouse gas emissions, increased accessibility for peripheral regions; and for road, reduced congestion, and increased safety. One can even conceive of extending the standard gauge route to Thaba Nchu, 65km from Bloemfontein, possibly by dual gauging a portion of the existing line eastwards to Maseru and Modderpoort.

Note that the existing Gauteng-Bloemfontein route is double tracked. Instead of constructing a new route, and depending on relative freight- and passenger capacity requirements, it may be feasible to convert it to two single tracks—one would remain narrow gauge, the other would be converted to standard gauge. Curve radii would be increased as appropriate on the standard gauge line. This option could minimize environmental impact and construction costs, and leverage value from TFR's reputed underutilized capacity.

Overall, this scenario could extend benefits of rail access to several corridors and municipalities on PRASA's high-priority list. In the light of the questions raised in §5.5.1.4, the scenario in this section may also represent a sensible intermediate stage for the Gauteng-Bloemfontein-Cape Town Primary Corridor, at least with contemporary passenger rail technology.

5.5.1.8 Gauteng-eThekwini via the Coal Line

One could view a possible Gauteng-eThekwini-via-the-Coal-Line route in the context of PRASA's Gauteng-Witbank-Richards Bay and Durban-Richards Bay-Nelspruit Primary Corridors. It would be valuable if one could find synergy with existing Coal Line infrastructure.

The 247km section Johannesburg-Ermelo via Trichardt, to connect with the northern end of the Coal Line, traverses relatively easy terrain, on single track beyond Springs. Existing alignment, if appropriately maintained, would be good for the current maximum passenger train speed of 90km/h: Noting that it carries substantial coal traffic, there would likely be contention for capacity. Simple conversion to standard gauge, or dual gauging to coexist with TFR, is likely to yield the same outcome as the existing Johannesburg-Bloemfontein route discussed above, namely it would not yield meaningful reduction in running time. Easing curves to increase speed would add substantial cost.

The 412km Coal Line, from Ermelo to Richards Bay was commissioned in 1976, and substantially upgraded in the mid 1980s. It is therefore features South Africa's most modern alignment. Its design parameters were optimized for exporting coal through rugged terrain: They resulted in a line with many curves of relatively small-radius. Aside from the 98km section between Ermelo and Piet Retief, which has curve radii in the 1000-2000m range, the remainder has many curves in the 600-800m range, the smallest radius being 503m. The line speed is therefore 80km/h, and the curves are superelevated accordingly. The integration of the infrastructure and trains is thus perfectly suited to its intended heavy haul purpose. However, from a passenger service perspective, there would be no advantage in using that route as is. Even re-gauging to standard gauge would not materially change the inherent constraint imposed by its relatively small radius curves.

The Coal Line illustrates the principle that optimum design of guided transport systems, such as railways, requires close alignment of infrastructure- and rolling stock characteristics with their intended purpose. Except in nearly flat terrain with no natural obstacles, it is as impractical to operate high-speed trains on heavy haul infrastructure as it is to operate heavy haul trains on high-speed infrastructure.

The 195km section Empangeni to Durban is riddled with small–radius curves limited to 50-, 60-, or 70km/h. In its present form, it does not offer significant passenger service potential.

Although the overall Johannesburg-Ermelo-Durban route option is only some 130km longer than the direct route via Newcastle, on existing infrastructure it simply adds distance, without contributing higher speed potential in return. Without upgrading for higher speed, it therefore cannot contribute usefully to passenger service aspirations. Noting the prevailing rugged terrain, all the way from Piet Retief to Durban, acceleration of passenger train schedules would require substantial investment in new infrastructure. In that context, any proposal would need to be evaluated against other options.

The following scenario could be one such option. A combination of ultra-high-speed service in the Johannesburg-Durban corridor, plus good regional services radiating from Johannesburg (among other to Witbank and Nelspruit), and from Durban (among other to Richards Bay) could conceivably concentrate demand sufficiently to justify hub-and-spoke rail linkages, rather than dilute the demand on more direct but more dispersed corridors, which individually could not support the requisite investment. This scenario should be explored further within the NATMAP process.

5.5.1.9 Learning from the routes selected

The seven routes or scenarios selected in §5.5.1 have a common thread: They illustrate possible outcomes of overlaying contemporary passenger railway technology on portions of South Africa. By comparison with the legacy passenger rail system, both the socio-economic challenges and the technological solutions are now vastly different. When integrated with all other possible challenges and routes, the future national mass mobility solution is likely to be a new departure, rather than an extension of anything from the past. Contemporary passenger rail technology offers competitive rail positioning that addresses different opportunities, which must therefore lead to different outcomes.

5.5.2 PRASA plans

5.5.2.1 General comments

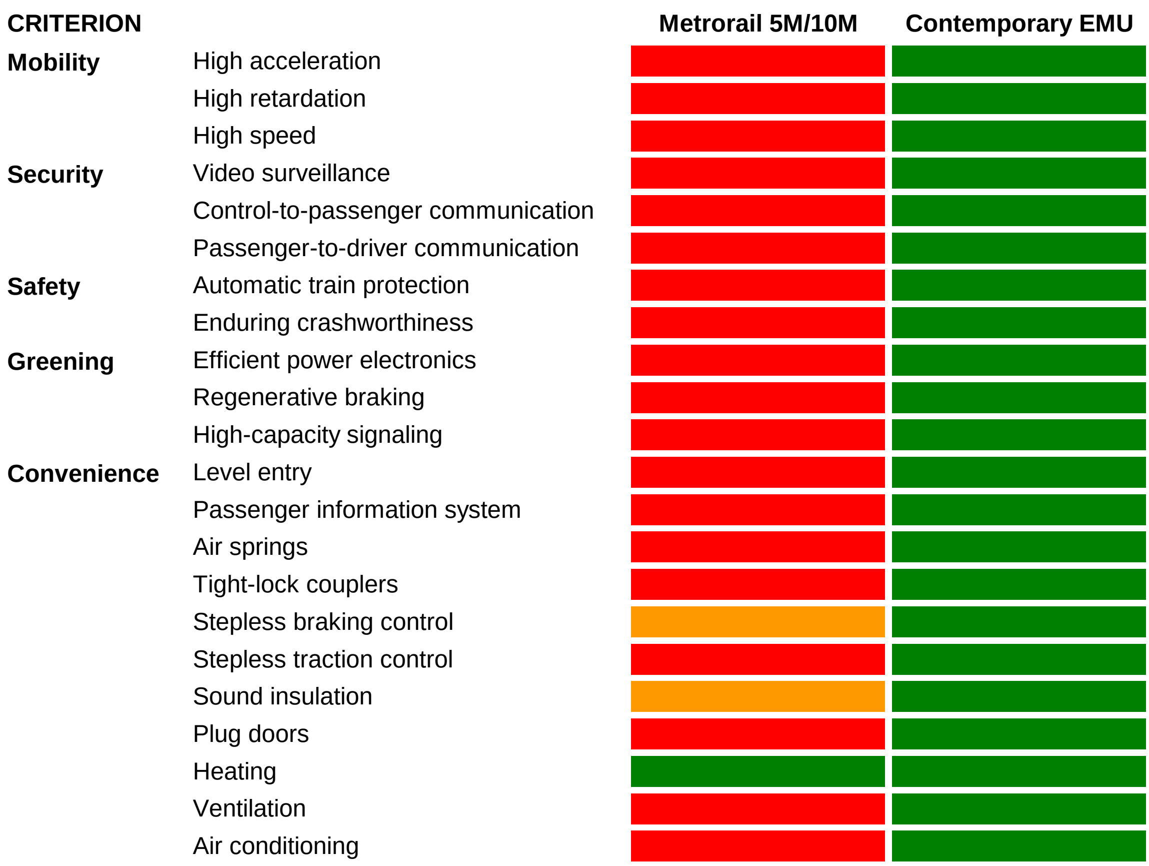
For the purpose of the following comments and discussion, the Consultant has perused the SARCC documents *National Railplan Consolidated Report* of August 2006, the *Business Plan 2008/09*, and the undated PowerPoint presentation *Rail Revitalization in Rural and Intercity Context*. The planning methodology and process is considered fair, sincere, rational, professional, and diligent. The treatment of PRASA’s strategic direction will therefore be cast in terms of §4 of this report, i.e. from a passenger rail technology perspective only. If comment is necessary, it is couched constructively.

No technology migration plan is implicit in the Business Plan. It appears that existing SARCC plans and strategic direction rest on extension and replication of existing technology. They do not open up migration paths to implement options from the menu of contemporary passenger rail solutions. While perusal of the document thus far should also lead to that conclusion, a few key insights are lifted out before moving on to recommendations.

5.5.2.2 Rolling stock implicit in plans

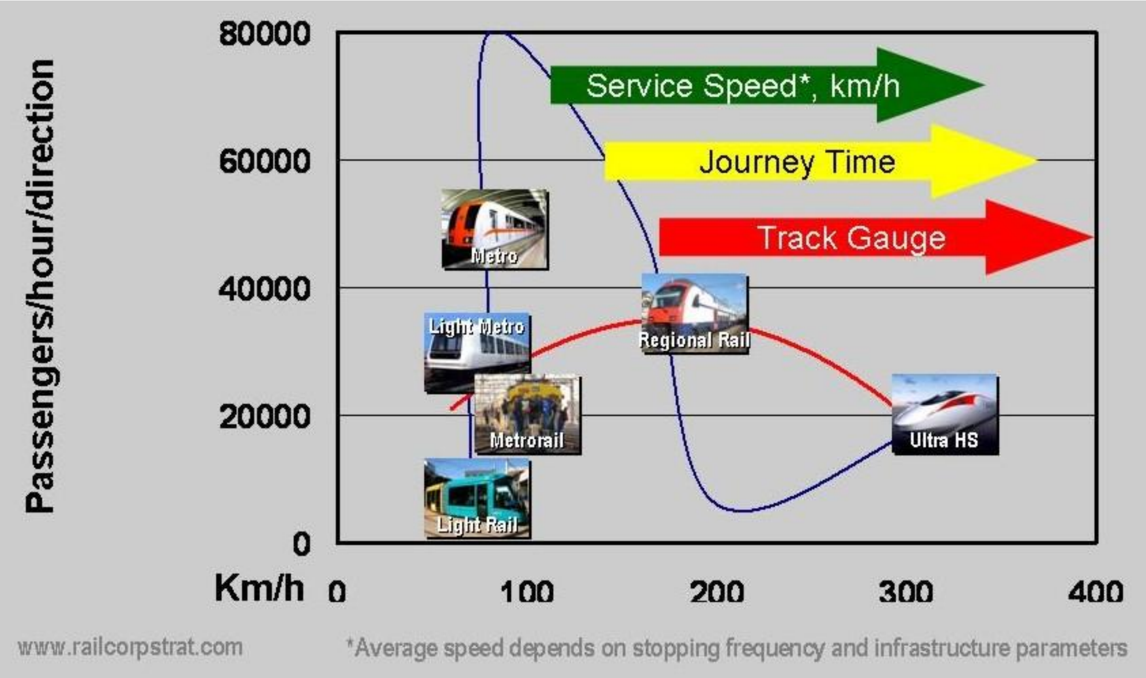
While Metrorail rolling stock has been upgraded in recent years, it nevertheless remains based on a fundamentally old design, which has inevitably imposed limitations. The following comparative diagram gives the requisite insight into the rolling stock implicit in existing SARCC plans.

It is evident that a shift to contemporary passenger stock would be appropriate. Note that no mention is made of Shosholoza Meyl stock. It would fare the same under a similar comparison. However, it is so far removed from contemporary regional and high-speed trains that a comparison will serve no purpose. It is best kept on a run-out basis (see §6.6.2).



5.5.2.3 Rolling stock options

The diagram below shows only the steel-wheel-on-steel rail contenders. Rubber-wheel contenders have been omitted, because the diagram becomes too crowded in the low speed /low capacity corner. That is a good sign of intense competition in the light mass mobility segment, so they obviously should also be considered. A recommendation is made in this regard (see §6.2.6).



The Figure shows the positioning of existing 5M/10M stock relative to contemporary rail technology mainstream solutions. Note that, for positioning purposes, there is no difference between 5M and 10M. In terms of capacity, both higher and lower rated solutions are available. In terms of speed, both higher and lower rated solutions are also available. System integrators have differentiated their offerings to maximize their competitiveness in particular market spaces. The 5M/10M solution is under attack from all directions, as follows:

- For lower capacity and lower speed, light rail would do a creditable job. However, if the only choice is between road solutions and 5M/10M, the decision may go in favour of bus, or even BRT, without giving the greener and more developmentally formative light rail a showing.

- For higher capacity and lower speed, light metro or metro would do a creditable job. However, if the only choice is between alternative spatial development and a maxed-out 5M/10M solution, the decision may go in favour of alternative development, without giving the greener and more capable high capacity rail solutions a showing.

- For higher speed and moderate capacity, regional rail would do a creditable job. However, if the only choice is between a 5M/10M solution and road, the default decision goes in favour of the urban sprawl that road supports so well, without giving the greener and more developmentally formative regional rail a showing.

- For ultra-high-speed and moderate capacity, current narrow gauge rail, whether 5M/10M or Shosholoza Meyl, is not in the running at all.

Applicable national development outcomes thus take on a *minus rail* colour: Regarding the competitiveness of nations, this can only disadvantage South Africa.

In terms of the systems approach, whatever the rules of the game (in the case of organismic adaptation) or the rules of engagement (in the case of socio-cultural adaptation), a solution will emerge, but it could bring unintended consequences with it. Not permitting and encouraging the best solution to emerge must compromise sustainability, whether environmental, economic, or social.

5.5.2.4 Rural Rail Plan

While SARCC Business Plan 2008/09 refers to a Rural Rail Plan[85], it is understood to not yet be complete. The following comments are thus based on fragmented but coherent information. Branch lines do not currently enjoy passenger service. Indeed, they were the first to lose passenger service as rail's competitiveness declined, and the relative competitiveness of other modes ascended. Branch lines were therefore not addressed under status quo in §2, but rather as a distinct issue in this Section.

Branch lines were generally not upgraded[86], as were main lines, in the first half of the previous century. They therefore generally follow contour routes to minimize earthworks. Small-radius curves abound, so route distances are significantly longer than road, more than 50% in some instances. Gradients are steep, and light-axle-load branch line diesel locomotives have small engines, so balancing speeds are low. Overall, performance is way behind any other motorized transport mode. Therefore, the demise of branch lines, other than those that carry heavy traffic (e.g. Steelpoort-Belfast), should come as no surprise.

The flagship Kei Rail project is the only current South African example of branch line revitalization. Whilst attractively refurbished rolling stock is used, the branch line basics remain. Maximum speeds are Amabele-Komga 50km/h, Komga Butterworth 30km/h, Butterworth- Mthatha 40km/h. Average speed, excluding stops, is ≈33km/h (Spoornet, 2005). Eastern Cape Province is leading the project aggressively, which may in time prove to be the only way to revitalize a branch line. They appear to require a subsidy from provincial government, or other public entity with an appetite for such support. In this respect, Kei Rail is comparable to many United States short lines. They also receive subvention from local authorities, dependent customers, or whoever else has an interest in keeping them open.

The alternative, concessioning, frequently leads to asset stripping. This is also unsurprising, because if there is insufficient revenue, a concessionaire is left with no option but to strip what it can.

From a passenger rail technology perspective, neither subvention nor concessioning normally or readily support new or upgraded technology. Branch line operators tend to make do with whatever used equipment they can afford.

[85] Page 8.

[86] There are exceptions, such as Belfast-Steelpoort, which was re-railed for heavy traffic. However, the alignment is still original.

6 Recommendations

6.1 General approach

6.1.1 Seize the opportunity

It is important to recognize that the present passenger rail technology backlog in South Africa offers a huge opportunity for implementation of contemporary passenger rail solutions. There has been little irreversible commitment to new systems in recent times, hence the way is open to recommend and to implement global good or best practice.

The course of the study to this point suggests that recommendations should follow a top-down approach, recognizing capacity and associated investment drivers. Recalling that systems are hierarchical, stakeholders should get the passenger mass transport vision and backbone system concept right, then add lower level sub-systems: Intercity and metro first, then light rail and regional rail, and ultimately buses and taxis.

The Consultant recognizes that the Client has already undertaken substantial investigation and planning of aspects that relate to, and possibly overlap, some of the recommendations below. They do not claim to be an alternative, but rather offer a framework within which to flesh out the passenger rail technology aspects of previous work.

6.1.2 Make opening moves

Existing Metrorail rolling stock is not far off global standards in terms of basic dimensions. System integrators are geared to accommodate variants, and car bodies to the South African height and width could be readily sourced. Narrow gauge bogies also exist, and accommodating adequate traction motors is not a challenge. Other major subsystems, such as control, propulsion, suspension, braking, coupling, communication, heating ventilation and air conditioning, doors, safety and security, and many other minor sub-systems, do not depend on track gauge or vehicle profile, and are available in a competitive global market. South Africa's 3kV dc is not unique, and could provide an acceptable traction power supply, at least in the early stages of new investment, although it is not a global standard.

- ***Recommendation 1: Proceed confidently to acquire state-of-the-art steel-wheel-on-steel-rail metro rolling stock, as and when funds become available. If it does not exist, draw up a performance specification. If one does exist, update it in the light of the recommendations that follow.***
- ***Recommendation 2: Compile the performance specification to allow the greatest possible freedom regarding non-critical requirements, to allow system integrators the greatest possible freedom to re-use existing solutions.***
- ***Recommendation 3: Contemporary metro rolling stock requires matched signalling to ensure high performance and minimum equipment for a given capacity: Synchronize rolling stock acquisition with implementation of complementary signalling, probably on a route-by-route basis.***

6.2 Address passenger rail technology issues

6.2.1 Migrate to standard gauge

Cities and countries around the world are increasingly basing mass mobility on integrated transport solutions built on a rail foundation. Since economic globalization started in the 1990s, not one such initiative has rested on narrow gauge. Standard track gauge, and all the technical parameters that associate with it, have become the entry ticket. South Africa is unlikely to join that league if it does not play by the same rules.

- ***Recommendation 4: Use standard gauge track for all new integrated infrastructure-plus-rolling-stock projects, even if they initially stand alone.***
- ***Recommendation 5: Support piecemeal migration by segmenting operations, where workable, to create opportunities to plant standard gauge when rolling stock is renewed.***

6.2.2 Rationalize vehicle profile and platform height

South Africa's present vehicle gauge is not much smaller than many standard gauge profiles, but it does not comply with any particular internationally recognized standard. Where track might be changed to standard gauge, non-preferred or non-standard vehicle profiles would come at a price premium. There is also no point in making the best of a bad job by moving to a different position on the constraint map.

As opportunities arise for implementation of new rail passenger technology solutions, consideration should be given to wider, more energy efficient, lower cost, single- and double decker vehicles, both in regional and interurban applications. The non-interoperability between Gautrain and Moloto Rail should also not be repeated.

Platform heights should also be addressed, to resolve differences between metro-, regional-, and intercity applications. They should recognize universal access/handicap access requirements, as well as level-entry requirements for high-capacity systems.

It is recognized that there is no quick fix, but countries and regions that have successfully tackled their railway vehicle size issues have done so progressively. The following recommendations also present an opportunity to align with global best practice.

- ***Recommendation 6: Allow a sufficiently large vehicle profile for all inherently competitive railway applications. In the case of passenger routes, accommodate double deck coaches and full-width bodies.***
- ***Recommendation 7: Determine a platform height, or heights, which optimizes allowable vehicle width for regional and intercity applications.***
- ***Recommendation 8: Determine a platform height that will support level entry for urban rail applications (Metro, and if applicable, Light Metro).***

- ***Recommendation 9: Determine an optimum, possibly internationally recognized, vehicle profile for implementation of new passenger railway technology in South Africa, with due regard for its small leverage in the global market.***
- ***Recommendation 10: Provide non-opening, restricted-opening, or emergency-opening windows, if and when necessary on wider vehicles, to keep heads and limbs inside, and provide air conditioning to control climate.***
- ***Recommendation 11: Recognize that TFR could also have an interest in a larger vehicle profile, and secure whatever synergy is workable.***
- ***Recommendation 12: Clear any routes or tracks that are re-gauged or dual-gauged to standard gauge simultaneously for vehicle profiles per Recommendation 6.***

6.2.3 Set aside selected interoperability requirements

Noting that it is unrealistic to change South Africa's entire passenger rail system in a single intervention, the pragmatic alternative is to do it piecemeal. It is therefore necessary to open interaction among the various railway systems and sub-systems, and their operational and technological environments, to elevate and to enlarge the overall system, to admit all stakeholders, including system integrators, and to loosen interaction among them. Note also that the SARCC Rail Plan Consolidated Report[87] raises the issue of complexity of the network, e.g. Wits and Western Cape: Segmenting subsystems is a useful way of reducing complexity by easing interoperability constraints.

- ***Recommendation 13: Set aside interoperability requirements in situations where they impede implementation of new rail technologies and migration to competitive contemporary passenger rail solutions. If this recommendation is not implemented, meaningful renewal and upgrading will not be possible.***

6.2.4 Implement automatic train protection

The Client gives safety a high priority. Existing systems of train control and operator compliance with movement and speed authorities have lagged behind global good practice in the same way as the more visible aspects of passenger rail technology. When re-signalling a metro route for higher capacity with matching new rolling stock, or re-signalling lines to support higher speed services, the incremental cost, if any, for ATP is likely to be small.

- ***Recommendation 14: Equip all new matched infrastructure-and-rolling-stock applications with automatic train protection to give peace of mind, increase performance, and eliminate senseless***

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[87] Page 4.

damage to property, and injury or death to passengers, public, and employees.

6.2.5 Evaluate automatic train operation

If one accepts the need for automatic train protection and video surveillance, and notes the sophisticated control technology that comes with contemporary multiple unit metro sets, the incremental complexity and cost to advance to automatic train operation is relatively small. Furthermore, train driving is not a popular occupation, particularly with respect to working shifts to cover morning and afternoon urban rail demand peaks. The ability and cost of operators being able to offer service in sparsely used times at night depends on being able to schedule train drivers. If necessary, people employed in the driving task could be redeployed to provide passenger care, a function envisaged in SARCC's Business Plan 2008/09.

- ***Recommendation 15: Investigate and develop a position on automatic train operation for metro (and possibly Light Metro) services, with due regard to overall utility and value of the rail system to its community, and incremental cost of providing it on all new matched infrastructure-and-rolling-stock applications.***

6.2.6 Examine rubber-tyred solutions

Rubber-tyred guided mass mobility solutions have not yet emerged in South Africa. They appear to have potential in the market space between buses and metro. Noting that several urban commuter corridors in offer more traffic than buses should handle, but less than can support current Metrorail service, there appears to space for such solutions.

- ***Recommendation 16: Assess the capability and cost-effectiveness of Automated Light Metro (VAL) in selected corridors that where demand would marginally justify Metrorail service by current criteria.***
- ***Recommendation 17: Examine how Automated Light Metro will be institutionally recognized, and how that recognition might influence its evaluation with respect to alternative modes such as BRT and Light Metro.***

6.3 Segment and focus

6.3.1 Create space

To create space within which to introduce and nurture contemporary passenger rail solutions, it is appropriate to segment the passenger rail network into standalone sub-networks, as far as is reasonably practical, and with due regard to the many sensitivities that such an intervention will touch. Any greenfields routes would greatly facilitate such an intervention.

Such space can only be institutionally created, to allow stakeholders to create a shared vision and then get on with implementing it. From an open, socio-cultural systems perspective, one cannot determine the ultimate outcome up front. However, it will be robust and satisfying.

6.3.2 Physically separate metro and mainline operations

The first objective is to physically separate metro from other passenger services[88], and from freight services. This is indeed envisioned in TFR's National Infrastructure Plan, but it should also envision mutual exclusivity. That is, TFR would allow metro operations their own space, but equally there should be no access by TFR to metro operations[89]. This arrangement would reduce network complexity, and allow each operator to dedicate its infrastructure and rolling stock to best advantage.

- ***Recommendation 18: Work toward, by identification of existing exceptions, and timetabled plans to eliminate them, consummation of the existing intent to separate physically metro and mainline operations, to allow planning for future metro investment to maximize its value.***

6.3.3 Share freight and passenger corridors

Dedicated freight and passenger rail corridors are ideal, but they are probably largely out of reach in South Africa in the short- to medium term. This means that all passenger rail applications outside metro (as addressed in §6.3.2), i.e. Shosholoza Meyl at present, and any regional- and intercity applications that may develop in future, will need to coexist with TFR. However, freight rail in general (and there are exceptions) is not well positioned against its natural competitor, road transport. TFR's ability to collaborate on future long distance passenger rail technology applications thus rests on fragile freight rail positioning.

- ***Recommendation 19: Analyze possible areas of synergy, and contention, between legacy long-distance infrastructure (currently TFR and a few PRASA assets) and possible future passenger operations that should ideally exploit advanced railway technology, including standard gauge track. Do this on a route-by-route basis.***
- ***Recommendation 20: Assess the viability and stability of TFR's strategic future, by way of a study similar to the present study, to develop an appreciation of whether its sustainability might influence routes and shared infrastructure of interest to regional and intercity passenger services.***

6.3.4 Align capacity and signalling

Contemporary signalling or train control needs to be aligned with rolling stock characteristics, separately for metro and mainline applications, to optimize the tradeoff between speed and headway, capacity and running time.

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[88] The institutional linkage between metro- and other passenger services (note lower case names) is recognized and respected. The intent of the recommendation is to create an environment that is not confounded by interoperability issues, but which can focus on moving forward to optimize the match between passenger requirements and rail technologies that best support them.

[89] This could affect existing TFR customers served via lines owned by SARCC.

- ***Recommendation 21: Examine the interaction between contemporary metro rolling stock performance, and appropriate signalling upgrade or renewal for local conditions, and develop a high-level system specification for expected throughput performance.***
- ***Recommendation 22: Examine the interaction between contemporary regional- and high-speed rolling stock performance, and possible train authorization system upgrades or overlays on mainline routes, and develop a high-level system specification for expected performance on standard-gauged or dual-gauged track.***

6.4 Develop metro infrastructure-and-rolling-stock prototype

On several, perhaps many, metro corridors, it is likely that at least one generation of new contemporary rolling stock will reach the end of its working life before the track gauge issue becomes pressing. It is however important not to dilute and obscure potential benefits by introducing new rolling stock into an environment where its performance, reliability, and maintainability benefits cannot be exploited and measured (or will be handicapped and dissipated).

- ***Recommendation 23: Select one route as a new-technology prototype for early full infrastructure and rolling stock upgrade. Learn and debug in preparation for rollout to other routes.***

6.5 Rationalize special trackwork

Many crossovers in metro areas result from overlaying freight service on a passenger network. Clearance for TFR vehicles precludes modifying crossings for higher speed. Physically separating metro from other services will allow removal of these impediments.

- ***Recommendation 24: Determine which crossovers are required for passenger service, and retain them. Remove those that are required for freight purposes to reduce maintenance.***
- ***Recommendation 25: Raise guard rails to increase speed from 30km/h to 60km/h through crossings. Prohibit access by TFR rolling stock.***

6.6 Re-brand passenger rail services

6.6.1 Segment Metrorail

At least two segments with potential tighter focus are present within existing Metrorail. They are Metrorail's interpretation of metro, comprising services into city centers over distances that would suit contemporary metro, namely 25-35km. Then there are services more akin to regional rail over longer distances, for example between Johannesburg and Pretoria or Vereeniging. Type 5M/10M trains currently work both segments, but satisfy neither by comparison with contemporary rolling stock solutions.

- ***Recommendation 26: Create new sub-brands within PRASA, to reflect the focused mass mobility solutions that contemporary rolling stock will ultimately support when it becomes available.***

- ***Recommendation 27: Identify routes, corridors, operations, whatever, that one can conceptually separate now for purposes of planning new or upgraded technology, with a view to operational separation when contemporary rolling stock becomes available.***

- ***Recommendation 28: Prioritize renewal/upgrade projects identified in terms of Recommendation 27, with a view to shifting shorter routes to true metro, and shifting longer routes to regional rail, each with its own rolling stock and, to the extent workable, its own infrastructure.***

6.6.2 Segment Shosholoza Meyl

At least two segments with potentially tighter focus are present within the existing Shosholoza Meyl. One is its traditional long-distance services from Johannesburg to the coastal cities. The other is what one could consider regional rail services to Polokwane-Musina and Nelspruit-Komatipoort (and probably additional destinations in future). EMU or DMU sets similar to Metrorail's notional "regional" services to Pretoria and Vereeniging could ultimately work the latter, particularly if standard gauge track eventually becomes available. See recommendation 31 regarding the remaining segment.

- ***Recommendation 29: Segment Shosholoza Meyl into medium-distance and long-distance services.***
- ***Recommendation 30: Focus on opportunities to implement contemporary rail solutions, not on existing rolling stock. The medium-distance segment within Shosholoza Meyl would align with, and ultimately integrate into, the similar Metrorail segment, to deliver regional rail services.***
- ***Recommendation 31: Recognize that Shosholoza Meyl's long-distance segment does not align with any contemporary rail solution, and that its long-term sustainability could be problematic.***

6.6.3 Re-deploy 5M/10M rolling stock

Unless dedicated standard gauge regional networks are viable, and some could be viable, it will likely be several years before TFR comes round to changing track gauge to standard.

- ***Recommendation 32: Noting that it seems likely that new metro stock will be the first contemporary rail solution in South Africa, as it displaces existing Metrorail rolling stock, and to the extent that a surplus develops, 10Ms and surviving 5Ms could be deployed on the 3kV dc routes radiating out from most cities.***

This could create a first round of regional services, to be followed up by high-performance regional trains, preferably on standard gauge.

6.7 Inform policy formulation

6.7.1 Ensure unobstructed migration paths

It should be evident from the preceding portion of this study that narrow gauge railways are out of the global mainstream, and that indulging interests that wish to preserve the track gauge status quo imposes a price premium on new rolling stock now and marginalizes narrow gauge railways into the future. However, without dealing with the interoperability issue, there can be no change. The debate around interoperability with the legacy systems versus the opportunity cost of not making a clean break needs resolution as follows:

- ***Recommendation 33: Recognize that unfounded interoperability requirements[90] may impede progress toward implementing contemporary rail solutions—consider all situations where interoperability is unavoidable, and determine the minimum set of interoperability requirements[91] for each.***
- ***Recommendation 34: In situations where interoperability appears unavoidable, but has potential to obstruct implementation of contemporary rail solutions, seek means to mitigate the problem rather than use it as a barrier to progress.***
- ***Recommendation 35: Recognize that interoperability for the sake of convenience[92], may need to be foregone in some situations to achieve overall optimization of a particular geographic mass mobility system.***
- ***Recommendation 36: Recognize that a physical connection among standard gauge systems would be advantageous, to reallocate resources if and when demand changes between cities or regions[93]. However, recognize also that unless and until that happens in the course of natural development, road transfer is possible, as in the case of cars for Gautrain.***

6.7.2 Maximize contribution by local industry

Globalization of the railway industry suggests the following strategy to extract maximum local value for South Africa:

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[90] For example, between light rail and freight, metro and freight, regional rail and metro, and possibly others.

[91] For example, tram-train could require standard gauge track and 25kV ac electrification, but not AAR couplers and -end strength.

[92] For example, to avoid changing trains at an intermediate interchange stations.

[93] At least one common node would be ideal—somewhere in Gauteng seems a natural place.

- ***Recommendation 37: Grow the size of the railway footprint on South Africa, to maximize the shift from road to rail where that is economically justified,***

- ***Recommendation 38: Trade off purchase price against extent of expansion or renewal for a given quantum of funding to best advantage.***
- ***Recommendation 39: Identify local opportunities to maximize added value, in construction, management, operations and maintenance, information technology, legal services, and so on,***
- ***Recommendation 40: Avoid becoming locked into suppliers that have been attracted into the market, and eventually becoming responsible for them, and***
- ***Recommendation 41: Recognize the need for rolling stock fleet scalability[94], i.e. the ability to acquire small incremental quantities for the vehicle fleet. This requires a trade off between commitment to local manufacture and the flexibility to acquire from the global market, by purchase or lease, new or second hand.***

6.7.3 Establish appropriate standards

This study has described a wide range of generic rail solutions, to give broad insight into the state of the industry. However, South Africa should be wary of importing a miscellany of standards and/or technologies. For example, Gautrain is being built to UK vehicle profile standards, while Moloto rail could be built to European vehicle profile standards, and they are not interoperable. Regional infrastructure shared between freight and passenger trains might be signaled to North American standards. Each in its own right could be a sound solution, but their integration and interoperation might be a technological challenge.

- ***Recommendation 42: One of the first projects in acquiring contemporary passenger rail solutions for South Africa should be determination of appropriate technical standards.***

6.8 Plan future study phases

6.8.1 Scope

The proposal included the following phases beyond Phase 1, this Framework Report.

6.8.2 Phase 2—Stakeholder workshop

The foregoing material is comprehensive. It touches on several aspects that taken individually may not find immediate acceptance, but which contribute to a robust overall solution. During preparation of this report, the Consultant gathered from stakeholders that there was a need to boost appreciation of what good passenger rail is, what it can do,

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[94] To avoid the New Generation 6M, 7M, 8M, and 9M saga, that eventually came to naught.

and how to do it. To find alignment among stakeholders, it is recommended that they be exposed to dialectical inquiry to ensure that the migration path is socio-culturally acceptable.

It is estimated that preparation for the Stakeholder Workshop, running the workshop itself, and formulation of terms of reference for international consultants thereafter, will require six weeks.

6.8.3 Phase 3a—Selected local case studies

This Phase was addressed by the Railway Gauge Working Group in respect of Gautrain and Moloto Rail, and rounded out in this report in respect of a Mthatha-Port Elizabeth high-speed link, so it can be considered complete.

6.8.4 Phase 3b International—specific questions for international consultants

6.8.4.1 Introduction

Railways in several countries have already implemented one or more of the passenger rail technologies contemplated in this proposal. It would accelerate appreciation of the potential contribution, of appropriate contemporary rail technology, to solutions in South Africa, by acquiring insight into relevant international solutions. This approach would be particularly valuable regarding aspects with which South Africa is unfamiliar, simply because it has not yet had exposure to such rail technology solutions, and therefore has no indigenous real world data on which to base analysis and comparisons.

6.8.4.2 Nature of Phase 3

At this stage, Phase 3b must necessarily be regarded as open-ended until its terms of reference have been completed, and the ensuing contractual arrangements with international-, and possibly local, consultants have been concluded. Actual execution time for Phase 3b will of course depend on the scope of work and the capacity of the consultants engaged to handle it.

6.8.4.3 Methodology

Railway Corporate Strategy CC (RCS) will draw up terms of reference for international consultants to address whatever questions emanate from the Framework Report and the Stakeholder Workshop.

After clarifying the terms of reference with the Client, RCS will liaise with the international consultants for delivery of the work, and with designated NATMAP Consortium members, or other entities designated by the Steering Committee, in respect of contractual- and payment arrangements.

6.8.4.4 Possible questions

The following elementary seed questions remain after this Framework Report, as non-exhaustive suggestions only, of the type of issues to which international consultants could add value. Actual questions would of course follow from execution of Phase 2 of this proposal:

Several of the Recommendations in this Framework Report relate to further work that could be assigned to consultants.

What considerations regarding right-of-way might influence the trade-off among and choice of guided surface transport solutions (acquisition excepted)?

What costing principles and generic details apply to urban rail, regional rail, and high-speed and ultra-high-speed intercity? Are there associations with indicators of economic development?

What economic- and other considerations inform selection at boundaries between guided surface transport system options?

What decision criteria are useful when borderline trade-offs between modes must be made? Are institutional arrangements helpful or a hindrance in achieving robust and expeditious resolution? What adaptation mechanisms support natural progress to the optimum solution?

If South Africa migrated away from the present choice between bus or 5M/10M suburban sets, and Shosholoza Meyl long distance trains, what would be the optimum range of passenger rail applications?

6.8.4.5 Possible routes

The following railway routes are offered, as non-exhaustive suggestions only, of situations in which study by international consultants could add value. Actual routes would of course follow from execution of Phase 1 and Phase 2 of this proposal, as well as direction by the Steering Committee:

KwaZulu Natal: A coastal railway northwards and southwards of eThekwini—a setting in which existing railways offer access to densely populated areas but pose an interoperability challenge to extend contemporary rail to areas beyond.

Western Cape: A Garden Route railway—the natural beauty is at once an attraction to tourists and a challenge for railways. Can contemporary rail solutions rise to the challenge?

North West: A Pilanesberg-Gauteng railway—deploy a contemporary rail solution to stimulate an economic development corridor. Possibly as an expansion of the Gauteng Regional Rail scenario in this report?

6.8.4.6 Prospective international consultants

Procurement of their services, and possibly the services of others, will rest on the questions ultimately generated at the Stakeholder Workshop.

6.8.4.7 Site visits

It is suggested that a Department of Transport and PRASA team visit some of the following sites:

- Contemporary narrow gauge commuter operations, to gain exposure to the level of service that is possible, and to assess first hand whether standard gauge can justify the cost of gauge change. Examples are Perth’s 130km/h regional sets, and several in Japan.

- Regional rail sites—Toronto GO Transit, with a mix of freight- and passenger trains.
- Light Rail sites—many around the world. Turkey would be interesting, for its background of ramping up investment in urban railways, for light rail, and its high speed project.
- Automated Light Metro (VAL)—Taipei, Rennes.
- Saudi Arabia—heavy freight and high-speed passenger sharing the same infrastructure.
- Toulouse—integrated bus, automated Light Metro (VAL), light rail, and regional rail.

These represent early opportunities of which decision makers should be well-informed through personal exposure. They are prime sites but not unique, so substitutes would be possible.

6.8.5 Phase 4

Completion of Phase 4 will be contingent on completion of all preceding work. For estimation purposes RCS proposed an indicative eight-week period between all inputs being to hand, and delivery of the final report. The actual time required will of course depend on the direction given by the Steering Committee, and the amount of integration required.

6.8.5.1 Integration

Integrate the external, local, and international inputs with respect to their terms of reference and the Framework Report, to develop a balanced overall perspective on passenger railway technology for South Africa.

6.8.5.2 Overall recommendations

Suggest considerations that should inform strategic positioning of passenger railway technology in policy formulation for South Africa.

Suggest priorities for ensuring rational migration from the status quo to a desirable future end state. The priorities will pay particular attention, where applicable, to identifying courses of action that could preclude attainment of a desirable end state.

7 Conclusions

7.1 Aspirational end-state scenarios

7.1.1 Moving technology forward

South Africa finds itself in a challenging situation regarding passenger rail technology. On the one hand, examination of the status quo found a substantial backlog. On the other hand, the global railway renaissance has developed a range of attractive mass mobility solutions that could change the face of South Africa. If the country wants integrated rail based mass mobility, the only conclusion can be that it needs to migrate from the former to the latter. In concluding, this report outlines a set of aspirational technology end-state scenarios, together with a prognosis on how far South Africa could reasonably attain them.

7.1.2 Urban rail

In conclusion regarding urban rail, it is the most immediately tractable of contemporary rail solutions for South Africa. In the high-capacity metro market space, it operates essentially on its own infrastructure, can reasonably be segmented to implement new technology piecemeal, and does not require changing to standard gauge to deliver substantial benefits. It offers capacity potential far beyond current services. A first step could thus be to acquire new high-capacity metro rolling stock for selected high-priority corridors (without losing sight of the need for matching investment in short headway signalling).

Following the example of Singapore, which grew around its metro system, and was greatly influenced by it, good urban rail seeds urban development, and provides a foundation for an integrated mass transport system.

Note also the emergence of a range of alternative rubber-tyred and steel-wheel-on-steel rail solutions in the urban market space. They could either provide feeder services to metro routes, or shoulder the transport task in lower priority corridors, and therefore warrant serious consideration.

7.1.3 Regional Rail

Regional rail solutions seed regional development, as well as interregional travel, in the 40-400km market space. It serves a market where short journey time is important, hence high speed and standard gauge are required. Of course, most existing infrastructure in this distance range is narrow gauge TFR property. This is the first market space in which the suitability of TFR infrastructure for competitive rail applications could become an issue. It may be economically viable to kick-start a dedicated standard gauge regional rail network in a compact, densely developed, province like Gauteng. It may even be found possible to expand such a network into the contiguous Free State, Mpumalanga, North West, and Northern Provinces. However, outside Gauteng, regional rail could require accommodation with TFR to leverage value from existing right of way. In conclusion regarding regional rail, it is likely to be the next contemporary rail solution in South Africa after metro.

7.1.4 High-speed Intercity

In principle, high-speed intercity trains, to 200km/h, need standard gauge track. They could also require substantial re-alignment of existing infrastructure, as well as substantial supporting work. High-speed intercity trains could possibly share infrastructure with TFR, if the latter changed track gauge to standard gauge on routes that coincided with passenger requirements. In that scenario, contention for line capacity between freight and passenger trains would likely be an issue. However, as most existing TFR infrastructure is riddled with speed-limited curves, it must be concluded that there is only limited prospect of high-speed intercity services in South Africa.

Proposals have been made, for further evaluation, regarding routes that are inherently unsuitable for freight traffic, which could be dedicated to passenger traffic. The economics of change, and the cost of maintenance under high-speed operations, will be important considerations.

7.1.5 Ultra-high-speed Intercity

The ultimate aspiration for any developing country is ultra-high-speed rail service between key cities. It is not possible to stretch the capability of conventional lines to handle train speeds of 350+ km/h, not even on standard gauge railways, so ultra-high-speed railways require dedicated lines. Such projects are therefore expensive: Although South Africa may not yet appear ready to justify such investment, several economic peer countries have already initiated studies or made commitments to ultra-high-speed rail service. It is likely that they have ways of evaluating positive socio-economic contributions outside conventional cost-benefit analysis, and a recommendation has been made in this regard.

7.2 Prognosis: Leap ahead

Conceptual migration paths to the foregoing solutions do exist, and have been outlined in this report. A mature approach to interoperability requirements can set them in motion.

Determining cost/benefit ratios of indicated mobility solutions was outside the scope of this study. However, analysis relative to the many socio-economic factors that influence mass mobility should clearly be a first step. Migration to any of the contemporary rail solutions will undoubtedly be expensive. Against this, one must weigh the opportunity cost to a society and its economy of its mass mobility system not supporting its developmental aspirations.

The most secure guidance comes from the green thread that runs through this report. It leads to the conclusion that, on the one hand lack of progress in realizing a back-to-rail aspiration is allowing less environmentally friendly commuter transport modes to capture market share, while on the other hand services based on legacy passenger rail technology are over resourced[95] by contemporary norms, and therefore hardly tenable as a better solution.

This situation must have a substantial impact on developments in the PRASA sphere of influence. If South Africa commits to contemporary rail mass mobility solutions, it will be in good company among its economic peers. If it does not, it should expect to be excluded from entering the global passenger railway mainstream, and possibly find it difficult to keep pace with its peers.

At this time, South Africa has a passenger rail backlog: Half measures will not adequately resolve the issues. Arguably, the most incisive strategy would be to emulate Korea Rail in its *Leap Ahead* strategy.

7.3 Opening a migration path

Good, well-conceived passenger railways grow, because they influence and attract development. First-mover advantage accrues to the transport mode that defines the basic urban and regional fabric for many years to come. The study has shown compelling economic, environmental, and technological reasons why that mode should be rail. It is evident that restoring passenger railways to their rightful role in South Africa will not be a trivial task. Success demands:

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[95] This conclusion refers particularly to the quantum of physical resources, such as infrastructure, rolling stock, energy consumption, and maintenance arrangements.

- A holistic view of global opportunities and solutions,
- An appreciation of the time-scale of the challenge
- A clear, shared vision by all stakeholders, and
- A bold approach.

Many constraints stand in the way of implementing contemporary passenger railways in South Africa. If a foundation is not laid for realizing that aspiration in manageable portions, the process could falter. The task is enormous, but with clear thinking and resolve, there is no way it should not happen.

7.4 Some cautions

7.4.1 Potential hazards

Two possible immediate hazards for the NATMAP process should be recognized.

First, one of the major challenges is that the passenger rail status quo is hardly a secure basis from which to project the future. One would expect implementation of the rail solutions described in this report to stimulate a shift from bus and taxi to rail, and even to create new mass mobility opportunities that existing solutions cannot support.

Second, to the extent that possible future regional rail services may need to build on TFR plans in respect of issues such as shared access and changing gauge, TFR plans themselves do not appear to recognize many of the inherent weaknesses of freight rail positioning in South Africa.

The NATMAP Consortia need to factor in these planning hazards as best they can.

7.4.2 Phasing-in

Contemporary rolling stock would, to the extent that its features address the shortcomings of existing rolling stock, alleviate negative passenger perceptions. To the extent that the fleet is expanded, it would also provide increased capacity.

Note however that aligning infrastructure- and rolling stock performance characteristics maximizes overall system performance. While contemporary rolling stock can be made to run on existing South African infrastructure, maximizing overall system performance would also require upgrading infrastructure performance. Not doing so would fail to extract the full potential of the rolling stock, and result in an economically sub-optimum solution.

As a minimum, aligning infrastructure with contemporary rolling stock performance characteristics would require a signalling system that could support the short headways to which contemporary metro stock can run, and would likely require examining the necessity for all existing points and crossings, as well as permissible speeds through them.

At this time, the caveat is mentioned simply to preempt the possible misperception that investing in rolling stock will be a panacea. Greenfields routes should as a matter of course implement infrastructure that matches the performance of contemporary rolling stock.

7.4.3 Cherry picking

This report has presented a coherent set of technologies with indications of how they relate to and complement one another. It is not recommended to cherry pick portions of different solutions that may seem to appeal.

8 References

ADIF allows freight access to HS lines. 2009. International Railway Journal, Vol. 49(2), p. 8.

African Union of Railways. Undated. http://en.wikipedia.org/wiki/Union_of_African_Railways, retrieved 2009-02-25.

African Union. 2007. Professional Conference on Interconnection, Interoperability and Complementarity of African Railway Systems, 20-21 November 2007, Johannesburg, South Africa. http://www.africa-union.org/root/ua/Documents/Reports/IE/2005%20till%202008%20meetings/Johannesburg%20-%2019-20%20November%2007/French/Draft%20Recommendations.doc, retrieved 2009-03-05.

Automating Brazil's busiest metro lines. 2009. Railway Gazette International, Vol. 165, pp. 27-30.

Barouski, D. 2008. Dar, Kigali to build EA's first wide gauge railway line. http://africannewsanalysis.blogspot.com/2008/03/dar-kigali-to-build-eas-first-wide.html, retrieved 2009-02-25.

Bhatnagar, G.V. 2006. Conflicting views over Mumbai Metro gauge. The Hindu (Online Edition), May 26.

Boagey, A. & Genain, M, 2009. London's cross-city line follows the RER model. Railway Gazette International, Vol. 165, pp. 62-64.

Bowen, D.J. 2008. DLRT seeks its niche. Railway Age, September, pp. 65, 67-68.

Briginshaw, D. 2008. Green Train shows Swedish technology. International Railway Journal, Vol. 48(9), pp. 51-52, 54.

Briginshaw, D. 2009. A stark warning to others. International Railway Journal, Vol. 49(1), p. 2.

C2 class Melbourne tram. Undated. http://en.wikipedia.org/wiki/C2_class_Melbourne_tram, retrieved 2009-0426.

Cairns Tilt Train derailment. Undated. http://en.wikipedia.org/wiki/Rosedale_train_crash, retrieved 2009-04-04.

China develops maglev train for urban transport. 2009.
Chūō Shinkansen. Undated. http://en.wikipedia.org/wiki/Ch%C5%AB%C5%8D_Shinkansen, retrieved 2009-03-07.

http://news.xinhuanet.com/english/2009-02/18/content_10839686.htm, retrieved 2009-03-07.

Dedicated Freight Corridor construction launched. 2009. http://www.railwaygazette.com/news_view/article/2009/02/9360/dedicated_freight_corridor_construction_launched.html, retrieved 2009-03-25.

Drapa, J., Moore Ede, B. & Polivka, A. 2007. PTC starts to roll out across the USA. http://www.railwaygazette.com/news_view/article/2007/05/7210/ptc_starts_to_roll_out_across_the_usa.html, retrieved 2009-03-06.

Driverless metros. Undated. http://mic-ro.com/metro/driverless.html, retrieved 2009-01-02.

Eskisehir launches Turkey's newest light rail tramway. 2005. http://www.lightrailnow.org/news/n_newslog002.htm#ESK_20050306, retrieved 2009-02-26.

European Commission. 2008, Proposal for a Regulation of the European Parliament and of the Council concerning a European rail network for competitive freight. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2008:0852:FIN:EN:PDF, retrieved 2009-03-25.

European Union. 2008. Directive 2008/57/EC of the European Parliament and of the Council of 17 June 2008 on the interoperability of the rail system within the Community. Official Journal of the European Union, 18 July.

Gauge change train. Undated. http://en.wikipedia.org/wiki/Gauge_Change_Train, retrieved 2009-03-05.

Gevert, T. 2008. HS project in the fast lane. International Railway Journal, Vol. 48(11), pp. 44-45.

Gharajedaghi, J. 1983. Corporate pathology. Philadelphia: University of Pennsylvania.

Hondius, H. 2008. Gröna Tåget spawns EC04. Railway Gazette International, Vol. 164, pp. 725-726.

Industry projects. Undated. http://www.railway-technology.com/projects/, retrieved 2009-03-09.

Kei Rail launch part of beefing up rail services. 2009. http://midafricam.co.za/main/component/option,com_joomlaboard/func,view/id,30/catid,17/, retrieved 2009-04-09.

Kennedy, R.R. Undated. Considering monorail rapid transit for North American cities, p. 24. . www.monorails.org/webpix%202/RyanRKennedy.pdf, retrieved 2009-01-02.

Korea's first commercial maglev train line to be set up at Incheon airport. 2007. http://www.korea.net/News/News/LangView.asp?serial_no=20070627004&lang_no=1&part=106&SearchDay=, retrieved 2009-03-07.

Lukov, B. 2009. Three-stage programme to update RZD's fleet. Railway Gazette International, Vol. 165, pp.31-34.

Lew, A. 2008. Maglev Project in Munich: Cancelled. http://blog.wired.com/cars/2008/03/maglev-project.html, retrieved 2009-03-07.

Magnetic levitation technology (maglev). Undated. http://www.railway-energy.org/tfee/index.php?ID=220&TECHNOLOGYID=59&SEL=210&EXPANDALL=3, retrieved 2009-04-06.

Morocco to build high-speed rail link. Undated. http://www.railway-technology.com/news/news2841.html, retrieved 2009-03-09.

Mumbai monorail contract. 2009. Railway Gazette International, Vol. 165, p. 15.

National Railroad Passenger Corporation. 2007a. Annual Report. http://www.amtrak.com/pdf/AmtrakAnnualReport_2007.pdf, retrieved 2009-03-25. p. 6.

National Railroad Passenger Corporation. 2007b. Annual Report. http://www.amtrak.com/pdf/AmtrakAnnualReport_2007.pdf, retrieved 2009-03-25. p. 20.

National Transport Master Plan. 2009a. Rail Gauge Report.

National Transport Master Plan. 2009c. Rail Gauge Report, Annexure 2.

National Transport Master Plan. 2009d. Rail Gauge Report, Annexure 3.

National Transport Master Plan. 2009f. Rail Gauge Report, Annexure 5.

National Transport Master Plan. 2009g. Rail Gauge Report, Annexure 6.

New 350km/h High-speed train efSET aiming at the global market. 2008. http://www.khi.co.jp/ba/2008data/ba_c3080911_1.html, retrieved 2009-03-04.

New Pendolino. Undated. http://en.wikipedia.org/wiki/ETR_610, retrieved 2009-03-04.

Okada, H. 1994. Features and economic and social effects of the Shinkansen. Japan Railway and Transport Review, October, pp. 9-16.

On the fast track to reform. 2009. Railway Gazette International, Vol. 165, pp. 53-55.

Perry, A. 2009. Africa, Business destination. Time, Vol. 173(12), pp. 32-34.

Planned high-speed rail by country. Undated. http://en.wikipedia.org/wiki/Planned_high-speed_rail_by_country#India, retrieved 2009-03-25.

Platform screen doors. Undated. http://mic-ro.com/metro/platform-screen-doors.html, retrieved 2009-03-05.

Rail Safety Improvement Act of 2008. United States House of Representatives. http://transportation.house.gov/Media/File/Rail/Rail%20Safety.pdf, retrieved 2009-04-13.

Roland Berger Strategy Consultants. 2008. Worldwide rail market study—status quo and outlook 2016. Hamburg: DVV Media Group.

Segregation for 200km/h running. 2008. Railway Gazette International, Vol. 164, p. 477.

Shosholoza Meyl Routes. Undated. http://www.spoornet.co.za/ShosholozaMeyl/index.jsp, retrieved 2009-03-08.

Siemens H-Bahn (SIPEM). Undated. http://www.monorails.org/tMspages/TPSiem.html, retrieved 2009-04-14.

South African Rail Commuter Corporation. 2006. National railplan consolidated report.

South African Rail Commuter Corporation. 2008/09. Business Plan.

South African Rail Commuter Corporation. Undated. Rail revitalization in rural and intercity context, PowerPoint presentation.

South African Transport Services. 1980a. Second quarterly report of the Task Group investigating high speed suburban and intercity passenger services, Annexure K, p.19.

South African Transport Services. 1980b. Second quarterly report of the Task Group investigating high speed suburban and intercity passenger services, Annexure K, p.23.

South African Transport Services. 1980c. Second quarterly report of the Task Group investigating high speed suburban and intercity passenger services, Annexure K, Appendix 15.

South African Transport Services. 1980d. Second quarterly report of the Task Group investigating high speed suburban and intercity passenger services, p.7.

Spoornet. 2005. Working Time Book No.107.

Taylor, C. 2007. World Speed Survey: New lines boost rail's high speed performance. http://www.railwaygazette.com/news_view/article/2008/09//new_lines_boost_rails_high_speed_performance.html, retrieved 2009-03-03.

Tests to cease on Emsland guideway. 2009. Railway Gazette International, Vol. 165, p. 23.

The days they changed the gauge. Undated.. http://southern.railfan.net/ties/1966/66-8/gauge.html, retrieved 2009-04-05.

Transit ridership continues to roll. 2009. Progressive Railroading, Vol. 52(1), p.4.

Transnet. 2008. Annual Report, Freight Rail. http://www.transnet.co.za/AR_2008/pdf/freight-rail.pdf, retrieved 2009-01-05.

UIC. Undated. General definitions of highspeed. http://www.uic.asso.fr/uic/spip.php?article971, retrieved 2009-03-03.

UIC. Undated. In view of operating standpoint. http://www.uic.asso.fr/gv/article.php3?id_article=17, retrieved 2009-03-03.

UIC. Undated. In view of rolling stock. http://www.uic.asso.fr/gv/article.php3?id_article=16, retrieved 2009-03-03.

UIC. Undated. Wide-body stock. http://www.railway-energy.org/tfee/index.php?ID=220&TECHNOLOGYID=22&SEL=210&SEKTION=Sec2_closed#a_General%20criteria, retrieved 2009-04-06.

UNIFE. Undated. Research. http://www.unife.org/page.asp?pid=26, retrieved 2009-01-05.

Van der Meulen, R.D. & Möller, L.C. 2006. Railway globalization: Leveraging insight from developed- into developing regions. Proceedings of the Seventh World Congress on Railway Research [CD-ROM]. Montréal, QC, Canada.

Van der Meulen, R.D. & Möller, L.C. 2008a. Strategies for sustainable mobility: Urban railways as global corporate citizens. Proceedings of the Eighth World Congress on Railway Research, G.2.2.2.1 [CD-ROM]. Seoul, Korea.

Van der Meulen, R.D. & Möller, L.C. 2008b. Ultimate interoperability: Line-haul railways as global corporate citizens. Proceedings of the Eighth World Congress on Railway Research, PN.1.2 [CD-ROM]. Seoul, Korea.

Van der Meulen, R.D. 2008. Eastern Cape Rail Strategy. Eastern Cape Rail Conference: Back to Rail, Port Elizabeth: Eastern Cape Department of Roads & Transport.

Van der Voort, J.J.P. 1980. Mass transit for urban groups: Systems and capacity considerations. Doctoral dissertation, University of Pretoria.

White Paper on National Transport Policy. 1996. Pretoria: Department of Transport.

Wide-body stock. Undated. Energy efficiency technologies for railways. http://www.railway-energy.org/tfee/index.php?ID=220&TECHNOLOGYID=22&SEL=210&SEKTION=Sec1_closed#a_General%20information, retrieved 2009-04-13.