

GAUTRAIN: ROUTE DETERMINATION

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FOREWARD

This paper is guided and obtains direction from the Spatial Planning Report for the Gautrain Rapid Rail Link prepared by Nico Kriek and Nina van Heerden of APS Plan Africa.

1 INTRODUCTION

The Premier of the Gauteng Province in South Africa, Mr Mbhazima Shilowa announced ten Spatial Development Initiatives as part of the economic development strategy for the Province during February 2000. The Project concept provided for a rapid rail link between three nodes, namely Johannesburg, Pretoria and the Johannesburg International Airport (JIA).

This paper is one in a series of four papers that respectively address the Project Concept, the Demand and Revenue Forecast, Route Determination, and The Business Case, Feasibility Criteria, Technical Integration and Economic Evaluation of the project. In view of the extremely tight time schedule during which the feasibility study of the project, both from the technical and financial point of view had to be completed, it was essential to formulate a planning framework that would facilitate a rapid rate of progress, ample provision for liaison and co-operation between team members, a structured planning and analysis approach, as well as a comprehensive consultative structure. This approach had three major benefits:

- Maximum synergy between team members and exploitation of their collective experience, expertise and knowledge base
- Maximum co-operation and quality control to minimise the potential for error
- Maximum consultation and liaison to ensure that the maximum benefit is achieved from the extensive background information and understanding of salient aspects and local knowledge.

The paper discusses the processes followed to determine the alignment of the Gautrain Rapid Rail Link including the Spatial Planning Framework, the Rail Network Concept, Determination of Station Locations, Operational and Design standards, and the selection of a preferred alignment. As a result of the density of development and very high land values along the section between Sandton and Johannesburg, the feasibility to construct the rail link in a tunnel below natural ground was investigated and will be briefly reported on.

2 SPATIAL PLANNING FRAMEWORK

The Gautrain Rapid Rail Link is one of the Spatial Development Initiatives (SDI's) that resulted from the 1997 Trade and Industrial Strategy of the Gauteng Provincial Department of Economic Affairs and Finance and is aimed, collectively with the nine other SDI's to unlock inherent economic development potential and to establish Gauteng as the "Smart" Province. From a spatial perspective, the project has the following aims:

- Enhance economic growth and encourage new growth in areas affected by the rail
- To connect people and jobs
- To improve accessibility
- To promote the redevelopment and revitalisation of CBD's

- To encourage the development of new-town core areas
- To strengthen existing vibrant nodes.

A holistic and comprehensive approach was followed in the Spatial Planning process. The process included research from available literature, input from the project team and other consultative structures that were built into the project framework, interrogation of existing planning instruments (Gauteng Spatial Development Framework and local government Land Development Objectives and Integrated Development Plans). The seven steps in the incremental planning approach that was followed are briefly discussed below:

a) International Review

Rail systems have a very large passenger carrying capacity and therefore require a strong land use base to ensure adequate ridership. Densely populated residential developments around stations are essential, particularly people within walk-in distance. A joint development approach is required to trigger large-scale development that would create ridership and induce increased transportation demand through development of station nodes. Available suitable land, favourable economic conditions and particularly political support are key success factors.

In South Africa there is a lack of a culture of public transport use, and in particular commuter rail systems do not currently achieve their full market potential.

b) Spatial and economic development Analysis

The Gauteng Spatial Development Framework (GSDF) identifies five critical factors for a framework of future growth and development, namely

- Resource-Based Economic Development that is focussed on existing and potential resources. The core resource concentration is located in a triangle located between Pretoria, Johannesburg and the Johannesburg International Airport (JIA), and defined by the N1 (Pretoria – Johannesburg), R24 (Johannesburg – JIA) and R21 (Pretoria-JIA) freeways
- Contained Urban Growth within a defined urban edge that would discourage urban sprawl and an associated private car orientated urban structure
- Re-direction of Urban Growth to correct the distorted settlement pattern in which low cost developments occur on the periphery of the urban zone, removed from economic opportunities and social resources and burdened by high transportation costs
- Rural development beyond the Edge. An Urban Edge is indicated in the GSDF and defines the limit of urban development
- Mobility and Accessibility to enhance and improve movement of people and goods.

The analysis also took into consideration Land Development Objectives (LDO's) and Integrated Development Plans (IDP's) as well as Statistics regarding the location of Population Concentrations, Population Densities (specifically areas with population densities of 25 dwelling units/ha), Functional Employment areas, and Employment Densities.

c) Critical Conclusions

The review of international examples and analysis of the spatial and economic structure in the study area led to six key conclusions that would form the corner stones of the Gautrain Rapid Rail Link planning:

- Rail aligned with current planning
The Gautrain project is in line with current planning philosophy and there is opportunity to mould the environment surrounding stations to adapt to the needs of the project.

- Lack of Density. Current residential densities are too low and a new urban form will have to be established that provides increased density and development nuclei around stations.
- Linking Employment Zones in CBD's and decentralised business centres.
- Primary function of the Rail to enhance economic development by improved accessibility and mobility and by providing a connection between people and jobs.
- Secondary function of the Rail to achieve fundamental change in the urban form in Gauteng and that will create a sustainable new urban form.
- Integration of the existing Rail System. Despite the fact that the Gautrain is considered to be different and superior, it should support increased rail system ridership on the existing network.

d) Spatial Development Concept

The status quo regarding urban form and growth dynamics are heavily influenced by private transport and new development is often directed by the ability to travel, and areas that experience a high level of accessibility created by the expansive road network.

The concept formulated for future growth is focussed on the rail corridor and avoids growth of important areas beyond the sphere of influence of the rail system. The conceptual new urban form is of a linear nature along the rail alignment with zones of compact urban form around stations and existing development nodes. A supporting road system supports the urban form and could result in future nodes and stations with an accompanying land use infill surrounding the central linear rail line corridor.

The implications of the spatial development concept are the support of the two "old" cities, namely Johannesburg and Pretoria, complemented by the development of "New Towns" at areas such as Centurion and Midrand where the potential for intervention and a new urban form are at a maximum.

It should be realised that planning initiatives will have to be co-ordinated and that incentive mechanisms will have to be devised to achieve the planning goals within a realistic framework associated with the implementation programme for the Gautrain.

e) Important Places

Johannesburg, Pretoria and the JIA have been identified in the project brief as the most important places affecting the Gautrain Rapid Rail Link. These areas are supported by a list of other areas of importance from a provincial development perspective. These places, if not served by the rail, should be connected by feeder and distribution systems and could also in future be served by an extension of the rail network. The Ekurhuleni Metropolitan Council indicated the need to expand the JIA link in an eastward direction to increase the catchment area of the rail system. A scoring and weighting system was devised in order to analyse the benefits or various potential stations. The list of key places/nodes for station development is as follows:

- | | |
|------------------------|---------------------|
| - Hatfield | - Midrand |
| - Pretoria CBD/Station | - Johannesburg CBD |
| - Menlyn | - Soweto |
| - Centurion Lake | - Sandton |
| - Ivory Park/Tembisa | - Alexandra Wynberg |
| - JIA | - Fourways |
| - Kempton Park CBD | |

The majority of these areas are served by the Gautrain Rapid Rail Link.

f) Implementation Consideration

Development objectives envisaged for the Gautrain, or any other major project, cannot be expected to happen automatically. "Because the access advantage alone that a new transit line offers in an auto-dominated setting is often insufficient to trigger large scale changes in land use, attention has increasingly focussed on the concept of joint development, which involves a deliberate effort to place large-scale projects adjacent to the transit facility" (Urban Rail in America, An Exploration of Criteria for Fixed – Guideway Transit, Pushkarev, B.S et al, Indiana University Press, 1982).

Successful achievement of the goals of the Gautrain would therefore require intervention by Government and the project has to be embraced in all relevant planning instruments (GSDF, LDO's/IDP's) as well as to be supported by incentive schemes regarding engineering services and/or rates and taxes to promote participation by the private sector.

3 RAIL NETWORK CONCEPT

The development of a network concept for the Gautrain Rapid Rail Link was influenced by the requirement to attract existing car users between Pretoria and Johannesburg and a target to limit the train travel time between the two cities to 40 minutes. Factors that were taken into consideration included the existing SARCC line that runs from Pretoria via JIA to Germiston on the East Rand and then to Johannesburg, and the scheduling of trains between the three primary destinations, ie Johannesburg, Pretoria, and JIA.

A critical factor, however, was the origins and destinations of air passengers at JIA that were dominated by the strong hotel, conference and business core at Sandton. Two distinct travel patterns therefore guided the rail network concept, namely the strong interaction between JIA and Sandton in an east-west orientation on the one hand, and the high travel demand along the north-south corridors between Pretoria and Johannesburg on the other hand.

The Gautrain Rapid Rail Link network comprises a primary north south axis between Johannesburg and Pretoria and a secondary east west axis between Sandton and JIA.

a) Alternative alignment

A very large number of alternative alignments with sub alternative options were investigated during the route alignment phase of the project. Two primary alternatives, however, showed maximum promise and were submitted to the Gauteng Cabinet for consideration:

- **Alternative 1:** Direct Alignment between Johannesburg, Rosebank, Sandton, Midrand, Centurion and Pretoria that offered the highest potential in terms of ridership. There was however a great concern regarding the environmental implications of a rail line through the highly developed section between Sandton and Johannesburg CBD as well as topographical constraints that would definitely require tunnelling.
- **Alternative 2:** Eastern Alignment that would utilise the Bezuidenhout Valley to approach the Johannesburg CBD from the east via the Bruma/Eastgate development node. This alternative promised to achieve significant cost savings, but fails to provide an effective service between Sandton and the Johannesburg CBD and is unbalanced within the Metropolitan area because it does not serve the western parts of the urban area that is already impeded by a lack of transport corridors and particularly public transport services.

b) Integration with SARCC

The existing commuter rail service provided by the SARCC was considered to be an important element of the feeder and distribution service for the Gautrain Rapid Rail Link. A vision of the planning team was also that the successful implementation of this modern and efficient service would result in a change in the perception of rail transit and that it would therefore create a turning point in public transport usage in the region.

Three interfaces between the Gautrain system and the existing SARCC system have been included in the planning:

- Location of a station at the Johannesburg Park Station that is the busiest commuter rail station in South Africa
- Interface between the Gautrain and the proposed Pretoria Ring Rail System
- Location of the Kempton Park Station on the JIA - Sandton line at its intersection with the existing Pretoria – Germiston commuter line. This station can be combined with an improved service in the East Rand to enhance the accessibility of the Gautrain to the ridership market in the East Rand.

c) Expansion of the Network

Transport demand modelling indicated strong desire lines from the eastern suburbs of Pretoria to Johannesburg and Sandton that motivated the extension of the north – south primary axis to the Hatfield area in the eastern part of Pretoria. Several factors motivated this decision including access to a strong development node with a relatively high population density, improved connectivity to the Ring Rail System, excellent road access for park 'n ride passengers and integration with the SDI Innovation hub between the CSIR and Pretoria University.

The network concept also allows for the future expansion of the network to the East Rand from JIA, to the Soweto area from Johannesburg, to the western parts of the Johannesburg Metropolitan area from Sandton and into the City of Tshwane Metropolitan area, from Pretoria Station and Hatfield.

d) Operational Efficiency and Capacity

The recommended alignment results in a T-shape network with the primary and secondary axes sharing of the section between Marlboro and Sandton. The operational diagram of the rail system is illustrated on Diagram 1.

4 DETERMINATION OF STATION LOCATIONS

The spatial planning analysis identified the highest potential locations for Gautrain stations, specifically from a sustainable urban development perspective.

The selection of stations was however also influenced by travel time targets where a balance had to be found between an increase in potential ridership, and travel speed and the travel time target of 40 minutes between Pretoria and Johannesburg.

The following stations were therefore included in the Network:

a) Primary Stations

- Johannesburg CBD
- Pretoria CBD
- JIA
- Sandton.

b) First phase stations

- Hatfield
- Centurion
- Midrand
- Marlboro (Close to intersection point of primary and secondary axes)
- Rosebank
- Kempton Park.

c) Potential expansion on existing lines

- Modderfontein
- Sunnyside.

The recommended positions for the individual stations were derived from a land use analysis of development potential and residential density, as well as a transport analysis to ensure accessibility by car (park 'n ride) as well as public transport feeder and distribution services, the feasibility of the rail alignment to serve the area and lastly, but very importantly, development policies contained in the Integrated Development Plans and development strategies expressed by transport and land use planning officials,

5 OPERATIONAL AND DESIGN STANDARDS

The planning of the Gautrain Rapid Rail Link included a holistic inter disciplinary approach.

From the technical perspective, however, the route alignment was dictated by many factors that covered a wide range of technical aspects of which the following are considered to be of specific importance:

- (a) Geometric standards required for high speed rail operation
- (b) Selection of a design speed to achieve operational objectives
- (c) Train capability and its impact on maximum gradient
- (d) Energy consumption
- (e) Rolling topography and cost of civil works
- (f) Operational analysis and train simulation
- (g) Scheduling of service
- (h) Geotechnical aspects
- (i) Construction techniques for sections where the rail is underground
- (j) Integration between the route alignment and station locations.

The first steps in the route determination process were to determine the rail network concept and to identify feasible routes from a topographical perspective. For this purpose a scale model was constructed that illustrated the constraints of the topography and that was extensively used in discussions with decision makers to put the Gautrain Rapid Rail Link into perspective both from a topographical and alignment perspective and in terms of the development dynamics of the region.

(a) Geometric Standards

The design criteria and standards include the following:

- Design Speed* : 180 km/h
- Minimum horizontal radius at design speed : 1 800 metres
- Desirable maximum gradient : 2.5%
- Absolute maximum gradient (only allowable under specific circumstances) : 4.0%
- Minimum gradient (in stations) : 0.15%
- Vertical curve radius for design speed : 25 000 metres.

* The Cape gauge used on the South African railway network is considered adequate for speeds up to 130 km/h. For higher speeds the wider standard gauge used internationally is considered to be more appropriate. The use of standard gauge would also benefit the supply of rolling stock.

If the design standards are compared to the maximum gradient of 5.0% on the parallel N1 Ben Schoeman, it is evident that the positioning of the route of the Gautrain Rapid Rail Link required special attention to the topography in an effort to minimise cost.

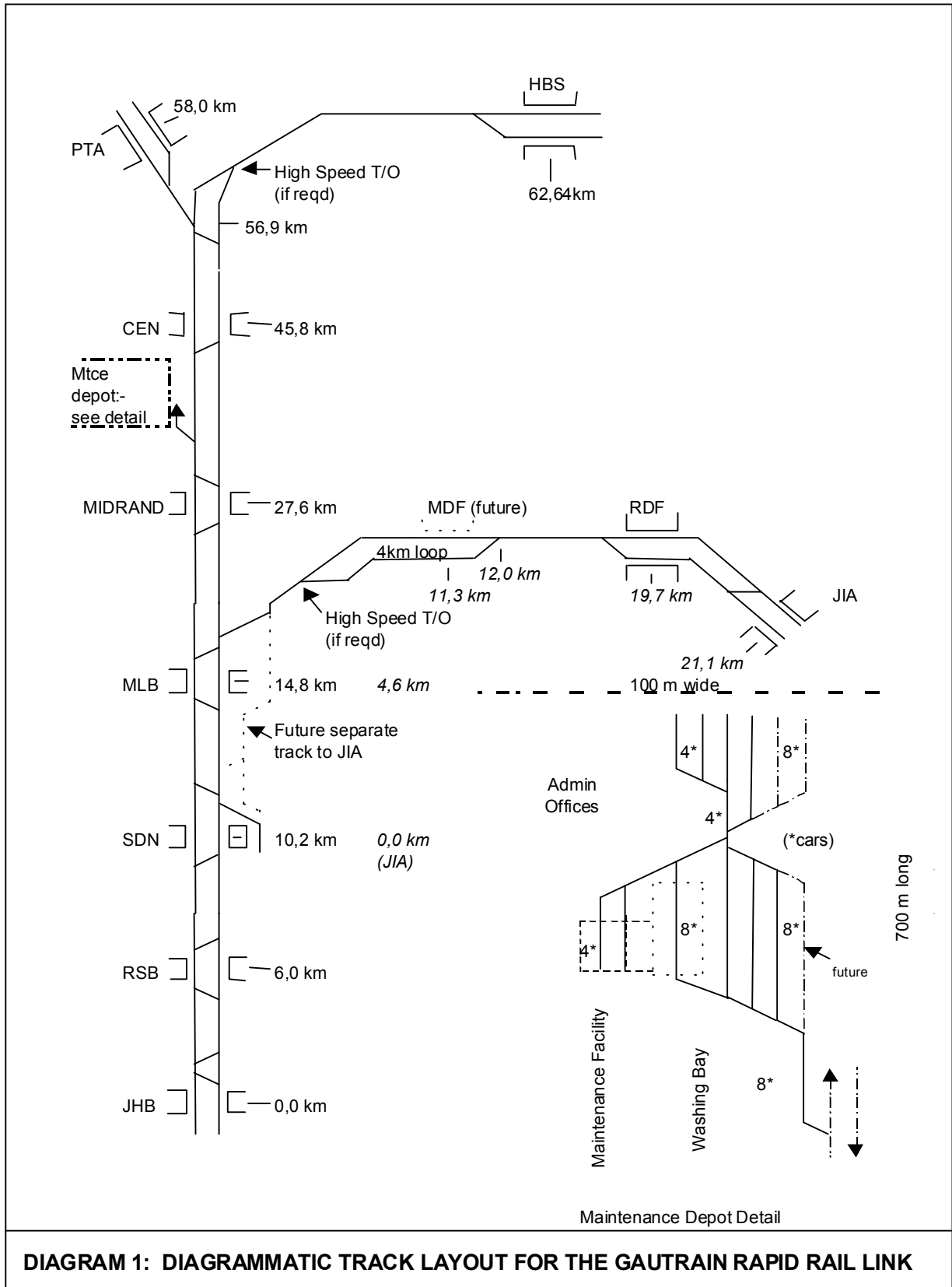
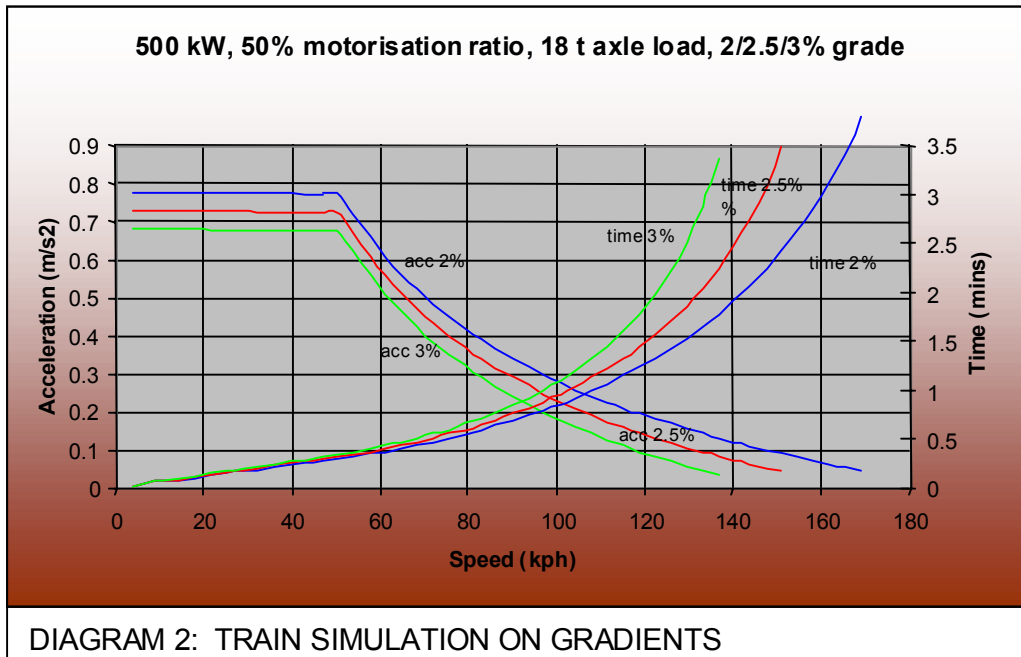


DIAGRAM 1: DIAGRAMMATIC TRACK LAYOUT FOR THE GAUTRAIN RAPID RAIL LINK

b) Train Simulation on gradients

A series of train simulations were undertaken to determine the speed on vertical gradients and the power requirements to achieve desired speeds on uphill gradients. An example is shown in Diagram 2.



The analysis indicated that a 2.5% grade could be accommodated with 50% motorised axles and a power input of 500 kW for each motor.

c) Simulation of energy consumption

Simulation of energy consumption were undertaken to determine the additional energy and power requirements to achieve a reduction in travel time. An example of the output of the simulation study is illustrated in Table 1. The results are a combination of arrival times at stations and the resultant energy consumption.

Table 1: Example of Simulation Output: 250 kW

Station	Arrival Time (Excluding dwell time at stations)			Energy (kWh)		
	Speed Limit (km/h)			Speed limit (km/h)		
	130	160	180	130	160	180
Jhb Park	00:00	00:00	00:00	5	5	5
Sandton	06:20	05:42	05:27	88	98	104
Marlboro	09:47	08:59	08:43	145	165	171
Midrand	17:18	15:28	14:44	281	295	308
Centurion	27:03	23:56	22:40	414	432	450
Pretoria	33:46	30:07	28:40	504	535	565

d) Techniques for underground sections

Although tunnelling has major benefits in the reduction of environmental impact and disruption of the road based transport system, it has major cost implications. International experience indicates tunnelling cost between R60 million and R150 million per kilometre.

As part of the route determination and project cost element of the project, four alternative construction techniques were compared:

- Open cut
- Cut-and-cover operation
- Single large bore tunnel
- Two small bore tunnels.

The conclusion is that up to 40 m depth, an open cut would be the cheapest from a pure construction cost perspective. In built-up areas, however, this option is not always acceptable in terms of its environmental and physical disruption implications.

Tunnelling becomes more economical than cut and cover at a depth exceeding 8 m, and the cost estimate indicates that two small bore tunnels are more economical than a single large bore tunnel. The rate of progress with tunnel operation is a concern and it will probably be necessary to undertake tunnelling simultaneously on a number of excavation faces.

An evaluation of the complex geology along the proposed tunnel section would prohibit the use of tunnel boring machines (TBM's) and the New Austrian Tunnelling Method (NATM) of excavation and support will probably be used.

Potential problems that have been identified and that will have to be addressed during the planning, design and construction process include the following:

- Tunnelling under the water table
- Blasting adjacent to existing buildings
- Settlement of buildings due to a drawdown of the water table
- Settlement of buildings due to shallow tunnels in soft ground
- Sinkholes and doelines in dolomitic areas.

e) **Major rail bridge structures**

The vertical alignment aimed at a balance between tunnels, cut and fill, and viaducts to achieve the high design standards dictated by the high design speed and operational requirements of the Gautrans Rapid Rail Link. A total of twelve rail bridge structures with lengths between 250 m and 1 750 m and maximum heights exceeding 14 m will be required along the route.

6 **SELECTION OF THE PREFERRED ALIGNMENT**

The Gautrain Rapid Rail Link is expected to play a major role in the spatial development and transportation system in Gauteng, specifically in the area between Johannesburg, Pretoria and the JIA. Major objectives of the project are economic development, urban restructuring, provision of an efficient modern rail system to serve transport demand and reduce congestion and to promote the image and utilization of public transport.

The process to identify a preferred alignment was therefore complex and had to address a number of criteria to ensure that all aspects are taken into consideration. The individual alternative alignments had to comply with very high geometric design standards and were therefore largely dictated by the topography, existing development and the gradients required at stations and were therefore optimized on technical grounds. However, the comparison of the two main alternatives was more difficult because the two alternatives served different areas within the Johannesburg Metropolitan area. The following factors were specifically taken into consideration in the comparative assessment of the two alternatives:

- Total passengers served
- Total passenger – km travelled

- Capital cost of land acquisition infrastructure and rolling stock
- Operational and maintenance cost
- Present value of projected revenue stream
- Nett present value

The Direct alignment between Sandton and Johannesburg enjoyed three specific advantages:

- No environmental impact as a result of largely underground alignment
- Greater socio-economic benefit estimated in the socio-economic analysis that was undertaken as part of the project
- Clear preference of the Metropolitan Municipality

The direct alignment alternative, although slightly more expensive, performed best in terms of all other criteria and could therefore be recommended to the Gauteng Cabinet with confidence.

7 CONCLUSION

A holistic and interdisciplinary approach was followed to establish a preferred alignment for the Gautrain Rapid Rail Link between Johannesburg, Pretoria and the Johannesburg International Airport.

The project has a strong spatial planning foundation aimed at economic development and a fundamental transformation of the urban structure in Gauteng. The spatial framework has a strong influence on the location of stations.

The benefit of the system is based on a thorough transport demand modelling process and an integrated feeder and distribution system.

At the technical level, the process included a number of studies to ensure the operational efficiency and optimum cost of the project, including:

- Development of design standards
- Selection of design speed
- Train simulation to determine maximum gradients and energy consumption
- Development of schedules and operational system
- Route determination and costing
- Tunnelling techniques and geotechnical assessment.

The process achieved a technically feasible route network that could be recommended to the Gauteng Provincial Government with confidence.

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After graduating at Pretoria University in 1975 Herman Joubert started his career as design engineer on projects that ranged from urban streets and stormwater to runways, provincial roads and a section of the N1 national freeway. He returned to Pretoria University for a research and teaching career of 17 years with specialisation in Economic Evaluation, Traffic Engineering and Road Network Planning and Design.

In 1983 he was a founder member of the firm Jordaan & Joubert and has since been involved in the Consulting Engineering field where his main interests are Traffic Safety, Traffic Engineering and Transportation System Development.

He has a keen interest in Local Government issues and was a member of the Negotiating Committee for the Transformation of Pretoria and was a council member of the Greater Pretoria Transitional Metropolitan Council where he was chairman of the Transportation and Land Use Standing Committee.

He was a director of ARCUS GIBB and on the Gautrain Rapid Rail Link project he was the Group Leader for Spatial Planning, Route Location and Civil Infrastructure. Herman is an independent consultant in Traffic Engineering and Transportation Planning.