TERRAIN SUITABILITY ANALYSIS FOR THE PROPOSED RAPID-RAIL LINK BETWEEN PRETORIA, JOHANNESBURG AND JOHANNESBURG INTERNATIONAL AIRPORT

By

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ABSTRACT

The proposal to build the Gautrain rapid-rail link between Pretoria, Johannesburg and Johannesburg International Airport was approved in June 2000 by the Gauteng Provincial Government. It was noted that this particular development could have serious environmental implications for the area involved. The aim of this research is therefore to identify the most suitable terrain in order to optimise the rail route alignment with minimal environmental impact. This will be accomplished by undertaking a terrain suitability analysis.

The different high-speed railway types are discussed and their impact on the environment is considered, culminating in an evaluation of the background and status of the proposed Gautrain rapid-rail link. The different approaches to terrain evaluation are discussed in order to draw conclusions relative to the methodology used in this research. Subsequently the activity approach as described by Mitchell (1991) and Hugo *et al* (1997) was chosen as the methodology to use for this research and the terrain within the study area was classified according to its suitability for the development of the Gautrain rapid-rail link. A Geographic Information System (GIS) was utilised to aid in the terrain suitability analysis.

As a result of the analysis an optimised route is proposed and compared to the rail routes already proposed for the Gautrain rapid-rail link. It is imperative that a terrain suitability analysis should form part of the preliminary phase of any environmental management cycle as portrayed in Fuggle & Rabie (1998), in order to identify suitable terrain for the development in question; the rapid-rail link route should be no exception.

OPSOMMING

Die Gauteng Provinsiale Regering het ‘n voorstel om ‘n sneltrein tussen Pretoria, Johannesburg en die Johannesburg Internasionale Lughawe te bou in Junie 2000 goedgekeur. Die projek het ernstige implikasies vir die omgewing. Die doel van hierdie navorsing is daarom om die mees geskikste terrein te identifiseer binne die studie area om sodoende die treinspoor met die minste omgewingsimpak met die gebruik van ‘n terreingeskiktheidsanalise te identifiseer.

Die navorsing bespreek die verskillende tipes sneltreine wat bestaan en oorweeg elk se omgewingimpak. Die bespreking lei tot die evaluasie van die agtergrond en status quo van die voorgestelde “Gautrain rapid-rail link” projek. Veskillende benaderings tot terreinevaluasie word bespreek en daaruit word afgelei watter metodologie gebruik sal word in hierdie navorsing. Die besluit word geneem om die aktiwiteitsbenadering soos bespreek in Mitchell (1991) en Hugo *et al.,* (1997) te volg. Die terrein is vervolgens geklassifiseer ten opsigte van terreingeskiktheid vir die “Gautrain rapid-rail link”. ‘n Geografiese Inligting Stelsel (GIS) is gebruik om die terreinanalise te vergemaklik.

Die resultate van al die analises in hierdie navorsing het dit moontlik gemaak om die mees geskikte treinspoor vir die studie voor te stel. Die roete is vergelyk met die roetes wat reeds voorgestel is vir die “Gautrain rapid-rail link”. Vervolgens is dit beslis dat ‘n terrainevaluasie die preliminêre deel van enige omgewingsbestuurs-siklus moet volg soos bespreek in Fuggle & Rabie (1998), om die mees geskikte terrein te identifiseer vir die ontwikkeling.

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ABB	:	Asea Brown Boveri
CBD	:	Central Business District
COD	:	Chemical Oxygen Demand
DEAT	:	Department of Environmental Affairs and Tourism
DWAF	:	Department of Water Affairs and Forestry
EDS	:	Electrodynamic System
EIA	:	Environmental Impact Assessment
EMS	:	Electromagnetic System
GDP	:	Gross Development Product
GIS	:	Geographic Information Systems
IPANet	:	Investment Promotion Network
JNR	:	Japan National Railways
Maglev	:	Magnetic Leviated Vehicles
MTC	:	Metropolitan Transportation Commission
SDI	:	Spatial Development Initiative
Seraphin	:	Segmented rail phased induction motor
TGV	:	French train à Grande Vitesse
TOR	:	Terms of Reference
UN	:	United Nations
WGS	:	World Geodetic System

1. GAUTRAIN RAPID-RAIL LINK- THE POSSIBLE SOLUTION TO TRAFFIC PROBLEMS FOR GAUTENG?

1.1 INTRODUCTION

In Gauteng thousands of people commute daily between Pretoria and Johannesburg; a distance of approximately 60 km, predominantly by a road-based mode of transport. The travel time by road can vary between one to two hours depending on the day of the week and the hour of the day (Crockett, 2001; personal communication). A high population growth of 3,3% *per annum* (DEAT, 2000) - exerts pressure on the transportation infrastructure of Gauteng because of the resultant increases in urbanisation and urban development to compensate for the increased population, which again generates additional road-based traffic. According to Maharaj (1996), it is generally recognised that uncontrolled growth in road-based transport is unsustainable in an urban environment. In order to reduce the major impact of transport modes, such as noise, congestion and air pollution, on the environment, new innovative means of public transport need to be investigated. In terms of the Constitution (Act 108 of 1996), public transport is the responsibility of the provincial governments and must be developed in a sustainable manner (Maharaj, 1996), meaning that public transport should be developed with the aim of minimising damage to the environment.

As a result of the constitutional requirements, the Gauteng Provincial Government has committed itself to the identification of possible solutions to traffic problems and to improving the general state of roads and public transport facilities. An important project that was conducted by the Gauteng Provincial Government, the “integrated multi-model transport system” pilot project, began in 1997 and was funded by the French Government. The aim of this project was to identify the current public transport status in the province and to propose a cost-effective solution in the identification of alternative corridors or transport routes (Gauteng Transport, 1997). According to the Policy Development and Implementation Office of the Development Planning Department of Gauteng a corridor is defined as “a tract of land forming a passageway” which allows access from one area to another (Carmona, 1998). One of the corridors that was identified as a passageway for a possible rail link during this project was between Pretoria, Johannesburg and the Johannesburg International Airport (Gauteng Transport, 1997).

Because of increased environmental education and environmental awareness, the need for sound environmental management principles has increased in recent years. The “prevention is better than cure” approach is being adopted more and more by developers, planners and environmentalists resulting in an approach where negative environmental impacts and problems are prevented rather than relying on the practice of damage control after the problem has manifested itself. This approach emphasises the importance of skilled terrain evaluation which will allow the developer or land user to understand as much as possible about the proposed area before development and construction commence (Hugo *et al*., 1997). The main aim of this research project is to identify the most suitable land within the proposed corridor boundaries for the construction of a rapid-rail link. The suitability of the land will be determined using terrain evaluation methodologies and techniques.

This study is important because Fuggle & Rabie (1998) state that terrain evaluation forms the preliminary part of any environmental management cycle. The starting point of this cycle consists of terrain evaluation progressing to an Environmental Impact Assessment (EIA), Environmental Management Programme (EMP), and regular auditing and improvement. Another reason is that according to the National Conservation Act 73 of 1989, the rapid-rail link is classified as a listed activity where an Environmental Impact Assessment is compulsory unless exemption is granted for reasons that the development will have little or no environmental impact. In the case of the proposed rapid-rail link, the process of terrain evaluation could ensure the optimal choice of land for this specific development resulting in the identification of a suitable terrain with minimal environmental impact. The results of the terrain analysis will be used to indicate the most suitable areas between Pretoria, Johannesburg and the Johannesburg International Airport where minimal environmental damage will be caused by the development and construction of such a rapid-rail route. This will include the identification of specific criteria that could be used to develop a framework against which selected environmental features could be measured in order to locate the most suitable route for a rapid-rail link within the study area.

1.2 THE STATEMENT OF THE PROBLEM

1.2.1 Background to the statement of the problem

Until recently, public transport infrastructure in South Africa has been neglected mainly because of the inequalities of the past. The South African passenger transport system was mainly designed to transport people from dormitory townships to their workplaces. The working poor spent a large amount of time and money on transport and often had to use more than one mode of transport to travel to work, owing to the spatial distances created by the dogmatic approach of the policy of apartheid. Few households in these traditional townships had access to a private car and accessibility of transport to the poor is limited (May, 1998).

According to Peterson (1998) there are “too many cars on South-African roads”. This general statement can be applied to Gauteng in the sense that in 1995 approximately 80 000 vehicles travelled daily between Pretoria and Johannesburg, with a 5% growth *per annum* (Department of Transport, 1995). By 2001, this growth had increased to 7.5% *per annum*, with over 160 000 vehicles per day (Blue IQ, 2001), and in 1995, the majority (65%) of commuters travelled to work in private motorcars (Department of Transport, 1995). Therefore, there is a serious need to improve public transport, especially in Gauteng. Furthermore some existing roads cannot be expanded or new roads cannot be built, because of land constraints such as spacing problems or land use restrictions, e.g. wetlands (Peterson, 1998). The ever increasing pressure of vehicle usage on the roads leads to traffic congestion and accidents and also has serious implications regarding air pollution owing to high levels of harmful emissions of Carbon Dioxide (CO_2) into the atmosphere (Miller, 1994).

For the past few years the Gauteng Provincial Government has attempted to rectify the inequalities of the past as well as the congestion problems by means of initiating various public transport projects, such as the Lekoa-Vaal public transport study, which quantified the current public transport situation in detail incorporating suggestions for improvement. The Gauteng Provincial Government holds this information. These suggestions are still to be implemented and most of the information gathered is difficult to obtain (Crockett, 2001; personal communication).

With proper planning and the improvement of public transport, congestion problems on the roads could be reduced with a positive spin-off in the form of a reduction in harmful emissions from motorcars and subsequently, air pollution. The proposal to build a rapid-rail link between Pretoria, Johannesburg and the Johannesburg International Airport, is an attempt to improve public transport in the Gauteng region, and also to improve transport in general. However, the construction of such a rail route has serious implications for the environment, because a large area of land will be needed for construction, which could lead to environmental problems such as soil erosion, water pollution and noise. On completion of the construction, problems may persist such as noise and vibration from the rail and serious land-use changes, such as residential or agricultural land that changes to commercial or business land-use due to the proximity to the rail.

This research aims to identify suitable land within the proposed train corridor boundaries in the study area and optimise the rail route alignment with minimal environmental impact by means of the use of a terrain suitability analysis. Areas already identified for the rapid-rail link will come under consideration on the assumption that the rail will be built above ground and not underground as proposed for certain areas.

1.2.2 The statement of the problem and main objectives

The proposed rapid-rail link construction and implementation could have extensive environmental impact and implications for the study area. It is therefore important to identify the most suitable route alignment in the study area with the aim to minimise environmental impact, such as noise and water pollution, soil erosion and disturbance of land, before detailed design and construction begin. This will assist in the decision-making process. As discussed earlier the terrain evaluation forms the preliminary part of any environmental management cycle (Fuggle & Rabie, 1998) and this should optimise the alignment of the route with the minimum amount of damage to the environment.

The main objectives of this research are the following:

i. *Research the various high-speed railway types already in use in other countries to consider their impact on the environment;*

This objective will set the scene relative to high-speed rail technologies in the world today. It is important to understand the different high-speed rail technologies, since it is still not very clear from literature which technology will be used for the Gautrain rapid-rail link. For this purpose the different high-speed rail technologies will be explained and reference will be made to the Gautrain rapid-rail link.

ii. *Evaluate the background and status of the proposed rapid-rail link;*

This objective will assist in an understanding of the current status of the proposed Gautrain rapid-rail link. It is important to have knowledge of what studies have been completed and which studies still need to be completed and to show how this research could contribute to the optimisation of the rapid-rail route.

iii. *Research the different approaches to terrain evaluation and show the relevance to the proposed Gautrain rapid-rail link;*

This objective is important in order to clarify the use of the term ‘terrain suitability analysis’ relative to this specific research. An explanation of the different approaches to terrain evaluation will be provided in order to indicate the approach that influenced the methodology applied in this specific research i.e. to determine the best route or terrain on which the rapid-rail link should be built.

iv. *Classify the terrain or study area according to suitability for the activity in question i.e. the construction of the Gautrain rapid-rail link;*

After the terrain evaluation approach to this research is made clear, the methodology that was used in this research will be explained in detail. The terrain will be classified into homogeneous units of suitability, which will assist in the optimisation of the rapid-rail route alignment with minimal environmental impact.

v. *Identify the most suitable terrain for optimising the rapid-rail route alignment with minimal environmental impact;*

After the classification of the terrain has been completed, it will be possible to identify the most suitable terrain for optimising the rapid-rail route alignment with minimal environmental impact. From this objective it will be possible to proceed to the next objective, which is to consider the proposed route alignments and mitigation options.

vi. *Consider the proposed route alignments and mitigation options.*

It is important to consider the proposed route alignments already under consideration by the Gauteng Provincial Government. A description of each route will be given in order to compare them with one another and ultimately to compare them to the optimised rail route alignment. Some mitigation options will also be considered in respect to minimising the environmental impacts resulting from the construction of the Gautrain rapid-rail link.

Finally, in completing the research objectives, the aim of this research project (which is to identify the most suitable land within the proposed train corridor boundaries in the study area in order to optimise the rail route alignment with minimal environmental impact) will have been reached.

2. TERRAIN SUITABILITY ANALYSIS TECHNIQUE RELEVANT TO THE GAUTRAIN RAPID-RAIL PROJECT

2.1 STUDY AREA

The study area is situated in the Gauteng province and covers approximately 1,300 km². The area includes the existing rail corridors between Pretoria, Johannesburg and Johannesburg international airport. The demarcation areas of Tshwane Metropolitan (Pretoria), Johannesburg, and Ekurhuleni (Greater Eastrand) Metro are included in the study area. The study area was chosen because these rail corridors were identified as the potential links for the rapid-rail proposed for this area and according to Blue IQ (2001) this area has been identified for the rapid-rail system because the project will provide a stimulus for economic growth and social development in an attempt to rectify the inequalities of the past, specifically those related to job creation.

Currently the main road commuter routes in the study area include the N1 freeway, the M1, M2 and the N3 (Figure 1). The increased use of these main routes by private motorcars (See Table 1) causes extensive traffic congestion, accidents and air pollution (Department of Transport, 1995). During morning and afternoon peak periods the N1 freeway virtually comes to a standstill.

Table 1: Vehicles registered in Gauteng

VEHICLES REGISTERED AT 30 JUNE 1992			
TYPE OF VEHICLE	**GAUTENG**	**SOUTH AFRICA (TOTAL)**	**GAUTENG AS % OF TOTAL**
Cars	1 480 167	3 483 507	42.5
Minibuses	86 319	209 446	41.2
Busses	8 994	25 994	34.6
Commercial vehicles	409 362	1 265 199	32.4
Motorcycles	104 720	280 813	37.3
Other	247 058	903 603	27.3
TOTAL	2 336 620	6 168 562	37.9

(DEAT, 2000)

FIGURE 1

There is an increasing demand by commuters for more effective and faster transport within these rail corridors because of the current vehicle congestion problems. Between the three city centres (Pretoria CBD, Johannesburg CBD and Johannesburg International Airport), road congestion exerts pressure on the environment specifically associated with air pollution caused by harmful emissions from vehicles, such as carbon monoxide, carbon dioxide, diesel particles and airborne lead. This is one of the underlying reasons for the proposal to build a rapid-rail link between the transport corridors of Johannesburg, Pretoria and the Johannesburg International airport.

There is an existing rail network to the east of the study area and this, together with the N1 national route, were identified as potential rail corridors for the proposed rapid-rail link. This will include an upgrading of the existing infrastructure in the study area (Van Zyl, 2000 personal communication).

Various terminology's' were used and exist in referring to the above project. Initially it was called a "light rail", later a "high-speed rail" and currently referred to as a rapid-rail link. Since most references make mention of the term "high-speed rail" this term will be used in the majority of the research where reference is not made directly to the Gautrain rapid-rail link.

2.2 A GENERAL DESCRIPTION OF HIGH-SPEED RAILS

This section will provide a description and discussion on high-speed rail operations in various locations all over the world and will provide an overview of the presently used technologies in the construction of a high-speed rail. The different types of high-speed rails will also be discussed. Reference will be made to a number of high-speed rail operations in the world including the proposed Gautrain rapid-rail link.

High-speed rail construction dates back over 40 years. Since the first high-speed rail was constructed in Japan, the technology has improved considerably. A high-speed rail system has significant implications, both socially and environmentally. Environmental impacts may include noise and vibration from the rails during and after construction and social impacts may include the development of commercial nuclei alongside the route contributing greatly to the economy of the area (Straszak & Tuch, 1977).

2.2.1 Definition of high-speed rail

According to the Technical Assistance Manual on High-Speed Rail Cars, Monorails and Systems of the United States Access Board (1992), a "high-speed rail" can be defined as "….an intercity-type rail service. This rail service operates primarily on a dedicated guide way or track not used, for the most part, by freight, including, but not limited to, trains on welded rail, magnetically levitated (maglev) vehicles on a special guide way, or other advanced technology vehicles, designed to travel at speeds in excess of those possible on other types of railroads".

The definition of other rail commuter services could be worded as follows: "This class consists of units mainly engaged in operating railways (except tramways) for the transportation of freight or passengers, in operating railway terminal or depot facilities for receiving, despatching or transferring rail freight or cargo, or in providing services allied to railway transport" (ECNext, 2001).

The conclusion that can be drawn from these two definitions is that high-speed rail is mainly a passenger rail service with speeds in excess of 160 km/h (James & James, 1996). Other rail services combine the freight and commuter travel services and travel at speeds of less than 130 km/h.

2.2.2 History and background of high-speed rail

To understand the move towards a proposal for the Gautrain rapid-rail link, a clear understanding of the history and background of high-speed rail is necessary to set the scene for high-speed rail technologies in the world today.

The era of high-speed rail transport began in Japan in October 1964 with the introduction of the Shinkansen "bullet train" running between Tokyo and Osaka (a distance of 800 km), currently with a maximum speed capability of 240 km/h (Figure 2).

Figure 2: Japanese Shinkansen high-speed rail (De Gama, 2000)

The creation of the Tokaido Shinkhansen represented a revolution in land transportation, resulting in a faster, more effective mass transit system, and was brought about by the technology of the Japanese National Railways (JNR) and the courage and hard work of its personnel. The successful operation of the Shinkansen firmly established the importance of Japanese railway technology throughout the world. The planning, construction and implementation of the Shinkhansen took approximately 8 years in total (Straszak & Tuch, 1977).

This was followed by the French Train *à Grande Vitesse* (TGV) in 1981. The TGV network began with a Paris to Lyon service (known as the Paris Southeast route, with a distance of approximately 500 km), followed by the TGV *Atlantique* line to Angers, and a Paris-London route via the Channel Tunnel (distance of 130 km), which went into service in 1994. TGV trains are capable of top speeds of between 270 and 320 km/h.

The early 1990s saw the introduction of the X-2000 running between Stockholm and Gothenburg (distance of 500 km) in Sweden, and the Intercity Express lines from Stuttgart to Mannheim and Hamburg to Munich/Frankfort (distance of 450 km) in Germany. The Intercity Express, like the Shinkansen and TGV, operates on dedicated track that excludes its use by other conventional trains. It is capable of a top speed of 250 km/h. The X-2000 has a top speed of 200 km/h and operates on a track shared with freight and commuter trains (Pilorusso *et al.*, 1995).

The Gautrain rapid-rail link and its design speed is set at 180 km/h (Joubert *et al.*, 2001) and will operate at speeds of between 160 km/h – 180 km/h (Van der Merwe, 2000), which per definition classifies it as a high-speed rail. The two alignments currently under consideration (Joubert *et al.*, 2001) - which will be discussed in detail later in this research – indicate that the rail will have a dedicated track. This means it will operate on an exclusive track specifically built for this rail, and will not be shared with other commuter and freight services.

The following sections will provide an overview on current operating high-speed rail technology.

2.2.3 High-speed rail technology

It is important to understand the different high-speed rail technologies, since it is still not very clear from literature which technology will be used for the Gautrain rapid-rail link. In this section the different high-speed rail technologies will be explained and reference will be made to the Gautrain rapid-rail link.

High-speed trains operate at speeds above 160 km/h, sometimes on upgraded conventional track designed to handle mixed freight and passenger traffic and sometimes on purpose built, dedicated high-speed track (James & James, 1996). If the layout of the route for the Gautrain rapid-rail link is examined (Figure 3), it is debatable if the train will reach speeds above 160 km/h since the stations are in quite close proximity of each other, such as the stations between Marlboro and Sandton (distance of 4.6 km) and the stations between Pretoria CBD and Mears Street (distance of only 1.1 km). On the other hand, high-speed rails tend to be most economic between distances from 160 km to 800 km (James & James, 1996). The estimated distance of the Gautrain rapid-rail link is approximately 80 km in total (Blue IQ, 2001). A conclusion that can be drawn is that it might not be economically feasible to build the Gautrain rapid-rail.

Very high-speed trains, which operate at speeds of 300 km/h or above, require separate rights of way of precise tolerance and clearance from slower freight traffic. The major

FIGURE 3

technological limitations on train speed are aerodynamic effects, sound shocks, and wheel friction. These problems are partially overcome by the TGV, tilt train, Maglev and Seraphim designs, which will be explained in the following sections (James & James, 1996).

There are four types of high-speed rail:

- High-speed-steel-wheel-on-steel,
- Maglev (Magnetic Levitation),
- Monorail, and
- Seraphim (segmented rail phased induction motor - developing technology)

Each of the above types of high-speed rail will be discussed separately.

2.2.3.1 *High-speed-steel-wheel-on-steel*

The high-speed-steel-wheel-on-steel trains are similar to traditional standard trains, but differ in that they can travel at speeds of over 160 km/h. It is the preferred technology above Maglev or Monorail because of cost implications. The very high-speed trains can reach speeds of up to 260 km/h (MTC, 1999). The French Train *à Grande Vitesse* (TGV) and tilt trains are two types of high-speed-steel-wheel-on-steel trains which will be discussed in the following sections.

(i) The French Train à Grande Vitesse (TGV)

The French Train *à Grande Vitesse* (TGV), French for ‘high-speed train[s] system’, incorporates a number of innovations including line design, aerodynamic rolling stock and reliable network control (Figure 4). It utilises overhead power supply, specialised continuous signalling and relatively steep gradients to avoid costly tunnels and earthworks. Train management operations permit four minute spacing at peak periods at speeds of over 270 km/h.

Figure 4: French train à Grande Vitesse (TGV) (Kriman, 2000)

While the TGV system was initially quite an operational and financial success, in recent years some planned extensions in France have met with resistance from government officials and anti-development groups. Areas of land would have to be bought and cleared to provide space for the rail tracts that have to be built. Nonetheless, the TGV system forms part of a wider network of high-speed European trains extending from the Netherlands to Belgium, France, Germany, Great Britain, Italy and Switzerland (James & James, 1996).

Recent TGV upgrades featured onboard-computerised control systems, fewer motors and better braking for use on new cross-country routes. The TGV can operate at lower speeds on existing railway track, although some track modifications may be required. A derivative of the TGV serves the Channel Tunnel route as the Euro Star train, while Spain has purchased TGV rolling stock for use on its special high-speed routes (James & James, 1996). TGV remains only suitable for countries with available credit, high-density rail corridors and valid reasons for building a high-speed line mainly for passenger use (United Nations, 1988). TGV holds the world rail speed record of 515 km/h.

The Gautrain rapid-rail link has been proposed to "unlock the inherent economic potential" of Gauteng (Joubert *et al.*, 2001). The budget set aside specifically for this project is not very clear, but there has been a call for private investors to get involved (Blue IQ, 2001). The rail is also perceived as a conduit for the job creation, improved accessibility between different nodes and enhanced economic growth of areas affected by the rail (Joubert *et al.*, 2001). An assumption could be made that economic growth will be stimulated because of increased tourism and job creation as result of the construction of the Gautrain rapid-rail link. It would seem that there is enough reason and motivation to built the rail because of the job creation opportunities. Furthermore, the Pretoria, Johannesburg and Johannesburg International Airport corridor is perceived as a high-density corridor with more than 160 000 vehicles travelling within the corridor boundaries per day.

(ii) Tilt trains

Tilt trains use suspension systems that allow them to take curves at greater speeds than usual, such as above 160 km/h (Figure 5). They have been operating for some years in Europe using traction bogies with radially self-steering axles and a car body tilt control system, all under computer control. Tilt trains are equipped with extra brakes to cope with the higher speeds at curves at which they operate. The European companies Siemens and Adtranz (formerly Asea Brown Boveri; ABB) offer tilt train versions using Italian and Swedish technology (James & James, 1996).

Figure 5: Swedish X2000 tilting train, top speed 200 km/h (Keating, 2000)

Tilt trains offer an economic solution that allows at least 25% faster services on existing curvilinear routes without requiring investment in new high-speed train rights of way or in upgrading existing rail routes. Germany is presently introducing tilt trains on a number of regional routes which would otherwise not justify upgrading to international standard. France is investigating tilt train services to supplement its existing TGV network (James & James, 1996).

The proposed Gautrain rapid-rail link's vertical curve radius to accommodate for the design speed is set at 25 000 meters (Joubert *et al.*, 2001). This required radius was calculated according to international standards. It will still be required of the train to slow down at the curves and then speed up again. The technology of a tilt train might assist in this regard. The train does not have to slow down and in this way it could get rid of the curve problems.

2.2.3.2 *Magnetic Levitation transportation (Maglev)*

Maglev is an abbreviation for magnetic levitation transportation (Markham, 1999). This technology is a generic term for a family of technologies in which magnetic forces suspend, guide and propel a vehicle, unlike the electromechanical techniques used by conventional trains. Although conceived over thirty years ago, research and development have taken some time, with virtually all concentrated in Germany and Japan.

The economics of the Maglev-technology remain unclear as there is at this stage no long distance Maglev train services in commercial operation. A Maglev vehicle's magnets lock into a magnetic wave created by an alternating current fed to windings along the guide way. Variation of the electrical energy controls speed to provide direct linear motion rather than conventional rotational wheel motion, to speeds up to 400 km/h.

Figure 6: Maglev vehicle (Markham, 1999)

Maglev-technology utilises a linear induction motor that creates a powerful magnetic force enabling trains to float above a guide rail. The linear motor operates like an ordinary cylindrical motor split down the middle and stretched out along the track. The train wraps around the guide way to prevent de-railing and, as there are no wheels, noise is minimal and mostly due to air flows.

Maglev trains use around 30% less energy than standard trains at the same speed, and far less than cars or commercial aircraft. Magnetic fields inside train cabins equal the Earth's field, but do change rapidly; which is a potential health concern. Maglev trains can reach speeds of up to 400 km/h and negotiate grades as steep as 10% (1:10) with a track radius of 2,2 km for a speed of 300 km/h. The first operational Maglev system was introduced at Birmingham Airport as a shuttle in 1984 (James & James, 1996).

There are two types of magnetic levitation: electromagnetic (EMS) as used by Maglev and electrodynamics (EDS) as used in Japan:

I. The electromagnetic system (EMS)

This technology relies on attraction between vehicle-mounted electromagnets and others on the underside of the guide way to counter the weight of the train.

II. The electrodynamics system (EDS)

This technology uses a greater gap with repelling super conducting magnets to counter vehicle weight, allowing less precision in guide way construction giving poorer ride quality (James & James, 1996).

The Gauteng rapid-rail link will only be capable of reaching speeds of up to 180 km/h. For this reason Maglev technology would probably not be required, for Maglev trains exceed speeds of 300 km/h. Distance will also play a role in the economic feasibility of such a rail since the Maglev technology has only been applied over relatively short distances (7 – 15 km) with few stops along the way.

2.2.3.3 *Monorail*

The monorail technology is extensively used for inner-city corridors where there is no room for a new right-of-way, as it can travel at very high speeds and can follow an interstate highway's route while staying within the existing right-of-way. It is also less expensive than other rapid transit systems, conventional trains such as the TGV, and Maglev systems. It has also been introduced to crowded metro (commuter) systems where high passenger-carrying capacity is needed. Its elevation above existing roads (Figure 7) eases land acquisition and usage problems, offers high passenger-carrying capacity, and can be integrated seamlessly with an intercity system with the same monorails, thus building ridership throughout the system (Guthrie, 1999).

The monorail has a wrap-around-the-beam design. Its vertical load is carried by two wheels, which run on the bottom flange of the guide way beam (wheels at each end of each vehicle segment), and it is guided by two horizontally mounted wheels which are higher up and run against the side of the beam. This makes the monorail extraordinarily safe, stable, comfortable, and fast. Current monorail technology is an evolution of earlier monorail designs and has greatly improved performance. The high-speed monorail is powered by a linear motor which is very quiet as it has no moving parts, can travel at high speeds, manages steep grades, and operates in rain, snow or ice.

The centre of gravity is low (the motors are mounted below the guide wheels), enabling it to turn tight corners at high speed and to withstand high crosswinds. The high-speed monorail, with its unique suspension and with a special version of the linear motor, is expected to be capable of speeds of up to 400 km/h in some corridors. The linear motor's reaction rail is mounted on the guide way beam and its coils are mounted on the vehicle.

The monorail is less harmful to the environment: it is quiet, requires minimal earthworks and rock cuts, limits the acquisition of new right-of-way, and is energy efficient. Economic benefits reflect a system with low capital cost, low operating costs, high passenger comfort and service, and significant indirect benefits to society such as reduced highway congestion and reduced automobile exhaust emissions. When estimating the cost of a monorail system, the dominant factors are the cost of pre-cast concrete, and the need for special structures such as tunnels and bridges (Guthrie, 1999).


Figure 7: Monorail: Sydney Australia (PhotoEssentials, 1999)

The monorail could be a solution to the problem of inner-city travel within the corridor boundaries of the proposed Gautrain rapid-rail link, especially within the highly developed sections between Sandton and Johannesburg CBD. It is anticipated that some of the rail will be built underground to avoid high-density residential areas (Joubert, 2001) if the rail uses high-speed-steel-wheel-on-steel technology.

2.2.3.4 *Seraphim – future technology for monorail and Maglev*

Engineers at the Sandia National Laboratories at Albuquerque, New Mexico, have developed a way to operate an electromagnetically propelled train on conventional tracks. The segmented rail phased induction motor (Seraphim) operates on wheels at 300 km/h over conventional but modified tracks. Conventional rail propulsion depends crucially on the friction between train wheels and the rail to drive the train forward. As train speed increases so does wind resistance, such that, at 300 km/h, it is stronger than the frictional force, requiring elevated tracks to enable the air to pass below the train.

The principle underlying electromagnetic induction is that a current is induced in a conductor when a changing magnetic field is applied. The current sets up a magnetic field in opposition to the original field, resulting in a force that pushes the magnet away. To utilise this principle, rail tracks require a series of aluminium plates or an adjacent segmented aluminium rail along the track. Seraphim motors consist of pairs of electromagnets arranged so that the segmented rail pass through the gap between them as the train moves along the track. Complex switching on the electromagnets as each segment passes between them propels the train forward. Each locomotive could have up to thirty electromagnets powered by an on-board gas turbine generator.

However, significant development problems remain including the complex switching between trains, shielding passengers from the magnetic fields, resonance noise, cooling and wheel friction. Without levitation, the Seraphim train would subject track beds and rails to considerable wear. The gas turbine generator would add weight, mobile pollution and energy costs. Its linear induction motor would also add weight, unlike Maglev linear synchronous motors. Concerns about brakes for safety also arise. Unlike Maglev, Seraphim could use existing tracks if ever proven to do so (James & James, 1996).

The technology of Seraphim is still developing and requires further refinement. In 2001, $2 million were granted to Sandia National Laboratories (Singer & Kelly, 2001) for further research and development. In this regard, it probably would not be considered as the desired technology for the Gautrain rapid-rail link.

2.2.4 Environmental impacts associated with a high-speed rail

A number of factors need to be considered in assessing the net environmental impact of a high-speed rail service. These include the impact on agricultural lands and environmentally sensitive areas, such as wetlands, as a consequence of the construction of new dedicated rail lines, as well as noise in populated areas. The key environmental impact associated with high-speed rail is wayside noise. The mitigation of environmental impacts, primarily noise, can be costly, since extra money should be put aside to construct sound barriers next to the rail (HCSCT, 1992).

According to Hothersall & Salter (1977) the environmental impacts associated with a high-speed rail are the most severe during the planning, construction and implementation of a high-speed rail. The environmental impacts include noise and vibration impacts; visual incompatibility; incidental effects; and land acquisition and land use problems. Other environmental impacts that should be considered are associated with hydrology, water quality and the impact on local ecosystems (Cohn & McVoy, 1982). These impacts will be discussed accordingly.

2.2.4.1 *Noise and vibration*

The operation of a railway generates considerable noise, especially when high-speed passenger trains are in service (Hothersall & Salter, 1977). Noise and vibration were the two most serious environmental problems generated by the Shinkhansen in Japan. The level of noise as well as the duration of the noise close to the Shinkansen track cannot be prevented, as steel sheets are running on steel rails at a speed of 240 km/h. It became a social problem. The government was forced to buy the land along the route, pay compensation to those concerned and construct sound barriers along the route (Straszak & Tuch, 1977). Thus, land use and land values are affected by noise levels. As long as railways are not close to residential areas, communities do not experience the full annoyance of the noise generated by the rail operation (Hothersall & Salter, 1977).

The goal of noise analysis should be to identify those parameters which will affect the emission, transmission, and reception of noise by a human. These parameters include:

temporal distribution of sound; magnitude of sound; cyclic frequency of sound; and coherence or time-variance of sound (Cohn & McVoy, 1982). Several technologies exist to minimise the sound levels. These technologies mainly include changes in the design of the rail track and train, such as improvements in the design of both rolling stock and track to reduce the noise due to rail-wheel interaction (Hothersall & Salter, 1977).

Vibration owing to the operation of the rail, especially high-speed rail, can cause several problems. Buildings can be severely affected if proper design criteria are not followed, such as cracks in walls as result of the shaking of the buildings. Houses in residential areas can also be damaged. The mitigation costs, such as improving the design to minimise noise and vibration, can thus be very high. Since the aim of this study is not to provide technical "advice" on how to reduce the noise and vibration levels, such recommendations should be considered in a full environmental impact study.

(i) The human response to noise

The measurement of sound pressures and the expression of decibels can only indicate the physical properties of sound waves. It cannot express the loudness of sound, which depends upon the sensitivity of the human hearing mechanism. Human response depends further on the sound-pressure level and also upon the frequency of the sound. To a certain extent it is modified by the age of the hearer. Loudness is further a very subjective quantity, and different experiments using differing techniques could obtain different results (Hothersall & Salter, 1977).

(ii) Mitigation measures implemented for the Shinkhansen high-speed rail since December 1972

According to Straszak & Tuch (1977) the measures required to minimise the problems of noise and vibration since December 1972, are as follows:

- Implement countermeasures at the sound sources, so that the noise level is below 80 phons in residential areas along the line.

- For dwelling houses in an area where the noise level persists at 85 phons or more after countermeasures have been taken at the sound sources, take steps to remove the nuisance so that daily life is not impaired too much.
- Give special consideration to schools, hospitals and other institutions that are particularly affected by the nuisance of noise,
- For areas suffering from damage due to vibration, consider methods to ease the impact.
- During night-time track maintenance work, endeavour to reduce the noise level by improving the method of job execution.

2.2.4.2 *Visual incompatibility*

Visual incompatibility involves the loss of amenity of convenience, direct or indirect, or being deprived of places or landmarks formerly used to obtain amenities (Straszak & Tuch, 1977). A new railway and stations will have a visual impact. Land will have to be cleared and previous landmarks such as monuments could be altered or moved to make way for the proposed route. Several mitigation methods exist, such as landscaping to improve the visual impact, and to make the new development compatible with the rest of the surrounding areas.

2.2.4.3 *Incidental effects*

This involves the items of pollution caused by, for example, an unexpected increase in tourism, motorway congestion, and infrastructure change. This will put stress on the environment with an increase in air and water pollution, owing to increased activities, such as development along the route (Straszak & Tuch, 1977).

There is an anticipation of increased travelling and tourism in the area once the rail has been constructed, which will result in the above-mentioned effects. More detailed studies are required to clearly understand the various impacts that may result from increased travel and tourism, other forms of development along the route and the overall impact on the public transport system.

Other secondary issues may include the impairment of television reception and the obstruction of sunlight (Straszak & Tuch, 1977). These environmental “pollutants” are not directly detrimental to man or the environmental health, but are seen as an annoyance or as impacting adversely on the living environment.

2.2.4.4 *Land acquisition and land use problems*

Land acquisition and land use problems are associated with the transformation of land areas from traditional uses to transportation infrastructures, including such items as railways, roads, stations and parking lots (Straszak & Tuch, 1977). The construction of the high-speed rail in Gauteng will definitely imply such changes. Since there is mention of the construction of a new rail infrastructure, as well as 10 new stations (IPAnet, 2000), land will have to be bought by the Gauteng Provincial Government and transformed and re-zoned to suit the new land use.

2.2.4.5 *Environmental impacts on hydrology, water quality and ecosystems*

The impact of transportation systems on hydrology, water quality, and local ecosystems can be very complex (Cohn & McVoy, 1982). There are few standard procedures available to assess the impact since the complexity of the impact on these systems is in many cases unpredictable.

Transportation systems, such as a high-speed rail, can affect local hydrology and water quality as well as aquatic and terrestrial ecosystems in a number of ways:

- The restriction of surface and groundwater flows can result in severe changes in the characteristics of the water catchment area.
- The filling of floodplains or paving of permeable soil can aggravate local flooding problems.
- Construction activities can create serious erosion and sedimentation problems contributing to the water pollution problems.
- The construction of a transportation system, can attract growth in the form of commercial, industrial, retail development and wastewater treatment works. The

indirect impacts, such as increased use of water and pollution, can therefore be more severe than was originally anticipated. (Cohn & McVoy, 1982).

(i) Hydrologic and Water Quality Impacts

Unfortunately, transportation facilities are often close to streams, lakes and wetlands (Cohn & McVoy, 1982). If the high-speed rail is built close to any of these systems, it will result in either the destruction or modification of these systems, which may have a ripple effect on the resident aquatic ecosystems in the area, which could result in flooding problems. Thus a detailed understanding of the hydrological cycle of the study area is necessary to predict any changes in the surface and groundwater flows as well as aquatic ecosystems.

Other impacts can include: canalisation of streams to constrict flow which result in flooding; damage caused during the construction of the rail; increased erosion and sedimentation; and changes in the vegetation and water table levels. The water quality can also be affected during construction as a result of the generation of erosion, turbidity, and sedimentation together with increases in COD (chemical oxygen demand) and nutrient levels that may be associated with the increases in turbidity levels. (Cohn & McVoy, 1982)

(ii) Ecological Change

Ecology is a branch of biology that deals with terrestrial, marine and freshwater systems (Cohn & McVoy, 1982). Ecological change resulting from the construction or operation of a transportation system may cause damage to the natural ecosystem balance (Straszak & Tuch, 1977). Any deposits into the freshwater system, such as building material which results from construction of the rail, may cause ecological change. Water could be polluted since the nutrient composition of the water has changed and this might have a negative effect on the biodiversity of the system. Factors that need consideration to predict the ecological changes in an area are the natural selection, trophic levels, biodiversity, nutrient cycling, wetlands, and rare and endangered species. (Cohn & McVoy, 1982)

The assessment of ecological impacts is a exceedingly difficult and uncertain task and few standard techniques are available to guide the analyst. Part of the problem is owing to the fact that most impacts are a result of secondary and tertiary actions, such as a disturbance in the aquatic environment that may result in disturbances in the ecological cycles. This may not always be detected immediately after the impact had occurred. The most important aspect to consider is that everything is connected to everything else (Cohn & McVoy, 1982), for example, changes in the surface water can result in changes in the aquatic life and so forth.

The implications of ecological change for the construction of the rail are that areas that have already been "flagged" could be impacted by the Gautrain rapid-rail link. The wetland in the Glen Austin area in Midrand (Blue IQ, 2001) is one example where the construction of the rail through this area could result in extensive changes of the surface water quality causing changes to the aquatic life in this ecosystem. Extensive research will be required to fully understand the impact of the construction and implementation of the rail on this particular ecosystem.

2.2.4.6 *Other considerations*

Various other aspects of a high-speed rail line should be investigated, such as:

- The necessity for a new line, i.e. are there other alternatives, such as the improvement of the existing public transport infrastructure;
- Type of structure and technology of the new line;
- Funding, construction, and operation of the new line;
- Transport demand on the high-speed rail line;
- Integration with various modes of transport, such as busses and taxi's;
- Date when the high-speed rail line service would reach saturation;
- Economic regeneration;
- The cost of land, i.e. land that should be bought to build the rail link;
- Land ownership, i.e. who owns the land that needs to be bought; and
- The target markets and groups, i.e. who are targeted to use the new rail service.

(Straszak & Tuch, 1977) & (Mason, 2000, personal communication)

2.3 BACKGROUND AND STATUS OF THE PROPOSED GAUTRAIN RAPID RAIL LINK PROJECT

According to the Spatial Development Initiative (2000a) website, the Johannesburg-Pretoria corridor (Figure 1) is one of the fastest growing areas in South Africa. Gauteng was established as recently as 1994, and the province comprises essentially the region known historically as the PWV (the Pretoria-Witwatersrand-Vereeniging complex) – the industrial, financial and commercial heartland of the former Transvaal province, and of South Africa. Since the discovery of gold on the Witwatersrand, Gauteng has been the engine of South Africa’s transformation from an agriculture-based society to a modern industrial nation. The Gauteng province accounts for some 40% of the country's Gross Domestic Product (GDP) (GEDA, 2002).

Historically, Gauteng’s economy was centred upon mining and minerals. More recently manufacturing and the services sector have become predominant, with financial services, information technology and telecommunications now the fastest growing industries (GEDA, 2002). Gauteng prides itself for being the “smallest, richest, smartest, most go-ahead” province in South Africa. With the initiative of the Spatial Development projects, Gauteng made it clear that it was serious about creating a business environment for investors that was innovative, imaginative, stimulating, supportive and rewarding. The province is committed to encouraging the growth of trade and industry. R1.2 billion was committed to a programme specially designed to stimulate economic growth in the province. This project was labelled the “Spatial Development Initiative programme”, more recently, labelled as “Blue IQ – the plan for a smart province”. The Department of Trade and Industry, the Gauteng Government, Investment South Africa and the Gauteng Economic Development Agency are all supporting this programme (GEDA, 2002).

The Gautrain rapid-rail link is one of 11 projects specifically identified for the purpose of stimulating economic growth in the province. It involves the implementation of a new rail-bound mass transit system serving the Johannesburg-Pretoria corridor, including the Johannesburg International Airport (SDI, 2000b). Some of the other projects include the innovation hub, the cradle of humankind and the Johannesburg International Airport and surroundings (GEDA. 2002).

2.3.1 Current status of the Gautrain rapid-rail link project

The Gautrain rapid-rail link project was approved in June 2000 by the Gauteng Provincial Government (Xundu, 2000). Mr. Jack van der Merwe, Head of Transportation and Public Works of the Gauteng Provincial Government and Project Manager of the rail project, commented that a pre-feasibility study had shown that there was enough patronage demand (estimated at 64 000 daily passengers) and financial interest (from investors) for the project to go ahead. The feasibility study was carried out by the British and American rail company Arcus Gibb, as well as the local electrical, mechanical and engineering firm Lebone and the Khuthele Project (Forsyth, 2000).

A planning and implementation study was completed in June 2000 by the above mentioned consultants, the objectives of which were to focus on the scope of the study, providing a background of the study, to identify those factors that would influence the study, and also to provide an outline of the business plan and study design (Gautrain, 2002).

A general feasibility study was completed in August 2001. The objectives of this study were the following: Firstly, to broadly plan the project which involved the system planning (including land use, route alignment, station placing, technology and operations) and the needs assessment (including market focus, demand determination and revenue estimation). Secondly, to perform a feasibility analysis, including a financial analysis with the focus on financial viability and bankability, inter alia in order to confirm the findings of the pre-feasibility study and to prepare a Request for Proposal (RFP) to prospective bidders (Gautrain, 2002).

Some of the conclusions drawn from this report were the following: The project was technically feasible with reference to the route alignment, station location, appropriate technology and technical risk. Secondly the project was economically feasible, in that the benefits greatly outweigh the costs. The project also proved environmentally feasible in that no fatal flaws were found and a few red flag issues were identified for further attention. These red flag issues included the wetlands in the Glen Austin area; the open, vacant land through which the route passes in the south-east quadrant of Centurion which is characterised by different types of grassland, including the rare Bankenveld type; and the Modderfontein Nature Reserve just north of Alexandra which the route is to cut through. Some of the major environmental impacts that were identified included noise and vibration within residential areas, wetland loss, and the proximity of conservation areas (Gautrain, 2002).

It was clear from the general feasibility study that a comprehensive Environmental Impact study would have to be conducted before the inception of the project. There are also other studies being undertaken into *inter alia* the route alignment, an implementation study and a financial model. This is to determine whether the Gautrain should be a design built, operated and transferred public-private partnership and to identify ways to attract private sector participation. Most of these studies still need to be completed.

Two network options were under consideration. The first option stations in the Pretoria CBD, Hatfield, Mears Street, Centurion, Midrand, Malboro, Sandton, Rosebank or Bruma, Johannesburg CBD, and the Johannesburg International Airport (Blue IQ, 2001). This route will follow a T-formation (Figure 3). Another route that was considered was the construction of a rapid-rail route outside the built-up areas of Johannesburg proceeding straight to the Johannesburg International Airport (Van Zyl, 2000; personal communication).

From information currently available, the decision was made to choose network option 1 which links to the main business centres of Rosebank, Sandton, Marlboro, Midrand, Centurion, Pretoria CBD and Hatfield (Blue IQ, 2001). A number of factors were considered in choosing the main business centres or station locations, such as existing population density, current economic growth rate, future growth potential, accessibility and road potential and integration possibilities with other modes of transport (Gautrain, 2002). The private sector has shown an interest in funding the stations on condition they are built next to their places of business (Van Zyl, 2000; personal communication). Sections of the route will be built underground, because of noise and vibration problems as well as land-use acquisition problems. The routes between Rosebank and Sandton, as well as Marlboro and Midrand will be built underground. Thus a total of 11 km of the route will be underground (Blue IQ, 2001).

The pre-feasibility Environmental Impact Study (EIA) which had the aim of developing the Terms of Reference (TOR) was completed by the end of February 2001. The full EIA is currently underway. The consultant that was appointed to complete the EIA is Bohlweki Environmental (Pty)Ltd (Blue IQ, 2001). The EIA is expected to take approximately 18 months to complete.

Blue IQ has set a very high standard for all the services that will be provided, such as the planned feeder distribution system to complement the Gautrain rapid-rail link. This will contribute to the effectiveness of the public transport system (Van Zyl, 2000; personal communication). The feeder and distribution system that is proposed is not to interfere with or to compete with the existing public transport systems of Gauteng. The rapid-rail link will be a system operating privately on its own, where the government is expected to share in some of the profits (Blue IQ, 2001).

Although termed a rapid-rail project the trains are only expected to reach maximum speeds of between 160-180 km/h. In order to operate consistently at these speeds, certain geometric design standards will have to be met, with reference to the horizontal and vertical alignments of the rail route (Van Zyl, 2000; personal communication). A comprehensive cost-benefit study is still to be completed to fully understand the costs involved (Eybers, 2001).

The Gauteng Provincial Government has set aside R1.7 billion for all the current and planned SDI Projects in the province. The total expected cost of this specific project is estimated at R700 million, of which R300 million will be subsidised by the Government (Eybers, 2001). However the total expected capital costs of the project are not known at this stage as it is anticipated that the cost may increase as the project proceeds.

The rapid-rail link will be a partnership between the private and public sectors. Advertising and public call for tenders took place in September and October 2001. A standard tendering process for large projects will be followed: Pre-Qualification; short-list of consultants; 6 months to complete the tender; and choice of the successful consultant. The construction of the rail route could commence as soon as 2003, and very ambitiously be completed by 2006 (Van Zyl, 2000; personal communication).

2.4 TERRAIN EVALUATION AND ITS RELEVANCE TO THE GAUTRAIN RAPID-RAIL LINK

2.4.1 Concept and Definitions

The term *terrain evaluation* has been adopted following the precedent of previous research carried out under the auspices of the Military Engineering Experimental Establishment. It was developed in response to the need for an understanding of terrain by an increasing variety of disciplines concerned with its practical uses. These are both scientific, such as geology, hydrology, geography, botany, ecology and zoology; and applied, such as agriculture, forestry, civil engineering, and urban and recreational landscape design (Mitchell, 1991). According to Kantey (1997): “The function of terrain evaluation is to provide the user with a reliable estimate of the effect of the terrain on his/her proposed activity or project.” This short definition sums up the whole purpose of terrain evaluation, which is to identify areas that are suitable for a proposed activity or project and can be of use to a wide variety of sciences, such as agriculture, forestry and urban development (Beaven, 1994).

Terrain is defined by the New English Dictionary as a ‘tract of country considered with regard to its natural features and configuration’. *Evaluation* is defined as the ‘act or result of expressing the numerical value of; judging concerning the worth of’ an object (Mitchell, 1991). In other words *evaluation* is concerned with assigning a numerical value to a piece of land. *Suitability* means the fitness, ability, capability or potential for something. In environmental terms the word ‘suitability’ should only be used for evaluations based on assumptions about potential usability or productivity if specified management alterations were to be made (Lasting Forests, 2000).

Thus *‘Terrain Suitability Evaluation’* is concerned with the fitness or potential of the terrain for a specific activity, for example the proposed Gautrain rapid-rail link. When detailed terrain evaluation has taken place and alternatives have been identified, the suitability of each option will be considered and evaluated, and thus the potential of the terrain for that specific activity will be determined. Land suitability on the other hand is described as the fitness of a given type of land for a defined use. The land may be considered in its present condition or after improvements (FAO, 1981). Thus a Land

Suitability *Analysis* will estimate which areas are suitable for a specific activity or development and will include a scientific methodology of determining the potential of an area for a specific use. An *analysis* also involves the collection, organisation, and interpretation of data (Mitchell, 1991).

The term ‘terrain’ and ‘land’ are closely related to each other, since terrain refers to a piece of land. By substituting the term ‘land’ in “Land Suitability Analysis” with ‘terrain’, one comes to the conclusion that “Terrain Suitability Analysis”, as referred to in this research, is concerned with the suitability of the terrain for a specific activity. In this case the proposed Gautrain rapid-rail link, which will involve data collection, organisation and interpretation.

2.4.2 The importance of terrain evaluation in relation to environmental management

Terrain represents a vast number of features, which include water, soil, rocks, land-use and vegetation. The acceleration in population growth and land-transforming technologies, such as building structures, is constantly changing the environment. More land is needed to accommodate the increased development that is associated with the acceleration in population growth. This leads to changes in the environment such as clearance of land for building structures. More effective ways of managing these changes are needed to access the environmental impact associated with new developments (Mitchell, 1991).

According to Fuggle and Rabie (1998), the terrain evaluation forms the preliminary part of any environmental management cycle. The starting point of this cycle consists of the terrain evaluation progressing to an Environmental Impact Assessment (EIA), Environmental Management Programme (EMP), and regular auditing and improvement. Thus the terrain evaluation can aid the decision-making process, during for example an environmental impact assessment of a particular development, in this case the proposed Gautrain rapid-rail link. When a suitable site and its alternatives have been identified through terrain evaluation, environmental impacts and problems can be minimised and avoided. The process of terrain evaluation could ensure the optimal choice of land or area for the proposed Gautrain rapid-rail link while minimising the environmental impact of such an activity.

2.4.3 Approaches to classifying the terrain

According to Hugo *et al*., (1997) there are two main approaches to terrain evaluation. The Landscape approach and the Activity approach. These two different approaches are important in relation to the classification systems for the terrain. According to Beaven (1994), the classification system that is used reflects the purpose of the terrain evaluation and the background of the user and that the purpose of any classification approach is to group all similar objects together and to separate them from those with different characteristics. One of the major challenges in terrain mapping is to create a classification system that can accommodate the variability and variation on the ground. The two approaches as referred to in Mitchell (1991) are firstly the 'physiographic' or 'landscape' approach, and secondly the 'parametric' or 'activity' approach. These approaches will be discussed in the following two sections.

2.4.3.1 *Landscape approach*

The landscape approach is based on the identification of landscape patterns as seen in remote sensing imagery (Beaven, 1994). The goal is to identify relatively homogeneous areas with respect to the various variables considered, such as hydrology, agriculture and forestry, nature conservancy and climatology. The landscape approach can aid the developer or researcher to identify regions with similar potentials for various activities. (Mitchell, 1991). An example of this method could include a soil classification system where all relevant factors contributing to the different formation of various types of soil are classified in categories to show a soil potential for agricultural activities (Beaven, 1994).

The landscape approach is often used in relatively undeveloped areas where data is not readily available and where there is not any definite plans regarding an activity for a given area (Hugo *et al.,* 1997). Based on this consideration, the landscape approach was not used as a base methodology for this research project as the activity was clearly defined, in this case the Gautrain rapid-rail.

2.4.3.2 *Activity approach*

The activity approach is more specifically related to a specific activity (Hugo *et al*., 1997), such as a proposal for a high-speed rail. This form of terrain classification is based on the identification and mapping of the individual factors that affect the intended land use, such as slope, soil condition, soil type and geology. Combinations of these factors are used to identify areas of land with closely defined characteristics (Beaven, 1994).

This type of mapping would give more detailed results and with the use of a GIS the activity approach could be effectively implemented for the mapping procedure (Beaven, 1994). A clear definition of the activity or development exists, in this case the Gautrain rapid-rail. The area is then interpreted with the specific activity in mind (Hugo *et al*., 1997).

When the development has been identified the environmental requirements of such a development could be determined. The parameters are identified in order of importance. The homogeneous areas with respect to these parameters are mapped and given different values or ratings according to suitability for the activity in question, hence the term terrain suitability analysis (Hugo *et al.*, 1997). The activity approach formed the base for the methodology of the terrain suitability analysis in this research. The methodology will be explained thoroughly during the following sections.

3. INFORMATION GATHERED AND METHODS OF ANALYSIS, RELEVANT FOR DEVELOPING THE TERRAIN SUITABILITY ANALYSIS MODEL

3.1 IDENTIFICATION OF THE SET OF PARAMETERS RELATIVE TO THE CONSTRUCTION OF THE GAUTRAIN RAPID-RAIL LINK AND THE COLLECTION OF RELEVANT DATA

As discussed in various literature (FTA, 1995; VTA, 1996; SRA, 1997; UNB, 1999; and Arup, 2001) the parameters relative to the construction of a high-speed rail link that need consideration are directly related to the environmental impact on each parameter. Thus the following parameters were chosen for further study: topography, gradient, slope, geology and soil, hydrology, vegetation, conservation areas, land use, and existing infrastructure, such as roads, power lines, schools and hospitals. Data regarding each parameter had to be obtained, either from persons and departments that manage the information, or had to be captured from existing maps, such as the 1:50 000 topographic map series of South-Africa. Table 2 shows a layout of all the data that has been collected and captured, and is found in Appendix A.

The parameters that were identified are significant in relation to the construction and implementation of the Gautrain rapid-rail link. As was seen in VTA (1996), the environmental impact assessment which was completed for the construction of a light rail extension named the “Tasman Corridor Project” included factors such as noise and vibration, land use, vegetation, water resources and drainage problems, soils, geology, and cultural resources. This explains the decision to obtain data regarding these factors, for example the location of schools and hospitals which may be affected by the noise and vibration of the proposed rapid-rail link.

Topography, gradient and slope were chosen for this particular study because any rail that is built will have an environmental impact on its direct surroundings, such as excavations that are needed to build a rail tract on a suitable slope. In the case of the Gautrain rapid-rail link, the slope is not to exceed 2,5% (1:40) (Blue IQ, 2001), because a steeper slope or gradient would result in difficulty in operating the rail. Geology is important, because of ground shaking during construction and also after construction where vibration from the rail may persist (VTA, 1996). The stability of the geology would therefore, require consideration, since it would play a role in the design criteria. The erosion potential of the soils (VTA, 1996) in the area is also important as the construction of the rail may cause increased erosion problems caused by the disturbance of the land. Data regarding the location of existing wetlands, rivers and dams is needed because the construction of the rail will impact on these systems such as changes in the drainage patterns of rivers, which in turn could increase the potential of flooding (VTA, 1996).

Information regarding the land use is important, since the construction of the rail may cause the permanent displacement of residential households (Varsona, 1996) in order to provide space for the planned rail route as well as the building of the stations. Data regarding conservation areas and vegetation types in the study area have already been identified by Blue IQ (2001) as parameters of concern. Consequently, information regarding conservation areas and vegetation types was included in the research.

The data that was used for this research was obtained mainly through utilising currently available data, such as those used for the digitising of the 1:50 000 topographic maps (see Table 2 for a detailed explanation of the source of data). The data includes information regarding gradient and slope, geology types, soil types, hydrology, location of rivers, wetlands and dams, vegetation types, conservation areas, types of land use, and location of existing infrastructure.

The main shortcoming of the data is that existing data sources were consulted in order to obtain the information and no new surveys were conducted to refine the data. To do so would have exceeded the scope of the terrain evaluation required for the purposes of a mini-thesis. Detailed surveys, site visits and sampling techniques would have required a more extensive research project, resulting in an extensive terrain evaluation. It is therefore, accepted that more extensive and detailed research in the form of site visits and sampling techniques, could have indicated changes to the currently available data.

3.2 TERRAIN SUITABILITY ANALYSIS AND ITS RELEVANCE TO THE DATA OBTAINED

According to Beaven (1994) the main components of the terrain evaluation process in assisting in the environmental impact assessment process regarding the data needed, include the following:

- collection of relevant data;
- classification of the relevant data;
- mapping or data storage;
- evaluation of the relevant data obtained; and
- the interpretation and assessment of the relevant data, which could include ranking and/or weighting methods of analysis.

Furthermore, modern methods of data capturing and processing make~~s~~ it increasingly possible to gather and manage large amounts of data associated with changes in the environment, such as the building of a rapid-rail link. These capabilities are best demonstrated within a Geographic Information System (GIS) which consists of computer-based software that can be manipulated and customised to suit the end users (Mitchell, 1991). GIS technology was used in this research as it was found that the GIS could integrate data regarding different sources such as land-use, soil, water, and vegetation to assist in the terrain evaluation process.

3.3 TERRAIN SUITABILITY ANALYSIS - METHODOLOGY

After the relevant set of parameters was identified and the relevant data collected a simple flowchart (DeMers, 1997) was developed to provide an overview of the methodology that would be followed (Figure 8). The objective to classify the terrain or study area according to the suitability for the activity in question, in this case the Gautrain rapid-rail link, will involve the use of a GIS model to automate the process of the terrain suitability analysis. This process will further assist in identifying the most suitable terrain for optimising the rapid-rail route alignment with minimal environmental impact.

FIGURE 8

The methodology of this research is based on the activity approach as discussed in Hugo *et al.*, (1997) to evaluate the terrain, since the activity was clearly defined, in this case the Gautrain rapid-rail link. This methodology would follow five main steps:

- Determination of the set of environmental requirements for the Gautrain rapid-rail link;
- Mapping of the homogeneous areas with respect to the identified parameters;
- Determination of the different rankings according to the suitability for the activity in question;
- Mapping of the homogeneous areas with respect to the assigned suitability rankings;
- Identification of the most suitable terrain for optimising the high-speed rail route alignment.

Furthermore, according to Mitchell (1991) a GIS model for a terrain suitability analysis consists of six elements which can be viewed as subsystems in the operation of the total system: data acquisition, input, storage, data processing, output and use within the context of a seventh, management. Since a GIS was used in order to automate the process of the terrain suitability analysis, the methodology of Hugo *et al*., (1997) will incorporate Mitchell's (1991) elements of a GIS for a terrain suitability analysis.

The methodology includes the following steps:

3.3.1 Determination of the set of environmental requirements for the Gautrain rapid-rail link

3.3.1.1 *Literature Study and other information*

The following resources and methods were used to collect information regarding the study area and relative information regarding the set of environmental requirements, such as the gradient that will be suitable for a rail to operate on, in order to determine the suitability of each land parcel to the activity in question:

(i) Published and unpublished material:

- Internet publications on high-speed rail in South-Africa, United States of America and Europe;
- Reports in journals and papers on high-speed rail;
- Information papers published by government departments in the study area;
- Other research projects related to the current research and technical reports (either published on the internet or hardcopies);

(ii) Maps and photographs of the study area as well as those of existing high-speed rail systems in the United States of America and Europe.

(iii) Personal Interviews

- Personal interviews were conducted with a number of persons, including transportation engineers, rail engineers and environmental managers. These persons were consulted in order to gather information regarding certain transport, environmental, and rail construction issues.

3.3.2 Mapping of the homogeneous areas with respect to the identified parameters

3.3.2.1 *Data input and storage*

This stage involved the pre-processing and formatting of the data for storage in order to bring all data together and make it accessible to the user (Mitchell, 1991). Data not digitally available were digitised and classified for application purposes within the spatial processing operation. Data was also manually manipulated for storage purposes so that the information was readily available in one system.

The software that used for this research were ArcView 3.2 and ArcView's extension; Spatial Analyst was used for the slope analysis. All data was converted to ArcView shape-files, within the World Geodetic System of 1984 or WGS 84 co-ordinate system (Surveyor General, date unknown). The central meridian is 25° Longitude. The 1:50 000 topographic and geology maps used for digitising included the following: 2528CA, 2528CB, 2528CC, 2528CD, 2628AA and 2628AB. A detailed explanation of all data sources and input can be found in Table 2, appendix A.

3.3.3 Determination of the different rankings according to the suitability for the activity in question

3.3.3.1 *Data processing*

This stage processes the data into a form which is translatable for the user. It includes the processing of the spatial data within an integrated computer based system (Mitchell, 1991). In other words all data was processed into one GIS system (ArcView) as shape-files. All information regarding the identified parameters relative to the terrain suitability model was stored in this system, so that further analysis could take place.

Separate shape-files were created for each data parameter as different layers, such as a soil layer, geology layer, and hydrology layer. The data was manually classified into understandable units, such as soil type, geology type, vegetation type and so forth, within the database created for each shape-file. The database further included information regarding the suitability ranking or score (DeMers, 1997) that was assigned to each parameter in its attribute table. As adopted from Lu *et al.,* (1994), Table 3 indicates the suitability ranking that was used for this research.

Table 3: Suitability ranking used for this research

	Suitability ranking
Most suitable	**1**
Moderately suitable	**2**
Least suitable	**3**

Thus, the suitability ranking could be a one; most suitable, a two; moderately suitable, or a three; least suitable. A high suitability ranking or score of three indicates a lesser suitability of a land parcel for the rail route alignment. The lower ranking of one implies that the land parcel is more suitable for the rail route alignment. These suitability rankings were chosen because they were deemed to be the most effective for the calculation of a composite suitability score with the aim of not complicating the terrain suitability model too much. It is important to note that in choosing a suitability score or ranking for a specific terrain evaluation, the only criterion is that it should be a numerical value which can be used in calculating a composite suitability score. In other words, it is required to add up all the scores after the series of map overlays have been performed in order to arrive at a composite score of terrain's suitability for a specific development.

Thus a series of map overlays (Lu *et al*., 1994) of each parameter's suitability were obtained by overlaying all the different shape-files to produce a combined suitability layer for the relevant individual environmental features (Knapp, 1978 & DeMers, 1997). This was accomplished by using the Union function within ArcView. In this way, the information from the different sources is integrated (Chrisman, 1997). The result of the Union function is one shape-file, which incorporates all the information from all the different sources, such as soil type, hydrology and land use, into one database. It includes information regarding the scoring of each parameter according to suitability. A composite suitability score can be calculated for each land parcel by adding all the scores of all the different parameters. The physical environment, land use and existing infrastructure within the study area were combined in order to classify areas according to site suitability (Chrisman 1997), for the identification of the most appropriate rail alignment for this area. Finally, graded ranges were calculated involving a cartographic classing technique that groups ranges of numerical values into single classes (DeMers, 1997). For the purpose of this research the calculated scores ranged from 1-20, and were grouped into five ranges: 1-4, 5-8, 9-12, 13-16, and 17-20. There is no set methodology that guide the researcher as to how many ranges or groups should be calculated. It is solely based on the researchers own interpretation and may therefore be subjective.

3.3.4 Mapping of the homogeneous areas with respect to the assigned suitability rankings

3.3.4.1 *Data output*

Data output is the stage at which the information is provided for the user, the format of which is governed by its requirements (Mitchell, 1991). The data output included a series of maps to show the overlay procedure explained in the previous section. A final map was produced (using the union function within ArcView as explained in the previous section) which shows the suitability of the study area for the Gautrain rapid-rail route, where, according to the analysis, the most appropriate rail route, i.e. that will have the least environmental impact, was identified.

3.3.5 Identification of the most suitable terrain for optimising the high-speed rail route alignment

3.3.5.1 *Data use and management*

This phase represents the application of information from the GIS to actual land problems and includes the subsequent monitoring of results. The system could be used within a management and administrative setting such as the Gauteng Government offices (Mitchell, 1991). For the purpose of this research project the aim was to identify the most suitable terrain for the optimisation of the high-speed rail route. The terrain suitability model developed for this research could provide and overview of the existing situation in the study area. The model to a high-speed rail route that is geographically delimited, meaning that the route chosen was identified from a geographer's point of view and not an engineering point of view, the latter which will involve detailed design. Furthermore, alternative route alignments could be considered and compared to the optimised route.

The management stage would involve the ongoing improvement and general maintenance of the terrain suitability model. This stage was excluded in this research because alternative resources would be required, such as the involvement of the Gauteng Provincial Government, in order to maintain the model, an aspect outside the scope of this research project.

4. RESULTS OBTAINED WHICH ARE RELEVANT FOR OPTIMISING THE RAIL ROUTE ALIGNMENT

In the previous sections a GIS method for terrain suitability analysis according to Hugo *et al*., (1997) and Mitchell (1991) was discussed. This method will be applied to the statement of the problem, in order to comply with the aim of this research, which is to identify the most suitable terrain for the proposed Gautrain rapid-rail link in order to optimise the rail route alignment.

Firstly, the main parameters identified such as soil, geology and land-use that are relevant to this terrain suitability analysis will be discussed and classified. Secondly, a set of environmental requirements for Gautrain rapid-rail link will be determined throughout the research and applied to a specific parameter. Thirdly, the homogeneous areas with respect to the identified parameters will be mapped. Fourthly, the different rankings according to the suitability for the activity in question will be determined and lastly, the most suitable terrain for optimising the high-speed rail route alignment with minimal environmental impact will be identified. This will assist in optimising the rail route alignment in order to consider the alternative route alignments and mitigation options. This section therefore will provide a detailed explanation of the results that was obtained from the analysis.

Since Network Option 1 (Figure 3) of the proposed Gautrain rapid-rail route is the preferred option for the route, this route will be shown on each map of the various parameters. This will assist in the understanding of the suitability of the route when compared to the optimised route.

FIGURE 9

FIGURE 10

4.1 THE PHYSICAL ENVIRONMENT

4.1.1 Gradient and slope

The Gauteng Province is situated high on the central highveld plateau of South Africa at an average altitude of 1 500 m above sea level (Anon, 2001a). Gradient refers to the steepness of a slope. Gradient is best described as a ratio, such as 1:100 (1%). Since most of the references consulted in this research refer to gradient as a percentage and also for the purposes of the GIS, a percentage was the preferred description to refer to gradient and slope in this particular study.

A Digital Elevation Model (DEM) was created by GIMS (Geographic Information Management Systems) using the 1:50 000 topographic maps with a contour interval of 20 m indicating the general slope of the study area. The value is represented as a percentage. The DEM was analysed in ArcView's extension Spatial Analyst. On completion of this analysis it was observed that most of the study area is characterised with gradients of more than 2,5% (1:40), which is regarded as steep for rail alignments (Figure 9). According to Blue IQ (2001), the gradient for the proposed rail route should not exceed 2,5% (1:40), since this can contribute to difficulties in operating the rail on steeper slopes. The map was then reclassified to show all areas with slopes less that 2,5% (1:40) and the result is shown in Figure 10. As can be seen from the figure, most areas have slopes greater than 2,5% (1:40). This implies that the majority of land would have to be excavated and flattened to provide a slope of less than 2,5% (1:40) for the proposed high-speed rail route, assuming that the rail will be built at ground level and **not** elevated as in the case of a monorail.

Accordingly, it appears that the environmental impact will be extensive as a result of the excavation that will be required to provide a gradient of less that 2,5% (1:40). Most of the area will be unsuitable because of the gradient being more than 2.5% (1:40). This parameter was therefore not incorporated into the GIS database for further analysis. The rationale is that it was not part of the numerical calculation to reach a composite suitability score since the logic behind a terrain evaluation is to eliminate all unsuitable areas; one cannot eliminate 80% of the study area because it has a gradient of more that 2,5% (1:40). The gradient was considered in order to decide on the most suitable route, but not part of the numerical calculations. It is important to note that detailed studies of the slope will be essential to determine the overall environmental impact and to decide on micro-level the location of the route.

4.1.2 Geology and Soil

A large proportion in the study area consists of a dolomite rock sequence. According to Harmse (2001; personal communication) these areas will be very sensitive to the construction and implementation of the high-speed rail route because of the possibility of sinkhole formation (Figure 11).

A granite dome forms the most important geological feature in the study area (Durand, 2001; personal communication). This is of particular importance when considering the high-speed rail alignment. If it should be required for a rail to be constructed underground, this would present a major constraining factor because of the hardness of the rocks. Another consideration is that granite erodes into expanding clays, which may present an additional problem (Harmse, 2001; personal communication). During rainy seasons the clay expands, and during dry seasons it contracts causing instability in the surface topology (Durand, 2001; personal communication). This instability in the surface topology would have to be considered when detailed design for the rapid-rail takes place, in order to minimise problems that may arise, such as movement of the rail tract caused by the expansion and contraction of the clay.

The soil analysis in the study area was undertaken from a geomorphological perspective, meaning that the type of geology was related to the soil formations in terms of its erosion potential. For the purpose of the construction of the rail, the stability of the type of soil was investigated. The majority of the area consists of sand (Figure 12). According to Harmse (2001; personal communication) the dolomite regions form deep eroded soils which will be sensitive to disturbance, owing to instability caused by sinkhole and water drainage patterns. Clay soils may be less sensitive to disturbance.

FIGURE 11

FIGURE 12

The following tables provide information regarding the mapping of the simplified geology and soil maps obtained from Prof. Harmse of the Department of Geography and Environmental Management, at the Rand Afrikaans University (2001):

Table 4: Suitability ranking of the geology within the study area

Geology (Simplified)	Geology	Suitability Ranking	Description	Reason for suitability ranking
Quartzite	Quartzite, Quartzite with interbedded shale and conglomerate, and Diabase.	**1**	**Most suitable**	Stable
Sandstone	Sandstone	**1**	**Most suitable**	Stable
Lava & Rock	Acid lava, Andesite, Basaltic lava, Basic & ultrabasic rocks, Hornfels, Hybrid rocks, Hortonolite dunite, Hybrid, metasomatised & fenitised rocks, Pyroclasts, Lava, Granophyne, Diamictite and Volcanic rocks.	**2**	**Moderately Suitable**	Hardness of the rocks could make tunnelling difficult since blasting would be required to break the rocks
Dolomite	Dolomite, Breccia, and Chert	**3**	**Least Suitable**	Formation of sinkholes poses a threat
Dolerite	Dolerite	**1**	**Most suitable**	Stable
Granite	Granite, Gneiss, and Grey	**2**	**Moderately Suitable**	Hardness of the rocks (same reason as for Lava & Rock)
Grabbro	Gabbro and Ferrogabbro	**1**	**Most suitable**	Stable
Shale	Shale	**1**	**Most suitable**	Stable
Alluvium	Surface deposits; Alluvium	**3**	**Least Suitable**	Majority alluvium is close to riverbeds, erosion potential high.

Table 5: Suitability ranking of the soil within the study area

Soil (Simplified)	Underlying Geomorphology	Suitability Score	Description	Reason for suitability ranking
Sand	Alkali-Feldspar, Arenite, Breccia, Chert, Conglomerate, Gneiss, Granite, Granodiorite, Granophyre, Metamorphic rocks, Migmatite, Pyroclastic Breccia, Rhyolite, Slate, and Tillite	**1**	**Most suitable**	Stable
Clay	Amphibolite, Andesite, Basalt, Diorite, Dolerite, Dunite, Gabbro, Lava, Norite, Sedimentary rocks, Shale, and Syenite	**2**	**Moderately Suitable**	Less sensitive than Deep Eroded Soil to disturbance, but could be affected
Deep Eroded Soil	Dolomite	**3**	**Least Suitable**	Sensitive to disturbance, causing increased instability, potential of sinkhole formation

Figures 13 and 14 are graphic representations of the terrain suitability relating to geology and soil as derived from Table 3 and 4 respectively. The major portion of the study area is moderately suitable in respect of the type of geology, owing to the granite dome featured in the study area. According to the type of soil, the majority of the study area is suitable with little erosion potential. The least suitable areas are found in the northern parts of the study area, owing to the dolomite rock sequence situated in these areas. A detailed analysis of the soils and geology will be needed to specifically identify the problem regions on micro scale. This will involve sampling and form part of further investigation outside the scope of this research.

4.1.3 Hydrology

The Jukskei River and Rietspruit are the main perennial rivers in the study area. Wetlands in the Glen Austin area near Midrand have been identified as areas of concern because of the threat to the ecological diversity in this area if the rail is constructed (Blue IQ, 2001). Major wetland areas are also situated in Van Riebeeck Park, Witfontein and Hartbeesfontein in Kempton Park (Figure 15). The location of wetlands, rivers and dams in the study area is of particular environmental importance because the inappropriate siting of roads, developments and railways in the past has led to a significant loss of wetland areas in the Gauteng region (DEAT, 2000). The environmental impacts of the construction of a high-speed rail on hydrology have been discussed in section 2.2.4.5. The most important fact is that the construction of a high-speed rail could ultimately lead to the loss or modification of wetlands, rivers and dams in the study area. Furthermore the contamination of rivers, caused by increased erosion or dumping of building materials into the river, could negatively impact on the water quality entering a wetland and the biodiversity it supports. Eutrophication is also an issue in many wetlands in the area (DEAT, 2000), owing to pollution caused by industries in the areas, resulting in encroachment by reeds and problem water plants, such as water hyacinth.

The Rand Water Board is the main supplier of water in the area (DEAT, 2000). Non-perennial rivers drain the majority of the study area. Water is also piped from Lesotho in the Lesotho-Highland scheme to provide water for households in the study area implying that water is a scarce resource in the study area. Particular precautions, such as the

FIGURE 13

FIGURE 14

FIGURE 15

avoidance of sensitive wetland areas when deciding on the alignment of the rapid-rail route, should be taken during the planning and implementation studies of the proposed high-speed rail link so as to not further destroy existing rivers in the area. Further degradation, or loss of rivers in the area could lead to biodiversity loss and flood problems in the study area.

4.1.3.1 *Terrain suitability classification for hydrology*

As was indicated in the previous sections, the proposed development of a high-speed rail will involve major building construction, which could result in serious erosion and flood related problems. For this reason all hydrological areas, such as wetlands and rivers were assigned a suitability ranking of three, least suitable, to represent its terrain unsuitability. This was not mapped, since all hydrological features have the same score, but was incorporated into the GIS database for further calculations. The following table shows the suitability ranking that was assigned for hydrology features:

Table 6: Suitability ranking of the hydrology within the study area

Hydrology	Suitability ranking	Description
Wetland	**3**	**Least Suitable**
Surface water	**3**	**Least Suitable**
Rivers	**3**	**Least Suitable**

4.1.4 Areas of conservation

The threat of uncontrolled urbanisation in Gauteng is a major concern for conservation of vegetation and wildlife in the province (DEAT, 1998). The conservation of the wildlife in Gauteng is of critical importance when building a high-speed rail, mainly because of the logical that one would prefer not to build a high-speed rail through a conservation area, such as for example a bird sanctuary. Another reason is wayside noise from the construction site and noise when the trains are up and running.

One of the most important reserves that needs mentioning within the study area is the Rietvlei nature reserve, which is situated within the Pretoria municipal area (Figure 16).

FIGURE 16

It hosts the Rietvlei dam, which is an important source of water for the city. This reserve was previously named the Van Riebeeck Nature reserve and covers an area of approximately 3 200 ha. Rietvlei lies some 1 470 m to 1 550 m above sea level (higher than Pretoria) and it is the only proclaimed Bankenveld nature reserve on a dolomite formation in South Africa. This veld type forms valuable land for agriculture, so the chances are that this city reserve will remain the only one of its kind. It is home to Blesbok, Eland, Black Wildebeest, Steenbok, Grey Duiker, Waterbuck, Springbok, Mountain Reedbok, Red Hartebeest and Burchell's Zebra, as well as several rare or threatened species of game such as Oribi, White Rhino and Aardwolf. Numerous bird species, including the Martial Eagle, are also found here (Anon, 2001b).

A number of other nature reserves are found within the study area (Department of Environmental Affairs and Tourism, 1997). These include the nature reserves Melville koppies, Diepsloot municipal nature reserve, Pumula private reserve, and the Rolfe’s pan provincial nature reserve.

The Austin Roberts bird sanctuary is situated in New Muckleneuk (Pretoria). A series of dams attract water birds, particularly Egyptian Geese, Common Moorhen and Yellowbilled Duck. The wooded grassland supports antelope and introduced Blue Crane and Crowned Crane. Thickbilled Weaver and Spottedbacked Weaver breed here, one of few breeding sites in Pretoria for these weavers. The sanctuary is not accessible to the public, but walking around the fence (1 hr) is permitted at any time of day or season (Oschadleus, 1999).

Other bird sanctuaries include the Eastford Park Bird Sanctuary and the Korsman Bird Sanctuary (Figure 16). There is therefore, a number of bird sanctuaries in the Pretoria, and the Johannesburg region which will need consideration, particularly in relation to wayside noise from the rail when in operation. It is important to preserve these areas since they are sources of biodiversity.

4.1.5 Classification of the conservation areas

All conservation areas were assigned a suitability ranking of three to reflect their terrain unsuitability for the construction of a rail. The operation of a rail through these areas would destroy their biodiversity. The determination of noise and vibration levels, as well as a suitable distance of building from the rail to minimise the nuisance of the noise and vibration to nearby features, such as residential areas or bird sanctuaries, is a very complicated exercise, requiring thorough research. This is clearly demonstrated in the report: “High-speed ground transportation noise and vibration impact assessment” which was published by the U.S Department of Transportation (1998).

A noise and vibration impact study that was completed for a railroad in Dakota, Minnesota in the United Stated of America, concluded that the distance of the noise and vibration impacts along the rail line could be between 120 m and 350 m, depending on the type of technology that is used as well as the number of trains in service (ESI Engineering, 1999). It was therefore decided by the researcher to assume a 500 m buffer around all features, such as schools, conservation areas and hospitals that might be affected by the noise and vibration from the rail. A 500 m buffer was therefore created around each conservation area in order to accommodate the wayside noise that will be a problem when the high-speed rail is constructed as well as when the trains are in use. This 500 m buffer was given a suitability ranking of two, moderately suitable. The reason for this ranking is because one would not prefer to built the rail close to conservation areas, but if mitigation measures are in place, such as barriers, the noise levels from the rail could be reduced and the rail could be built closer to these areas.

Table 7: Suitability ranking of the conservation areas and vegetation types within the study area

Type	Suitability ranking	Description
Conservation Area	**3**	**Least Suitable**
500 meter buffer around conservation areas	**2**	**Moderately Suitable**

4.2 BUILT-UP AREAS AND LAND USE

The study area (refer to Figure 1) covers approximately 1,300 km². The area is mostly urban/built-up residential land (approximately 60% of the land in the study area), with little cultivated land (5%). The main built-up areas include the southern parts of Pretoria and the north-western parts of Johannesburg (Figure 17). Tembisa and Centurion include the smaller built-up areas, and the Benoni built-up areas are situated in the south-western parts of the study area close to the Johannesburg International Airport.

There are various existing planned land uses within the study area (Figure 18*)*. Since the vegetation of Gauteng is highly threatened by urbanisation (DEAT, 1998) this will be discussed in a separate section, and be incorporated into the land-use of Gauteng. From the land-use classification map some forest plantations can be found near the Midrand area, where more open land is available. Agriculture, mainly subsistence, is also found in this area. Small areas of improved grassland can be found near the north-western parts of Johannesburg close to Modderfontein and Kempton Park. Areas of improved grassland are areas where grassland is conserved and protected within a proclaimed open space. Other improved grassland areas are mainly within the residential areas of Johannesburg, where open spaces have been proclaimed. Large portions of the non-residential areas are classified as unimproved grassland which indicates that there are poor conservation methods in place, particularly taking into account the high conservation value of the grassland. Areas of thicket and bushland are concentrated close to the improved grassland areas between Modderfontein and Kempton Park. Other areas are close to Tembisa and a small area of bushland can be found to the north of Pretoria.

In order to understand the suitability classification of the land-use areas, an understanding of the environmental problems and impacts associated with the construction of a high-speed rail required as discussed in precious sections. Problems associated with noise and vibration from the rail, visual incompatibility, incidental effects, land acquisition and land-use problems have all been considered in deciding on the suitability ranking.

FIGURE 17

FIGURE 18

4.2.1 Vegetation

The natural vegetation of Gauteng is known as Bankenveld, which is a type of open savannah, featuring sour, wiry grassveld (Figure 19). The dominant tree, characteristic of the Bankenveld, in the study area is the Common Hook Thorn - *Acacia caffra* (Harding, 1996).

Figure 19 : Natural vegetation of Gauteng – Bankenveld (Harding, 1996)

The Bankenveld is interpreted as a controlled fire-maintained grassland, which would develop into savannah if fire were excluded. Frosts during winter play the most important role in the distribution of the woody elements in this transitional zone (DEAT, 1998). Grassland vegetation is restricted to exposed sites in the irregular, undulating, high-altitude landscape, especially on the crests of rocky hills and ridges.

The predominant species in the valleys and kloofs are White Stinkwood - *Celtis africana,* Wild Peach - *Kiggelaria africana*, Tree fuchsia - *Halleria lucida, Ouhout* - *Leucosidea sericea*, Sagewood - *Buddleja salviifolia* and Orange Thorn - *Cassinopsis ilicifolia*. Rocky hills and ridges are a prominent feature of bushveld vegetation. Dominant species are the Common Sugarbush - *Protea caffra*, Common Hook Thorn - *Acacia caffra* and White Stinkwood - *Celtis africana* (Harding, 1996).

In the study area, the vegetation is seriously threatened by urbanisation, industrialisation and mining, and, to a lesser degree, agriculture. There are several reserves throughout Gauteng, but the only reserve where this particular grassland is conserved within the study area, is the Rietvlei Nature Reserve.

4.2.2 Classification of built-up areas and land-use

After consideration of the above-mentioned environmental impacts, the following scores were assigned to the different land uses as represented in Table 7. The impact of noise and vibration from the rail was one of the main considerations in choosing a suitability ranking for the different land-uses, especially in residential areas. The noise factor will come into consideration again when scoring the existing infrastructure, such as schools, hospitals and clinics.

Table 8: Suitability ranking of the built-up areas and land-use within the study area

Type	Suitability ranking	Description	Reason for suitability ranking
Cultivated/Agricultural land	**3**	**Least suitable**	EIA compulsory (Environmental Conservation Act 73 of 1989). Difficult to change land-use
Urban/built-up land: commercial	**2**	**Moderately Suitable**	Businesses and Shopping centres, will need land-use changes or removal if rail alignment is planned through these areas. Linear development along the rail is more likely to be commercial than residential because of wayside noise and vibration from the rail
Urban/built-up land: industrial/transport	**1**	**Most Suitable**	No major land-use changes necessary
Urban/built-up land: residential	**2**	**Moderately Suitable**	Relocation of residential holdings if rail alignment is planned through these areas. Noise and vibration impacts, if mitigation are in place, such as noise barriers, these impacts will be less
Urban/built-up land: residential (small holdings)	**2**	**Moderately Suitable**	Relocation of residential holdings if rail alignment is planned through these areas. Noise and vibration impacts, if mitigation are in place, such as noise barriers, these impacts will be lessen
Forest and woodland	**3**	**Least Suitable**	Conservation status
Forest plantations	**3**	**Least Suitable**	Conservation status
Thicket and bushland	**3**	**Least Suitable**	Conservation status
Grassland	**3**	**Least Suitable**	Conservation status

A suitability ranking of two, moderately suitable, was given to residential areas, since if mitigation measures are in place, noise would be reduced considerately and would not be such a huge nuisance. Cultivated/agricultural land was given a suitability ranking of three, least suitable, because of the considerable problems, such as resistance from owners or surrounding neighbours, that may occur during the process of agricultural land-use change to any other form of land-use such as transport. An EIA in this case is compulsory according to the Environmental Conservation Act (73 of 1989), and the EIA regulations. Industrial and transport land-use areas were given a suitability ranking of one, most suitable, since no serious land-use changes would be required. The conservation status of the grassland in Gauteng is high (DEAT, 2000) and particular attention should be given to the conservation and identification of indigenous species in the study area. For this reason all vegetation types were assigned a suitability ranking of three, least suitable.

Figure 20 is a graphic representation of the suitability of the land-use in Gauteng based on Table 8. From this map it is clear that approximately 50% of the land is unsuitable for the construction of a rapid-rail link. These areas mainly include the vegetation areas and agricultural holdings outside the built-up areas in the study area.

4.3 EXISTING INFRASTRUCTURE AND SOCIO-CULTURAL ASPECTS WITHIN THE STUDY AREA

The existing infrastructure and socio-cultural aspects for the purpose of this study include the following: all roads, railways, schools, hospitals and clinics, landfill and waste sites, mines, water canals, and power lines. The location of monuments, servitude’s and water mains were excluded from the analysis since detailed information regarding these locations was not surveyed as part of the research, because of time and money constraints, but will need to be incorporated in further research. The following sections explain the reasoning behind the classification of each of these features and will be discussed in the order mentioned.

FIGURE 20

4.3.1 Classification of existing infrastructure and socio-cultural aspects within the study area

According to Crockett (2001) a 50 m buffer should be acceptable around all existing main roads and railways to accommodate for the area used by this infrastructure. The data captured within the GIS regarding this infrastructure is only representative of the centre lines and does not include the total areas. Main roads were rated as two (moderately suitable) and railways as one (most suitable). The reason for this rating is mainly because the rapid-rail should be able to operate on the same elevation as the existing railways and can also share in its tract. In the case of the existing roads some excavation, tunnelling, or building of bridges will be needed to operate on the same elevation as the roads. Road infrastructure would also have to be avoided in order to cause minimum disturbance in the road traffic. It will be more suitable to operate on the existing railways when considering a high-speed-steel-wheel-on-steel rail system and moderately suitable when operating the high-speed rail close to roads, as extensive disruptions in traffic may result due to construction activities.

A 500 m buffer was generated, using ArcView GIS V3.2, around all schools, hospitals and clinics to accommodate for noise and vibration from the rail. The researcher, as explained, considered this to be sufficient in dealing with the wayside noise that will be generated during and after construction of the high-speed rail. These areas are generally perceived as areas where noise from the high-speed rail will cause a nuisance. As a result schools, hospitals and clinics were given a suitability ranking of three (least suitable). Landfill and waste sites were also given a suitability ranking of three (least suitable), for one would prefer not to built a high-speed rail close to these areas because of their unpleasantness and smell. Consequently a 500 m buffer was generated around such sites, to accommodate the area that these sites use, since the data that was captured within the GIS is point data and do not take into account the area used by these sites.

The Gauteng province is situated on the geologically stable Kaap-Vaal craton (continental centre). Seismic activity in the study area is rare (DEAT, 2000), although the existing mining activities in the area could increase the probability of tremors. The majority of mining activity involves stone, brick and sand, with gold mining situated in the southern parts. Since the construction of the rail is mainly targeted for public transport purposes and not for freight purposes, the suitability of land near mines and quarries in the study area for the rail alignment was assigned a suitability ranking of two, i.e. moderately suitable (Figure 20).

All water canals were given a suitability ranking of three (least suitable) the reason being that one would want to avoid relocation of the water canals. The water canals were chosen as they present an existing infrastructure, which would require consideration when a high-speed rail is constructed. A fourteen-meter buffer was generated around the existing power lines. Council regulations prohibit construction within this buffer zone in the Sandton area (Lamb, 2000; personal communication). Thus a suitability ranking of three (least suitable) was indicated.

The table below reflects a summary of the suitability ranking for the features indicated:

Table 9: Suitability ranking of the existing infrastructure and socio-cultural aspects within the study area

Type	Suitability Score	Description	Reason for suitability ranking
Roads (including the 50 meter buffer)	**2**	**Moderately Suitable**	Avoid road infrastructure, because of disturbance in road traffic
Rails (Including the 50 meter buffer)	**1**	**Most Suitable**	Rapid-rail could operate on same elevation as well as share the rail tract
Schools (Including 500 meter buffer)	**3**	**Least Suitable**	Noise and Vibration impacts
Hospitals (Including 500 meter buffer)	**3**	**Least Suitable**	Noise and Vibration impacts
Clinics (Including 500 meter buffer)	**3**	**Least Suitable**	Noise and Vibration impacts
Landfill sites (Including 500 meter buffer)	**3**	**Least Suitable**	Visual incompatibility, smell
Waste sites (Including 500 meter buffer)	**3**	**Least Suitable**	Visual incompatibility
Water canals	**3**	**Least Suitable**	Avoid relocation of this infrastructure
Mines and quarries	**2**	**Moderately Suitable**	Instability of the ground. Rapid-rail target public transport not freight.
Power lines (Including 14 meter buffer)	**3**	**Least Suitable**	Avoid relocation of this infrastructure as well as council regulations regarding the building near power lines

There are a number of other existing features that will need consideration which were not incorporated in this research because of the magnitude of survey required, such as the location of caravan parks, emergency services, recreation facilities, libraries and places of worship, such as churches and mosques. The majority of these areas need consideration because of the noise and vibration impact associated with the high-speed rail.

4.4 TERRAIN SUITABILITY ANALYSIS FOR THE OPTIMISATION OF THE HIGH-SPEED RAIL ROUTE

In the previous sections all parameters chosen for the development of the terrain suitability map, were discussed. The environmental impact associated with each parameter was considered, and the suitability ranking was accordingly assigned to each parameter's classification type. The GIS was then used extensively for the suitability scoring, overlaying and mapping of the criteria according to their terrain suitability for the construction of a high-speed rail.

In order to develop the final terrain suitability map, all the parameters need to be incorporated into one system. This is done by overlaying all the data sources, and then using the union function, which is a capability of ArcView, to combine all the relevant parameters within one database as one shape-file. The union function cuts each feature into separate land parcels. The best way to describe the overlay and union procedure is with the help of a simple diagram showing how these functions work, where a rectangle with all its information is overlaid over a circle (source), which again has its own information attached to it (Figure 21). All overlays require a source and an overlay. The union function acts like the boolean operator "OR", it includes all areas in the source and the overlay. In the example below there are five new polygons which will include all the information from both the circle and the rectangle.

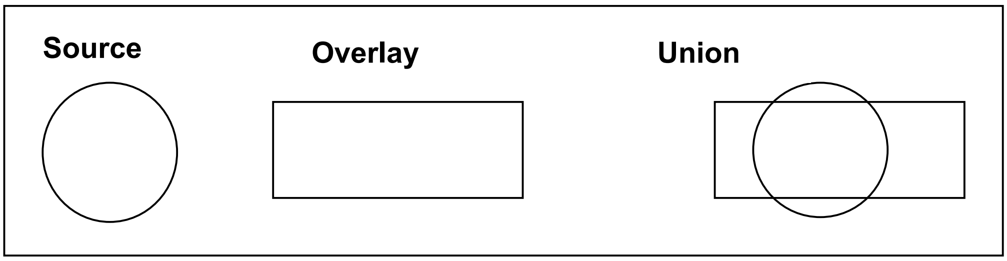

Figure 21: Example of the Overlay and Union method within the GIS

After overlaying all the information regarding the different parameters incorporated as one feature or shape-file, a query calculation was performed to add all the suitability scores of each land parcel together and resulted in the terrain suitability score for each separate land parcel (Figure 22). The diagram below demonstrates this query in relation with the example of the circle and rectangle:

Table 10: Example of the query calculation within the GIS

Circle – suitability score	**Rectangle** – suitability score	**Composite suitability score**
3	**2**	**5**

This calculation resulted in scores ranging between one and twenty. For a better understanding of the terrain suitability of each land parcel, it was decided to use the graded range technique as described in DeMers (1997), where ranges of numerical values are grouped into single ranges. Subsequently the calculated suitability score was grouped into five ranges. A lower score reflects a more suitable terrain, where higher scores reflect least suitable terrains. Table 9 represents the group ranges, which simplifies the terrain suitability map.

Table 11: Group ranges of the suitability score for the calculated units

Accumulated score	**Description**
1-4	**Most suitable**
5-8	↓
9-12	
13-16	
17-20	**Least Suitable**

The result of this simplification is reflected in Figure 23, which shows the simplified terrain suitability map of the study area for the construction of a high-speed rail. It is clear from this map that the majority of the study area is not suitable for the construction of a rapid-rail link. The most unsuitable areas are found north of Johannesburg, incorporating the dolomite sequence in this area. Other unsuitable areas are situated in the Johannesburg CBD area, where a high density of schools, hospitals and clinics is to be found. It is further important to consider all environmentally sensitive terrains within the study area, before finalising the high-speed rail alignment.

FIGURE 22

FIGURE 23

The following list provides an explanation of the environmentally sensitive areas within the study area, which contributed to the scoring of each land parcel and needs to be considered and investigated in more detail than was permitted within this research. Mitigation measures, for example sound barriers next to the rail to minimise noise, should be a priority in the following cases.

- Over 50% of the study area is covered by residential use, which will be particularly sensitive to noise and vibration from the high-speed rail;
- The hospitals, clinics and schools are also sensitive owing to the noise and vibration from the high-speed rail;
- 10% of the study area is covered by the grassland biome (natural vegetation), which has a high conservation value, since it is seriously threatened by urbanisation;
- The dolomite sequence is sensitive to disturbance owing to the possible formation of sinkholes;
- The deep eroded soil sequence south of the granite dome is also sensitive to disturbance owning to the instability that may be caused by sinkholes and water drainage patterns;
- All hydrological features, such as wetlands, rivers and dams will be sensitive to disturbance.

4.4.1 Optimising the Gautrain rapid-rail route alignment

The interpretation of Figures 22 and 23, makes it possible to propose a high-speed rail route alignment, which will be geographically delimited. Within the following sections the different proposed rail routes will be discussed. A comparison will be made between the different options and finally it will be compared with the optimised proposed route. Although Network Option 1 is the preferred route for the Gautrain rapid-rail link (Figure 3), Network Option 2 will also be considered in comparison with the optimised route.

4.4.1.1 *Proposed Gautrain rapid-rail route: Option 1*

This route is a direct alignment between Johannesburg, Rosebank, Sandton, Midrand, Centurion and Pretoria (Figure 24). According to Blue IQ (2001) this alignment offered the highest potential in terms of ridership. There was however a "concern regarding the environmental implications of the rail through the highly developed section between Sandton and Johannesburg CBD as well as the topographical constraints that would definitely require tunnelling." From information available this route alignment is the preferred option, since it has the highest potential of ridership and attraction to business.

4.4.1.2 *Proposed Gautrain rapid-rail route: Option 2*

This alignment also includes the business nuclei of Johannesburg, Sandton, Midrand, Centurion and Pretoria. The only difference from Network Option 1 is that the business nuclei of Rosebank is replaced with Bruma. This alignment would utilise an approach to the Johannesburg CBD from the east via the Bruma development node (Figure 25). According to Blue IQ (2001) this "alternative promised 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 westerns parts (meaning Rosebank) of the urban area that is already impeded by a lack of transport corridors and particularly public transport services."

4.4.1.3 *Proposed optimised route for the Gautrain rapid-rail link*

Firstly it should be noted that the terrain suitability map mainly focussed on the physical parameters within the study area, which will influence the alignment of the route. Since there are still many other factors such as social, economic, and ridership factors that may influence the alignment of the route, these have to be considered in further research. The Gautrain rapid-rail link was proposed as an optimal alignment between the three centres with the aim to cause minimum environmental impact, and can be viewed in Figure 26.

FIGURE 24

FIGURE 25

FIGURE 26

The route that is proposed as a result of this research links Pretoria, Johannesburg and the Johannesburg International Airport. The route utilises the existing rail tract, which links Pretoria CBD, Johannesburg International Airport and Johannesburg CBD. This will involve upgrading of the existing rail track and the usage of high-speed-steel-wheel-on-steel technology. It is also proposed that a dedicated rail tract for the Gautrain is built next to the existing rail tract in order to avoid sharing of tract by the Gautrain and other metro services to provide a fast and effective Gautrain service.

It is further proposed that monorail technology is utilised in order to link the main business centre of Centurion, Midrand, Sandton and Rosebank building a tract starting from Centurion linking the Johannesburg CBD, creating a circular linkage. Since monorail is relatively quieter than high-speed-steel-wheel-on-steel technology, the impact of noise would be reduced considerably when the rail is required to route via residential areas. This will also minimise the environmental impact associated with excavation that will be needed to build the rail on a suitable slope of less that 2,5% (1:40), since a monorail could operate on steeper slopes than the high-speed-steel-wheel-on-steel, and tunnelling would not be required as it is considered very costly.

4.4.1.4 *Comparison between the routes*

NETWORK OPTION 1	NETWORK OPTION 2	OPTIMISED ROUTE
High-speed-steel-wheel-on-steel technology	High-speed-steel-wheel-on-steel technology	Combination of High-speed-steel-wheel-on-steel technology and monorail technology
Link Pretoria CBD, Hatfield, Centurion, Midrand, Marlboro, Sandton, **Rosebank**, Johannesburg CBD and the Johannesburg International Airport	Link Pretoria CBD, Hatfield, Centurion, Midrand, Marlboro, Sandton, **Bruma**, Johannesburg CBD and the Johannesburg International Airport	Link Pretoria CBD, Hatfield, Centurion, Midrand, Marlboro, Sandton, Rosebank, Johannesburg CBD and the Johannesburg International Airport
Tunnelling required between Midrand to Marlboro, Sandton, Rosebank and the Johannesburg CBD in order to avoid steep slopes and residential and other built-up areas.	Tunnelling required between Midrand to Marlboro and Sandton. Also tunnelling from Marlboro to Bruma and the Johannesburg CBD in order to avoid steep slopes and residential and other built-up areas.	No tunnelling required, since monorail technology is used and will be elevated above ground, causing minimal environmental impact related to land clearance and noise impacts. Minimal residential land have to be bought and cleared to build the rapid-rail link, and monorail is generally more quieter than other high-speed rail technologies
No utilisation of the existing rail tract.	No utilisation of the existing rail tract.	Combination of the utilisation of the existing rail tract and building of new rail tract
The rail alignment forms a T-formation, linking the various nodes	The rail alignment acts like a feeder distribution, linking the various nodes	The rail alignment forms a circular movement, linking the various nodes
Choice of route based on travel demand statistics with the consideration of environmental impacts, such as impacts on hydrological features, after the alignment was chosen	Choice of route based on travel demand statistics with the consideration of environmental impacts, such as impacts on hydrological features, after the alignment was chosen	Choice of route based on the environmental impacts of the construction of such a route, in order to evaluate the terrain to conclude to a route with minimal environmental impact. Travel demand statistics was considered but not the main contributor to the route alignment

5. CONCLUSION

The main aim of this study was to identify the most suitable land for the optimisation of the Gautrain rapid-rail route alignment. Within this research the different high-speed railway types was discussed and their impact on the environment was considered, followed by an evaluation of the background and status of the proposed Gautrain rapid-rail link. The different approaches to terrain evaluation were discussed in order to explain the methodology used in this research. The activity approach was chosen as the base methodology for this research and the terrain within the study area was classified according to its suitability for the Gautrain rapid-rail link.

The main objectives of this research included the following:

a) *Research the different high-speed railway types and consider their impact on the environment;*

This objective set the scene relative to high-speed rail technologies in the world today. The different high-speed rail technologies used all over the world were researched and discussed. Some of the main conclusions in relation to this objective included the following:

- It was concluded that the Gautrain rapid-rail link could be defined as a high-speed rail, since it is not a shared freight and commuter service and it will also operate at speeds of more than 160 km/h.
- It was found that a high-speed rail is only economically feasible after a distance of 160 km, and any shorter distances need valid reasons for building the rail. The Gautrain's distance is set at approximately 80 km, and reasons for building the rail include job creation and economic development of the areas affected by the rail. The conclusion can be drawn that it might not be economically feasible to build the rapid-rail, however many other factors such as demand forecasting play a role in determining the feasibility of such a project
- The environmental impact of the construction of a high-speed rail can include noise and vibration impacts, land acquisition and land-use problems, visual incompatibility

and impacts on hydrology, such as wetland, rivers and dams. Thus it was concluded that the construction of the rapid-rail link would impact on the environment.

b) *Evaluation of the background and status of the proposed rapid-rail link;*

The current status of the proposed Gautrain rapid-rail link was discussed. This discussion assisted with the motivation behind the reason for constructing a rapid-rail link. Some of the main findings were the following:

- The Gautrain rapid-rail link is one of the Blue IQ's 10 projects in Gauteng in order to revive and stimulate economic growth in the province.
- The Gautrain rapid-rail link was approved in June 2000 by the Gauteng Provincial Government and Mr. Jack van der Merwe, Head of Transportation and Public Works was appointed Project Manager.
- Studies showed that there was enough patronage demand (estimated at 64 000 daily passengers) and financial interest for the project to go ahead.
- Since the route proposed by the Gauteng Provincial Government (Network Option 1) will have some environmental impacts, such as noise and vibration, it is necessary to complete an extensive Environmental Impact Assessment (EIA) for the proposed Gautrain rapid-rail construction.

c) *Research the different approaches to terrain evaluation and also show the relevance to the proposed Gautrain rapid-rail link;*

Discussions related to this objective clarified the use of the term 'terrain suitability analysis' relative to this specific research. The main conclusions reached include the following:

- It was concluded that the term "Terrain Suitability Analysis", as used in this research is concerned with the suitability of the terrain for a specific activity (Gautrain rapid-rail link) and will involve data collection, organisation and interpretation.
- After researching the approaches to terrain evaluation it was concluded that the activity approach to terrain evaluation as explained in Hugo *et al*., (1997) would form

the base methodology for this research since an activity was clearly defined and the study area was interpreted with this specific activity in mind.

- It was also concluded that a terrain evaluation should form the preliminary part of any environmental management cycle as proposed by Fuggle and Rabie (1998).

d) Classify the terrain or study area according to suitability for the activity in question i.e. the construction of the Gautrain rapid-rail link;

The methodology of terrain evaluation firstly involves the identification of a set of parameters in order to classify the terrain. It was found that in choosing the parameters it is directly related to the environmental impact (from the Gautrain rapid-rail link) on each specific parameter. Once the parameters were identified data was collected in relation to each parameter. The parameters identified from literature are the following: topography, gradient, slope, geology and soil, hydrology, vegetation, conservation areas, land use, and existing infrastructure, such as roads, power lines, schools and hospitals. Once all the data was collected analysis could take place.

Some of the main conclusions from the analysis include the following:

- It was found that more than 50% of the study area had a gradient of more that 2,5% (1:40). This is regarded as unsuitable for the operation of a rail since the slope will be too steep, and it will be too costly to excavate areas with slopes of more than 2,5%.
- A large proportion of the study area include a dolomite sequence (to the north of the study area). This area will be very sensitive to disturbance because of the instability of the ground and the possibility of sinkhole formation. Dolomite also erodes into deep eroded soil, which is also sensitive to disturbance. This instability in the surface topology will have to be considered when detailed design takes place.
- Various rivers, wetland and dams are situated within the study area. All of these areas were classified as unsuitable for the construction of a rail, since the construction poses a threat to the biodiversity of these ecosystems.
- It was found that the main vegetation type in Gauteng is grassland, which includes the rare Bankenveld type. This grassland has a high conservation status since it is

highly threatened by urbanisation. Areas of grassland were included in the land-use study and all classified as unsuitable for the construction of the rapid-rail link.

- A number of schools, hospitals and clinics are found within the study area boundaries, these areas were all perceived to be sensitive to noise and vibration impacts from the rapid-rail. These areas were also classified as unsuitable for the construction of the rail.

e) *Identify the most suitable terrain for optimising the rapid-rail route alignment with minimal environmental impact;*

After the classification of the terrain had been completed, it was possible to identify the most suitable terrain for optimising the rapid-rail route alignment with minimal environmental impact. From the final terrain suitability map (Figure 23) it was clear that most of the study area is unsuitable for the construction of a rapid-rail link, the most unsuitable areas were found to be north of Johannesburg, incorporating the dolomite sequence in this region. Other areas of unsuitability included the high-density residential areas within Johannesburg and Pretoria CBD as well as the areas that are covered by grassland vegetation (10%).

f) *Consider the proposed route alignments and mitigation options.*

The proposed route alignments already under consideration by the Gauteng Provincial Government were also considered and a description of each route was given in order to compare them with one another and ultimately to compare them to the optimised rail route alignment. The main conclusion from this comparison involves the fact that the rail route alignment for the Gautrain rapid-rail link as proposed by the Gauteng Provincial Government did not consider any environmental impacts before the route was chosen. The route that is proposed as a result of this research considered the various environmental impacts with the use of a GIS-based terrain evaluation technique in order to determine a route alignment with minimal environmental impact.

It was concluded that a terrain suitability analysis could aid an EIA in identifying the most suitable terrain for a specific development, in this case the Gautrain rapid-rail link. This is mainly done by the integration of all the relevant data, in order to arrive at the most suitable terrain for a specific development. An analysis of the research results indicates that the construction of a new rail could have severe environmental and socio-cultural impacts. The study area in general is not 100% suitable for such a project. One of the most severe environmental impacts associated with the construction and implementation of a high-speed rail is wayside noise and vibrations, and strict mitigation measures, such as sound barriers, should be put in place to minimise these impacts. This can have serious implications for the decision of placement of the high-speed rail alignment. This will also affect the type of technology that is used. Several other environmental impacts exist, such as impacts on ecosystems and the biodiversity they support, and these should be examined in detail and proper mitigation should be proposed. This will influence the suitability of the study area.

5.1 VALUE OF RESEARCH

The main value of this research is that it showed that when a development such as the Gautrain rapid-rail link, is proposed, it is essential to first apply a terrain suitability analysis, before any route alignments are proposed. From a terrain suitability analysis the optimised route alignments could be determined after which a full-scale Environmental Impact Assessment can commence. This could assist in the identification of suitable areas for the specific development as well as save money since the scope of the project (EIA) could be determined more clearly. In the case of the Gautrain rapid-rail, the proposed route alignment was determined without the benefit of a completed terrain evaluation, meaning that the route did not necessarily utilise the most suitable terrain. Only after the determination of the route, were the environmental impacts flagged. The route was mainly determined by demand forecasts of the amount of people that would use the rapid-rail link. The identification of the most suitable terrain should form part of the first steps proceeding to a full environmental impact assessment. Referring to Fuggle & Rabie (1998) where the terrain evaluation forms the preliminary part of any environmental impact process, it can be concluded that the proper environmental impact assessment (EIA) process was not followed by the authorities. The aim of this study was therefore, to indicate the importance of a terrain evaluation for proposed developments, such as the Gautrain rapid-rail link.

With the proper resources, the most appropriate route for the high-speed rail can be determined. The terrain evaluation before an EIA, could consequently lessen the scope and cost of an EIA and perhaps even save time. The optimised route alignment that is proposed in this research utilises the most suitable terrain, therefore resulting in the least environmental impact and most environmental advantages. The EIA will therefore specifically determine the biophysical and socio-cultural impacts, issues and mitigation options to further lessen the environmental impact of the development. This type of study is an important basis for the decision-making process in determining the most appropriate rail route alignment. The proposed alignment is to serve as an example and further studies could be conducted to refine the route alignment. In South Africa this is usually not done and projects are approved before any detailed studies are commissioned to determine the impacts on the environment, economy and the communities.

Generally the use of a high-speed rail will solve many problems, such as congestion and air pollution. It will also lead to the creation of work and economic growth in the Gauteng province, but on the other hand it can have detrimental impacts on the environment, if proper mitigation measures are not in place.

It is the viewpoint of the researcher that the development of the Gautrain rapid-rail link should only have commenced after a full terrain evaluation was undertaken. The terrain evaluation should then have been followed by the EIA, where all the environmental impacts were properly researched and in detail before the final rail route alignment is determined. Economic gain is usually put before environmental gain. Since the environmental impact of the proposed route is only now taking place it could have detrimental impacts on features such as wetlands and rivers it is submitted that a terrain evaluation (followed by an Environmental Impact Assessment) could have aided more concise and accurate perspective of the impacts involved. The researcher believes that by using a terrain evaluation of this sort the project could be properly evaluated and the most appropriate rail route alignment utilising the most suitable terrain with minimal environmental impact could be chosen.

The research limitations imposed by the requirements a mini-thesis of this nature, precludes the incorporation of all the various aspects of an Environmental Impact

Assessment (EIA) or terrain evaluation. Consideration of other factors such as socio-economic impacts and land-use impacts are also not possible. Given these limitations, the following recommendations are made for further research.

5.2 RECOMMENDATIONS

The following recommendations for further investigation, which are relevant to this research project, are proposed for the implementation of the proposed Gautrain rapid-rail route. They are not necessarily stated in order of priority:

- The socio-economic impacts require detailed study to fully understand the implications for the communities involved, such as economic development and job creation opportunities;
- Careful consideration should given in the choice of the type of high-speed rail technology that will be utilised as this will have an influence on any further studies such as the EIA and the socio-economic studies;
- A detailed terrain evaluation is needed in order to identify suitable terrain within the rail corridor boundaries. The limited scope of this research project precluded the incorporation of all the required data for a terrain evaluation. It is therefore recommended to undertake a detailed terrain evaluation which will incorporate all the data within the study area;
- A detailed Environmental Impact Assessment (EIA) is needed to identify the impacts and mitigation measures. This is now being undertaken by Bohlweki Environmental (Pty)Ltd;
- Noise and vibration mitigation studies should be undertaken, in order to identify the magnitude of the noise and vibration impacts of the rail;
- Detailed studies determining any hydrological, ecological, water quality and terrestrial impacts, should be conducted to determine the possible impacts. This is especially so for the sensitive wetland areas as the biodiversity they support could be affected by any disturbances, such as increased pollution from construction activities;
- Studies to predict the ridership, job creation advantages, interest and tourism opportunities in terms of the high-speed rail should be undertaken to determine the economic value to the communities involved;

- Studies to determine the impact of the high-speed rail on land-use and property values should be conducted, since this will be important to owners of land that are affected by the chosen rail route;
- A detailed analysis should be conducted to identify any endangered fauna and flora in the corridor, since they have a high conservation status;
- A detailed geology and soil analysis should be done to determine the stability of the land as design criteria will be influenced by these results; and finally
- The involvement of all Interested and Affected parties are essential for the final determination of the route alignment, this should be considered within the EIA.

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APPENDIX A