NOISE AND VIBRATION ASSESSMENT OF THE GAUTRAIN RAPID RAIL LINK

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ABSTRACT

The Gautrain Rapid Rail Link is a new high speed railway commuter (transit) system planned along two linked corridors in central Gauteng, namely between Johannesburg and Pretoria, and between Sandton and Johannesburg International Airport. The introduction of this rail system has the potential for noise and vibration impact if the railway system is not designed carefully and if appropriate mitigating measures are not taken where required. As part of the environmental impact assessment (EIA) of the project, a comprehensive investigation of the potential noise and ground-borne vibration impact from the train was undertaken. There are no existing South African noise and vibration standards related to railways and their operation, and thus such criteria needed to be established specifically for this project. International standards were considered to be applicable as the basis for the recommendations for the Gautrain project. There are also no existing "official" South African noise and vibration prediction models and appropriate calculation methods had to be sourced from international best practice. Although the implementation of the Gautrain project has the potential for significant noise and vibration impact if appropriate mitigating measures are not taken where required, the nature and level of the impact is such that appropriate mitigating measures are possible.

1. INTRODUCTION

The Gautrain Rapid Rail Link is a new high speed railway commuter (transit) system planned along two linked corridors in central Gauteng, namely between Johannesburg and Pretoria (JP Line), and between Sandton and Johannesburg International Airport (SA Line). Some 15 kilometres of the line (mainly in the Johannesburg and Sandton areas) will be in tunnel. There will initially be eight stations along the JP Line and four along the SA Line. Maximum train speeds of up to 180 km/h could be achieved along sections of the routes. There are several noise and vibration sensitive areas through which the planned routes will pass. As part of the environmental impact assessment (EIA) of the project, a comprehensive investigation of the potential noise and vibration impact from the train was therefore undertaken to establish the nature, extent, magnitude and implications of the project. Several alternative alignments were evaluated. This was one of the largest EIA studies that has been undertaken in South Africa and the first where a ground-borne vibration and noise impact study was commissioned.

In general terms, the assessment procedure comprised firstly the determination of the character of the Study Area and its prevailing noise and vibration condition and then, based on this and an understanding of the nature of the project, appropriate standards/impact criteria for the project were specified.

The next step was to predict the changed noise and vibration conditions in the areas along the railway corridors as influenced by the implementation of the project and then to evaluate the likely impact introduced by these altered conditions. A holistic and conservative approach was taken.

2. EXISTING CONDITIONS

The existing *noise climate* and *vibration climate* of the Study Area were determined in order to provide a reference base against which to relate the potential impacts of the project. The character of the various homogeneous land use areas along the two rail corridors was established, potential noise/vibration sensitive areas and the major noise/vibration sources affecting these areas were identified, and the specific related concerns of Interested and Affected Parties (I&APs) were determined in order to establish an understanding of the various affected areas and identify where there could be noise/vibration problems along the routes.

2.1 Noise

The current noise levels and the nature of the *noise climate* were determined by means of a comprehensive field inspection and from a measurement survey of 54 main sites and some 15 supplementary sites covering the whole Study Area but focussing specifically on the identified noise sensitive/problem areas. Daytime and late evening period measurements were taken at each site. The sound pressure level (SPL) (noise) measurements were taken in accordance with the requirements of the Code of Practice SABS 0103:1997, *The Measurement and Rating of Environmental Noise with Respect to Annoyance and Speech Communication*. At the same time as each individual measurement was being taken, the qualitative nature of the *noise climate* in the area of the measurement site was assessed and recorded. This comprised an appraisal of the general prevailing acoustic conditions based on the subjective response to the sounds as perceived by the listener (i.e. an *auditory observation* by the surveyor), as well as identifying those noise incidents which influenced the noise meter readings during that measurement period. This procedure is essential in order to ensure that that there is a *human* correlation between the noise as perceived by the human ear and that which is measured by the meter, as well as to establish any anomalies in the general ambient noise conditions during the measurement period.

The current ambient noise levels along the planned routes vary considerably according to the local land use character. It was found that the *noise climate* in many areas is already degraded, with the main problems originating from road traffic, railways, aircraft and industry.

2.2 Vibration

A comprehensive assessment of the existing land uses along the planned routes was undertaken to establish the sites that were potentially vibration sensitive and to identify the main existing vibration sources. There are no existing data available on the vibration profile along the routes. The area varies from urban, to suburban to rural and the existing vibration sources and resultant vibration levels are typical for these areas. The most common vibration sources present include those from transportation systems, namely road traffic on arterial routes and freeways (mainly from heavy vehicles), and railroads, and light industrial activity, all of which generate very low levels of ground-borne vibration. The northernmost section of the proposed JP Line (from Pretoria Station to Hatfield Station) as well as a section of the SA Line overlap with existing rail corridors. The rail traffic along these lines is much slower than the proposed Gautain operation and the current vibration levels experienced from this source are relatively low. Therefore, the population and other sensitive land uses along the two corridors currently experience no ground-borne vibration effects.

3. APPROPRIATE STANDARDS AND ASSESSMENT CRITERIA

There are no existing South African noise and vibration standards related to railways and their operation.

Thus appropriate railway impact criteria needed to be established specifically for this project. Standards related to various land uses are necessary. As the Gautrain is a new railway system to be introduced into an existing urban fabric, it was considered essential that stringent environmental standards be specified. The rationale behind the environmental management and control policy for the Gautrain and the standards that have been recommended is that the noise and vibration generated from the project should ideally not increase the existing ambient noise levels in critical areas or, at most, not increase the level above that which is accepted as suitable for the type of land use under consideration.

<u>3.1 Noise</u>

There are international railway noise impact criteria and standards that have been tested in practice over many years and thus these were considered to be applicable as a valid basis for the recommendations for the Gautrain project. The following maximum equivalent sound pressure levels (L_{Aeq}) and instantaneous maximum levels (L_{Amax}) have been proposed as the primary railway noise impact control criteria, with the railway reserve boundary (that is, the interface between the reserve and the first row of impacted properties) as reference control point:

Period of Day (T)	$L_{Aeq,T}$ (dBA)	L_{Amax} (dBA)
▪ 06h00 – 22h00 (daytime/evening):	60	85
▪ 22h00 – 06h00 (night-time):	50	85

In addition to this baseline control, a second level of control, directly related to the type of land use affected, has also been specified. The rating levels for ambient noise as given in the South African code of practice SABS 0103:1997 *The Measurement and Assessment of Environmental Noise with Respect to Annoyance and Speech Communication* have been specified as the standard to be used at defined noise sensitive areas.

These areas are:

- Outdoor noise sensitive areas such as parks, historic sites used for interpretation, amphitheatres, recreation areas, playgrounds and cemeteries.
- Residential areas comprised of single family residences and multifamily residences (apartment buildings, simplex and duplex housing complexes).
- Indoor noise sensitive areas inclusive of places of worship, educational facilities (schools, universities, technikons, etc), crèches, hospitals/ hospices, concert halls/ auditoriums/ theatres, libraries, recording/ broadcast studios, museums and specific historic buildings, and hotels/ motels/ B&B establishments.

<u>3.2 Vibration</u>

The international standard ISO 2631-2 *Evaluation of Human Exposure to Whole Body Vibration-Part 2: Continuous and Shock Induced Vibration in Buildings (1 to 80 Hz)* was used to derive the vibration level criteria that were in turn used to assess the impact of the predicted ground vibration levels. The impact of ground-borne low frequency noise was assessed according to the standards provided in the USA Federal Railroad Administration Manual *High-Speed Ground Transportation Noise and Vibration Impact Assessment* which are in accord with international practice. The maximum acceptable ground-borne vibration and noise levels used for this assessment are:

Period of Day	Vibration Level (dBV)*	Noise Level (dBA)
• 06h00-22h00 (daytime/evening):	112	40
• 22h00-06h00 (night-time):	103	35
• Critical working areas:	100	30

*Where dBV is the vibration velocity level with reference value, $v_r = 10^{-9}$ m/s.

Defined critical working areas include hospital operating theatres and precision laboratories for vibration; auditoriums, concert halls and theatres for ground-borne noise; and recording studios (including TV recording studios) for both vibration and noise.

These noise and vibration standards have been included as controls in the contract technical specifications for the train and in the Environmental Management Plan (EMP). There is general professional agreement that the main controls on noise and vibration should be at source, and the specifications are accordingly output based.

4. PRE-CONSTRUCTION AND CONSTRUCTION PHASES

The potential noise and vibration impacts during the pre-design, design and construction phases were evaluated and appropriate mitigating measures to prevent or reduce these impacts have been identified. In particular, there can be severe problems during construction, and even though this phase is of limited duration, strict control needs to be exercised. These control measures have been specified in the Environmental Management Plan (EMP).

5. ASSESSMENT OF THE OPERATIONAL PHASE

The main focus of the assessment for the operational phase of the project was to establish the potential change in *noise climate* and *vibration climate* directly related to and within the area of influence of the planned rapid rail system, and then to determine the potential impact as related to the existing conditions. It was necessary to take a conservative approach to predicting the future railway induced noise and vibration condition of the project as certain details of the train and operating conditions had not been finalised at the time the EIA was undertaken. Therefore the worst scenario conditions related to train characteristics, operational conditions and noise and vibration attenuation conditions were modelled. These input parameters to the prediction modelling, however, were realistic in relation to the type of train that is planned and the intended service to be provided.

5.1 Noise

There is no existing "official" noise prediction model in South Africa and an appropriate calculation method had to be sourced from overseas practice. Data from two noise prediction model systems were used to simulate the operational noise profile of the planned train. The intrinsic noise generation characteristics of the "model" train were based on various typical high-speed train data (operational electric-multiple unit (EMU) -type units to which the Gautrain will be similar) as provided in the USA Federal Railroad Administration Manual *High-Speed Ground Transportation Noise and Vibration Impact Assessment* and the UK Department of Transport's prediction model, *Calculation of Railway Noise* (1995) From this basic train-type data, the noise levels that could potentially be generated by the operations of the Gautrain, namely the propagation and attenuation prediction, were calculated using the UK model, *Calculation of Railway Noise*. Train speed profiles were developed using a power to weight ratio at the high end of the likely spectrum. The 16-hour (06h00 to 22h00 period) equivalent sound pressure levels ($L_{Aeq,16h}$) (that is the noise levels) were calculated along the cross-section profiles of the railway line at 200 metre intervals along the two planned railway corridors. The position of the 16-hour, 60dBA (daytime period) noise contour was also established.

The character (qualitative aspect) of the railway operational noise will have many facets. The components of noise that will predominate at high speed will be the wheel-rail interaction noise (in the frequency range of 2kHz to 4kHz) and the mechanical noise of the cooling fan system (in the frequency range of 900Hz to 1100Hz). The noise from the fans predominates when the speeds are low and when stopped in the stations. Aerodynamic noise will not be a factor with the Gautrain as this source only becomes significant when speeds of 250 km/h are reached.

The perceived noise at any one point along the rail corridors will fluctuate rapidly with a pass-by of each train, rising from the normal ambient noise level of the area to peak at the maximum pass-by level and then fall back to the area ambient level. The duration of each such event will last about 12 seconds when the train is travelling at 180 km/h and 22 seconds when at a speed of 100 km/h. The interval between these "single events" will depend on the optimised operating headways on the various sections of the system. There are likely to be a total of 12 trains per hour (two directional) on the JP line and 8 per hour on the SA Line. There will be very little noise from the braking systems and train and track design will control the "flange squeal".

Potential problems related to the stations, ancillary works (such as tunnel ventilation shafts and electrical sub-stations), tunnel entrances, workshops, maintenance works, onboard conditions for commuters and occupational health of railway employees were also investigated and the potential acoustic problems will be addressed.

5.2 Vibration

There is also no existing "official" vibration prediction model in South Africa and an appropriate calculation method had to be sourced from overseas practice. There are a number of methods to predict the vibration levels due to new underground rail systems that have been used in the past. One approach is to make extensive use of measured data, both to determine the vibration levels of the source (trains) as well as the attenuation along the transmission path. The data are then correlated with empirically derived predictions, which, in turn, are used to predict the vibration level of the new installation. For this approach, detailed information regarding the planned new train, the system construction and operational characteristics are required. Furthermore, access to similar type systems must be available and accessible for measurement purposes. It is also possible to approach the problem in a more fundamental way where a model is used to represent the coupling between the rail and the surrounding geological formation, the geometric spreading and the material damping. At present, there is still a lack of understanding of exactly how the geological formations influence the vibration attenuation. There are also additional effects such as reflection and refraction at discontinuities, and other phenomena such as dispersion that may occur and that complicate these calculations. This is therefore a very costly approach requiring very detailed information such as vibration input data and material properties and, despite this, the results produced may still not be reliable. Both of these approaches are more appropriate to the final design stage of the project when the more detailed information for the system is known.

The calculation method used for the Gautrain analysis was that as set out in the US Department of Transportation, Federal Transit Administration's *Transit Noise and Vibration Impact Assessment* as extended to include high-speed trains, namely the US Department of Transportation, Federal Railroad Administration's, *High-Speed Ground Transportation Noise and Vibration Impact Assessment*. The methodology consists of a process where a base curve, representing an upper-bound for typical high-speed train ground vibration measurements and based on typical operating EMU trains, is adjusted by various factors to incorporate known characteristics of the system being analysed such as construction of the track and tunnel; depth and geology; and the type and construction of the impacted building structures. The strength of the vibration source is expressed as a vibration velocity level, L_v, in dBV with a reference value, $v_r = 10^{-9}$ m/s, used to calculate it. These values were then adjusted according to a set of specified adjustments given in the model. The following corrctions were applied in this study:

5.3 Train speed

The level of ground-borne vibration increases with train speed. This increase/decrease has been predicted as 20 times the logarithm of the speed ratio, where the maximum proposed speed for the trains will be 180 km/h and the reference speed 240 km/h.

This means that for a doubling of train speed the vibration level will increase by approximately 6dB and if the speed will be halved it will decrease by 6dB. Train speeds in tunnels were limited to 140km/h in accordance with the technical specifications for the Gautrain.

5.4 Construction

As the track will be continuously welded, there will be no joints and the only adjustments applied were for special track-work, such as crossovers without swing-nose crossings. These were taken as +10 dB and applied where appropriate. Adjustments for structure type were also made, namely for subway tunnels (-15dB) and elevated structures in the form of bridges and viaducts (-10dB), while on at-grade and in cut and open sections no adjustment was necessary.

5.5 Geological condition

It is well known that some soil types and shallow bedrock lead to efficient propagation of vibration. In this study most of the tunnelling will either be in, or close to, bedrock. As it is generally accepted that vibration, especially high frequency vibration, propagates efficiently through hard, un-weathered rock care was taken to apply the appropriate corrections in this assessment. The required adjustment for this condition (+10dB) was made when the bedrock is at, or very close to the surface. In addition, the correction to take into account the distance that the vibration will propagate through solid rock was applied throughout. Furthermore, the soil conditions were studied and the appropriate adjustments made in cases where it is reasonable to expect that there will be limited attenuation due to absorption.

5.6 Building foundations

It was assumed that all buildings are on spread footings except for commercial buildings. Therefore the adjustments were taken as either –7dB for typical suburban houses and one- and two-storey commercial buildings or –13dB for larger, multi storey masonry and concrete buildings, selected as appropriate for the land use in the area.

5.7 Radiated sound

The A-weighted sound pressure levels were predicted using the values presented in calculation model.

6. ASSESSMENT OF IMPACT

The specific impacts have been assessed and areas of concern were identified. Consideration was given as to how residents in the rail corridors, users of facilities adjacent to the routes, commuters and railway staff will be affected. It was found that air-borne noise as well as ground-borne vibration and its resultant low frequency noise, if unmitigated, have the potential to be problems in several areas. Airborne noise will have an impact mainly along sections of the railway line that are aligned above ground level, that is at-grade or elevated on fill or structure. Train noise propagated from sections where the track is in cutting (deeper than four metres) will be significantly attenuated by the screening effect of the cutting and any impact in these areas will be low. Along the sections of the system which will be in tunnel, the potential "external" noise impacts will be localised around the ventilations shaft exits at surface. Vibration and ground-borne noise could potentially be a problem mainly where the system is in tunnel.

In order to assess whether or not there would be significant noise impacts it was first necessary to look critically at the existing conditions in the area under review and to ascertain whether it was typical and acceptable for that type of land use. The cumulative effect of the Gautrain-generated noise and vibration on the relevant area was then established for the unmitigated condition. The altered ambient noise level was evaluated for its acceptability related to the specified maximum standards and the amount by which the train would actually raise the ambient level.

The assessment of the potential impact thus was based on a comparison between what the current ambient condition, what the desirable level should be (according to standards), and what change will be brought about be the train.

7. MITIGATING MEASURES

There are numerous appropriate measures that can be taken to prevent any or reduce noise and vibration problems in the impact sensitive areas along the planned railway corridors. As the project is still at the planning stage, these measures range from modifications to the technical specifications of the trains (for example the braking, suspension and cooling systems), revision of sections of the longitudinal profile of the track, high-standard track and switching system design, track vibration isolation techniques, cut-and-cover construction and the application of acoustic/vibration isolation principles to the design of bridge/viaduct structures and tunnel entrances, through to variations of operational characteristics and the installation of noise attenuation barriers (walls or earth-berms alongside the track to reduce the propagation of the train noise). Architectural acoustic treatment of buildings such as the double glazing of windows, sealing the eaves of houses and the acoustic cladding of the facades of high-rise apartments overlooking the tracks may also be necessary. Regular effective maintenance of railway track and train wheels will play a significant role in controlling the operational noise and vibration. Acoustic design considerations will also need to be applied to the stations as well as to ancillary equipment and tunnel ventilation shafts. The necessary technical noise and vibration specifications have been specified in the tender documents for the contract.

The potential also exists for innovative redevelopment, where appropriate, of the some areas immediately adjacent to the railway to a type of land use that will be more compatible with a rail corridor environment, while, the same time, providing a noise buffer. As a further land use option, developments over the rail reserve (air rights option) should be seriously considered in places.

8. CONCLUSIONS

The following conclusions may be drawn from the noise and vibration impact analysis of the project:

- The existing ambient noise levels vary widely across Gauteng and thus the potential level of impact, in turn, varies significantly. The *noise climate* in a number of the noise sensitive areas is already severely degraded, that is the ambient noise levels already exceed the desirable levels specified for that type of land use and conditions are deteriorating. In general the prevailing vibration conditions along the planned routes are not a problem.
- The implementation of the Gautrain High Speed Rail Link has the potential for significant noise impact in the immediate environs of the railway lines in a number of areas along both of the planned corridors of the project during all phases of the project if appropriate mitigating measures are not taken where required. Ground-borne vibration and noise impacts were found to be limited.
- The magnitude of the impact will reduce rapidly with increasing distance from railway reserve due to normal attenuation effects.
- As there will be no train operations during the “middle night” period (22h30 to 05h00), there will be no train-related noise and vibration disturbance for this highly sensitive period of the day.
- The nature of the predicted potential noise and vibration impacts is such that, where necessary, appropriate mitigating measures are possible. In most instances, these would be relatively easy to implement in order to ensure that the specified maximum standards are not exceeded.
- The fact that the noise impact investigation was undertaken before the final train was selected, provided an opportunity to assess the possible worst condition scenario for the train type

envisaged for the project, thereby enabling appropriate technical specifications for effective mitigating measures to be set for the contract documents at an early stage of the project tender process.

- The project is therefore not fatally flawed from a noise and vibration impact perspective, as potential impacts can be controlled and managed.

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Biographies

Derek Cosijn is a partner with the acoustical engineering firm Jongens Keet Associates as well as managing his own company, Calyx Environmental. He is a qualified civil engineer and town planner, with both degrees being gained from the University of the Witwatersrand. He has been involved in environmental and transportation planning projects since the mid-1970s when he worked in Canada for several years. Derek is an environmentalist who likes to keep things quiet. His field of specific expertise is in environmental and transportation noise.

He is a registered Professional Engineer, a Fellow of the SAICE, and is an accredited Environmental Assessment Practitioner of South Africa (EAPSA).

Wikus van Niekerk is Professor and Chair of the Department of Mechanical Engineering at Stellenbosch University. He holds a PhD from the University of California at Berkeley in the USA. He specialises in noise and vibration with particular emphasis on human response to vibration. He has published more than 10 articles in refereed international journals and presented a number of papers at international conferences. Prof van Niekerk is a registered professional engineer and has been practising as a consultant to industry for nine years. He is 40 years old and married to Heidi Arndt with two children.

John Morgan has been a principal of R & H Railway Consultants for 32 years, having joined the firm in January 1962 immediately upon graduation from Natal University where he qualified as a civil engineer. He was appointed Managing Partner of the company in 1990 and since 1999 has been the Chairman and CEO.

He has a total experience of over 41 years as a civil engineer in railway related aspects of design, construction, maintenance and management in the rail transportation and consulting engineering environment. The greater proportion of his experience has been with freight and heavy haul railways, principally in the mining environment. Since 2000 he has been a member of the consortium of consultants appointed by Gautrans for the Gautrain project and is currently the group leader (technical). Since March 2002 he has also been responsible for the noise and vibration aspects of the project.

John is a Professional Engineer, a Fellow of the SAICE, and was President of the SAACE from 1990 to 1991. At present he is Chairman of the Committee of Railway Engineering and Vice-President of the Rail*Road* Association of South Africa.