The PRT Project
Phase 1 Design & Engineering

The Mechanical Engineering Perspective
Guideways, Vehicles and Stations

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CONTENT

The Mechanical Engineering Perspective

1 Executive summary

The concept of PRT has over many years inspired engineers to address the design challenges presented by the concept and their efforts have resulted in many novel and original solutions although none have progressed beyond the development stage.

In the process of attempting to design the perfect system, compromises have to be made and departure from the ideal has to be accepted in order to produce a practical, safe and affordable solution.

The design that has evolved from this study has departed little from the original concept and has been made possible by combining the knowledge and experience of a group of highly qualified engineers ably supported by professionals from other disciplines.

The group has also benefited from the pioneering work of others and the vast volume of material already published.

PRT is only possible now as a result of the relatively recent advancements in control, computing and communication technology permitting the systems designers to adopt radically different solutions to complex problems.

To fulfil the project Design Parameters and the operating requirements of reliability and low cost of ownership, the decision was made to fit the LIM propulsion units in the track. This was a radical departure from the design philosophy adopted by others, but one that met most closely the group's objectives.

This decision has enabled the vehicle to evolve into an uncomplicated, compact and lightweight unit where the emphasis has been directed towards passenger comfort safety and ease of use.

As with any new concept there are specific features, which have already been identified, requiring a degree of further development.

We are therefore confident that the design proposed is realisable and will fully meet with the specification as detailed within the Project Design Parameters.

2 The guideway

Unlike many PRT systems where the guideway and support forms an expensive and complicated integral structure, our design philosophy has been to develop a simple rail and guidance system independent of the support structure. This allows the architect or system designer freedom to develop the type of support most suitable for the application.

2.1 Track Profile

The track and guidance system comprises two square section running rails and two angle section guide rails suitably supported.

The running rail can either be manufactured from square hollow section or from an 'I' section beam. It is eventually envisaged that an ideal profile can be developed, which will be unique to this application.

The running rail function is to provide a flat and smooth surface on which the non-metallic tyres run. It is intended to reduce the width of this rail as experience is gained with various types of tyre material and as the effect of tyre wear in relations to tyre width is better understood.

The guide rail's function is to provide:

- Running surfaces for the guide and switching wheels.
- Independent surfaces on which the calliper brakes act.
- Vehicle captivation.

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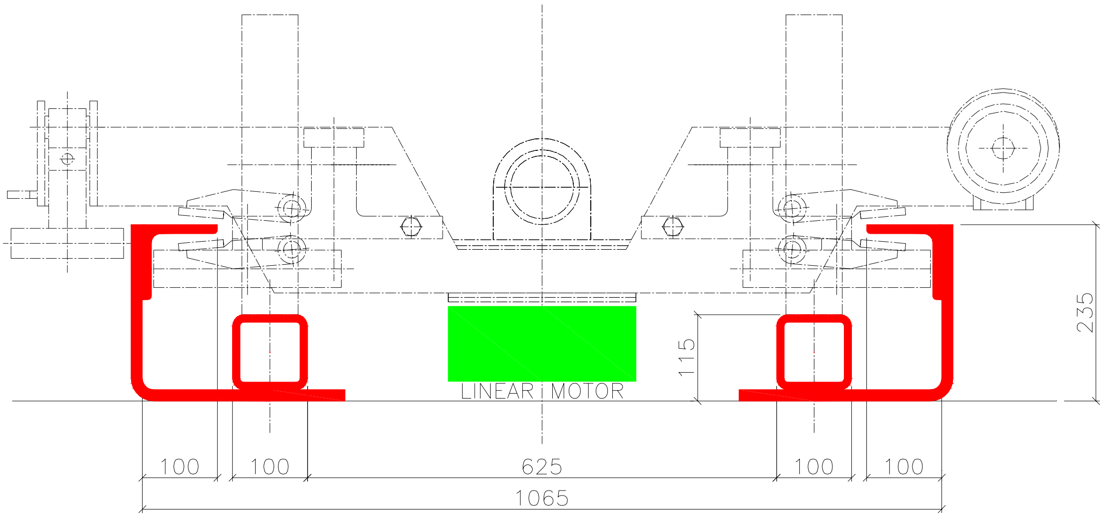

WEIGHT OF TRACK – 100 KG/METRE

2.2 Rail Connections

When the track is mounted to steel structures fitted with expansion joints, the track must accommodate similar movements.

Employing a conventional rail type expansion joint would result in rail gaps that would eventually damage the vehicle tyres and affect the ride quality.

Therefore, a gapless expansion joint has been incorporated into the rail end design eliminating a stepped transition.

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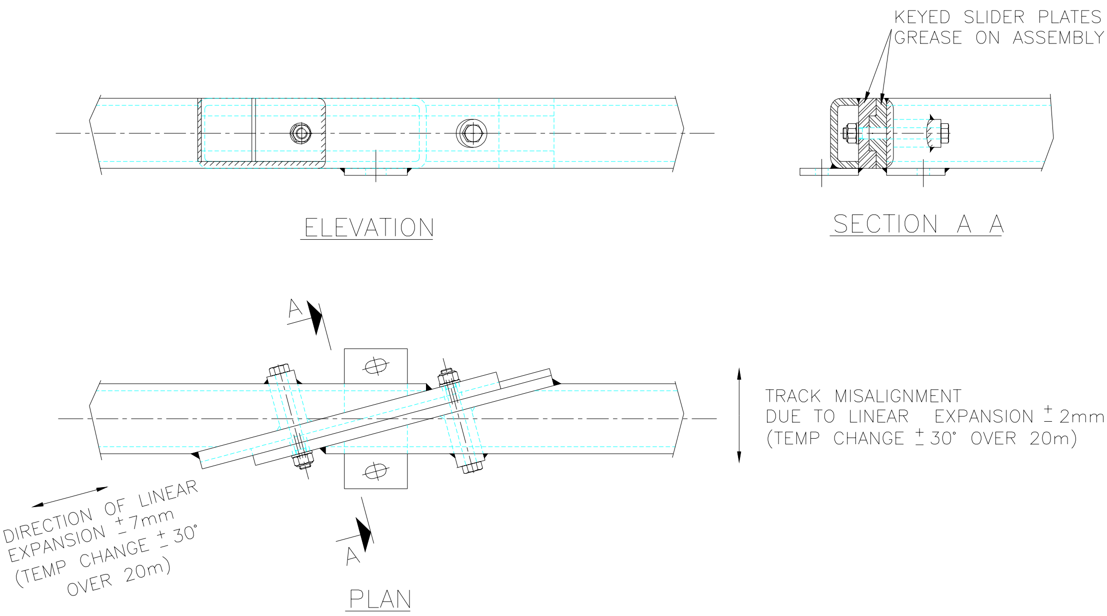
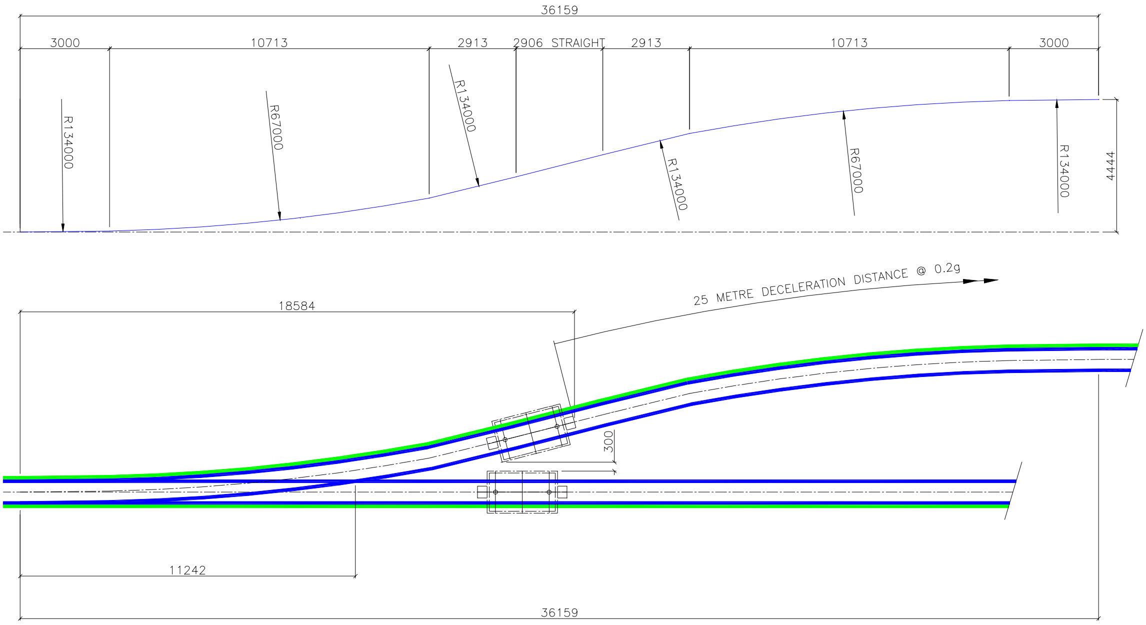
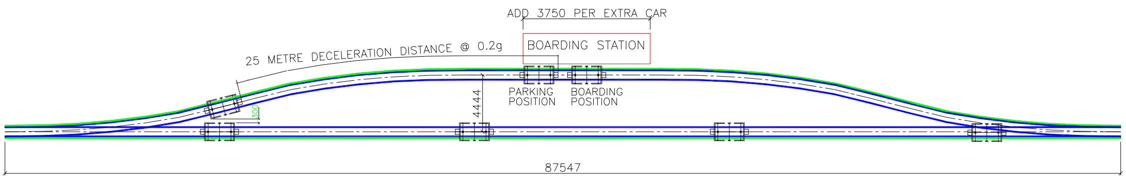


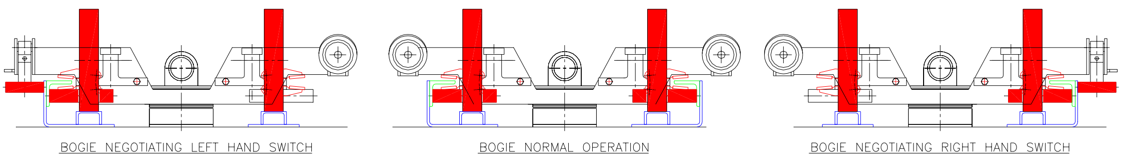
2.3 Switches

The design of the switch now becomes elegantly simple in its construction, eliminating the divergence points, which have the potential to be the most hazardous areas in the entire system and one which remains unresolved by competing systems.



The guide rail within the switch incorporates transition curves which reduce the effect of jerk and lateral acceleration to comfortable limits whilst permitting the vehicle to exit and enter at 10m/sec line speed. Check – DRG.NO. 1123/017 above and DRG NO. 1123/023 below:





2.4 Loop Transfer

The drawing illustrates a loop transfer showing a vehicle exiting a loop, in the same manner in which it would enter a station. The vehicle decelerates into an overlap section which is identical to the standard track profile. There the vehicle changes its switching wheels from left hand to right hand operation, permitting the vehicle entry into the adjacent loop. This overlap section also provides a parking facility, where vehicles may queue whilst awaiting an entry opportunity into the second loop.

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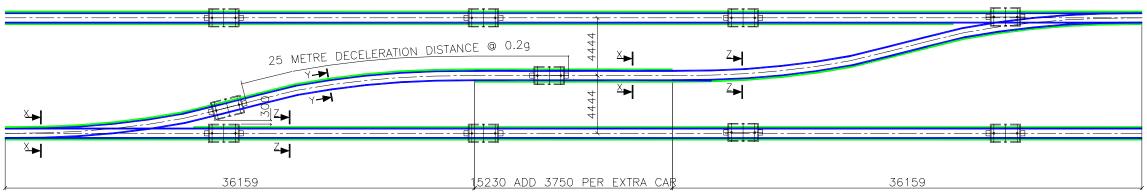
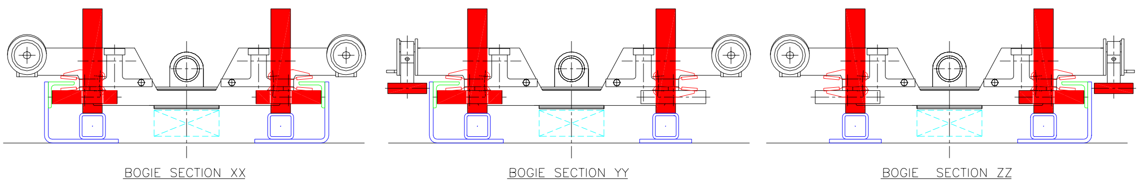




2.5 Station Track Layout

The station layout incorporates two standard switches and a lengths of track on which the vehicles decelerate and accelerate enabling them to exit and enter the main track at line speed. To prevent vehicle collision, local vehicle control is fitted at the re-entry switch operating as a controlled block system. The boarding platform length is determined by the number of loading positions and the vehicle control philosophy which has been adopted to meet the needs of any particular station.

Check – DRG.NO. 1123/023 on previous page.

3 The vehicle

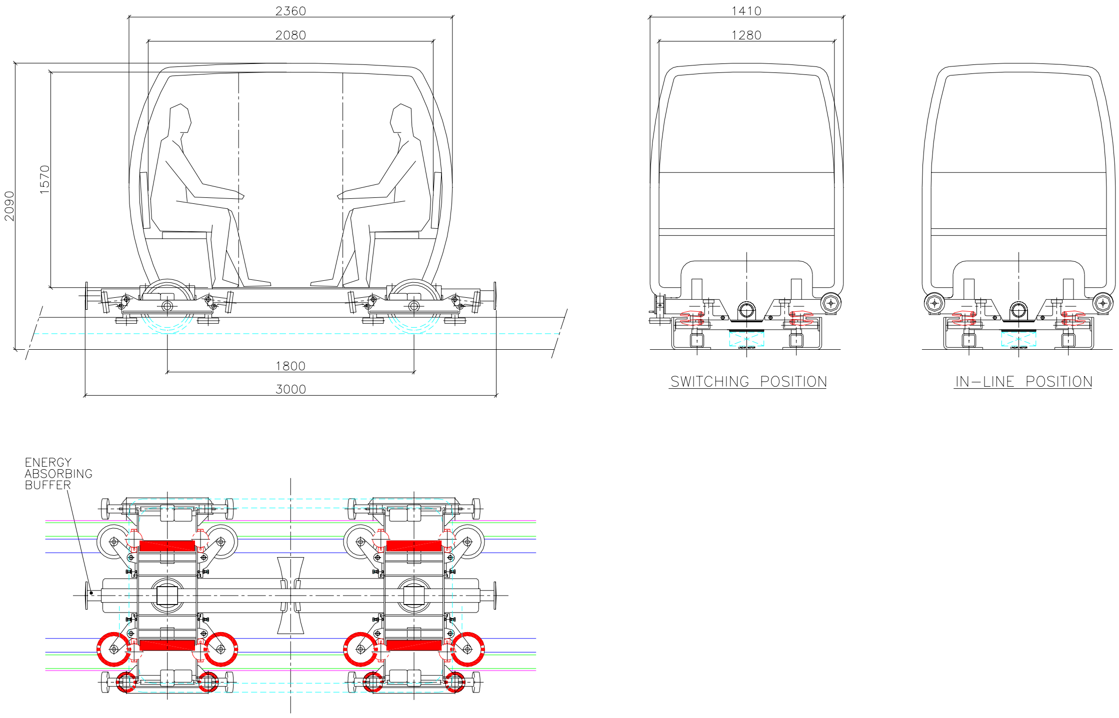
The vehicle is the first opportunity that the public has to interface with the system. It is therefore extremely important that this initial contact and the resulting experience provide a very positive and lasting impression on the passenger.

The illustrations below are artist's impressions, and no decisions have been taken as to final look and feel.

3.1 Cabins

The vehicle profile requires to convey the impression of a modern, clean, safe and efficient unit. This is achieved by employing simple curves, flush doors and glazing and designing the body profile to run as close to the track as is practical to conceal the bogies, giving the impression that the vehicle is gliding over the guideway.

Check external/internal dimensions – DRG. NO. 1123/006 below:

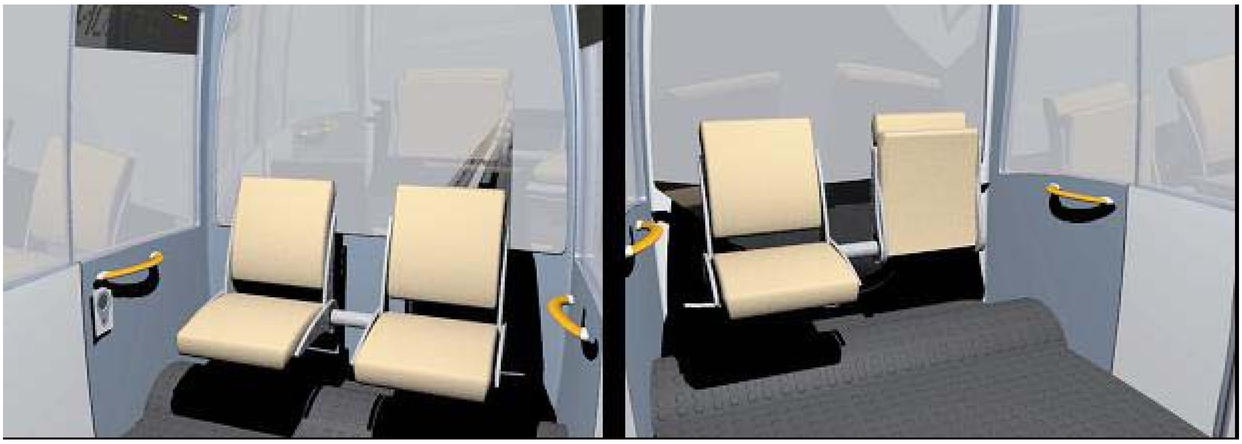


3.2 Interior and Access

The height of the four-seater vehicle is determined by safety requirements to prevent passengers standing and the need to provide ease of access. For both foot passengers and those in wheelchairs, the bi-parting doors provide ease of access, whilst meeting the requirement for the doors to have a short opening and closing time cycle.

The interior gives the impression of being light and airy by utilising large areas of tinted glazing, which is also considered to contribute to passenger security by preventing the concealment of non-desirable passengers or packages.

The interior surfaces, which have no sharp edges or corners, are moulded from a flexible material that is also scratch and vandal resistant and can be easily cleaned.



3.3 Ride Quality

Ride quality is affected by a combination of external influences:

- Rail surface condition
- Rail joints
- Track alignment
- Lateral and vertical acceleration and jerk
- In-line acceleration and jerk
- Seat design
- Centre of gravity of the vehicle

These effects can be minimised by:

- Maintaining a clean rail surface
- Using gapless rail expansion joints
- Limiting the lateral and vertical acceleration by matching the vehicle speed to the track radii.
- Limiting the effect of jerk by the introduction of transition curves both on the approach to horizontal curves and to super elevated track.

- Controlling in-line acceleration.
- Using large diameter wheels to reduce the effect of rail surface imperfections.
- Isolating the passenger cabs from the chassis with resilient mountings
- Developing a seat design which provides both comfort and security for this particular application.
- Maintaining a low centre of gravity reduces the effect of wind gusts and lateral acceleration forces, so aiding the vehicle's dynamic stability, which is especially important when the vehicle is relatively light.

3.4 Seating

The facing seats are sufficiently wide to provide generous shoulder room for two passengers, whilst the seat base is angled to retain passengers during rapid periods of acceleration and deceleration. The semi-resilient material also has good thermal qualities in order to reduce shock on contact with bare flesh.

3.5 Push Button Stations

The vandal resistant, stainless steel, flush units are similar to those used in building lifts and present the passenger with a sense of familiarity.

The push button station is designed to aid the visually impaired; the illuminated buttons having 15mm high raised tactile symbols with the Braille dots located below the symbol. The location within the vehicle being such that they can be easily operated from the seats or from a wheelchair.

The panel includes:

- The emergency call button
- Station selection buttons/start button
- Door opening button
- Door closing button
- Digital display indicating the approaching station

The speaker system announces:

- The identity of the approaching station
- Doors opening
- Doors closing
- Vehicle overload

3.6 Communication

The vehicle is fitted with two-way communication which enables passengers to be made aware of any external problem and which is automatically activated to connect the vehicle to the control centre in the event of the emergency call button being pressed.

An option we have considered is also to fit all the vehicles with video cameras that can either be activated by the people in the control centre, in case of an emergency situation, or by the passengers by pushing tha alarm butoon.

3.7 Doors

As with all public service vehicles the doors have a demanding duty to perform. In addition to permitting passenger access to the vehicle, they are required to be:

- Reliable
- Safe
- Weatherproof
- An integral part of the vehicle aesthetics

To meet these criteria, electrically operated, plug type, bi-parting doors have been selected. This design offers fast response to opening and closing whilst the large aperture permits easy access to both foot passengers and wheelchairs, minimising the standing time in the stations.

Door dimensions: Width = 900 mm, Height = 1500 mm

3.7.1 Door Operating Sequence

- Vehicle enters the station
- Audio advises arrival and identifies station
- Car stops and is locked in position on the track adjacent to the platform doors
- Car proven in position
- Audio advises “doors opening”
- System unlocks car and platform doors, opening both simultaneously
- Passengers exit
- New passengers enter and sit
- Passenger selects destination
- Audio advises doors closing
- Doors close and lock
- When locks are proven locked, vehicle moves off

In the event of there being no passengers to board, the vehicle stands with its doors open for 20 seconds before the platform and car doors close.

The vehicle remains stationary until:
a) the central control instructs it to move off to a new destination or,
b) it is requested by a passenger

3.7.2 Door protection and safety

- Door edges protected by rubber mouldings
- Torque sensitive motor control detects any obstruction and re-opens on contact – waits 1 second before re-closing
- Car and platform doors are synchronised in operation
- Mechanical locks in both car and platform doors prevent them being opened by passengers

3.7.3 Emergency Operation

- Platform and car doors can be unlocked by approved personnel from the outside
- Doors can be remotely unlocked from the central control permitting them to be opened by passengers in safe locations.

3.7.4 Station Door Failure

- Central control informed
- Cars instructed not to stop at the failed door

3.8 Heating and Cooling

3.8.1 Climate Control

The cabin interior temperature is automatically maintained to provide a minimum winter temperature of 14°C and a maximum summer temperature of 25°C.

3.8.2 Power For Heating

This is provided by a wheel driven generator and on-board battery. If the vehicle is stationary for long periods the heating will automatically switch off to conserve the battery power.

3.8.3 Power for Cooling

The air conditioner compressor is wheel driven and therefore does not operate when the vehicle is stationary. The option to drive the air compressor electrically is limited by the performance of the electrical system and may be a future option if inductive power is realisable. Manually operated vents are also provided for additional ventilation.

3.9 Bogies

A bogie wheel arrangement has been adopted to:

- Minimise tyre wear when cornering
- Permit the vehicle to negotiate curves down to 6 metre radius under power and 3 metre radius manually in the workshops.

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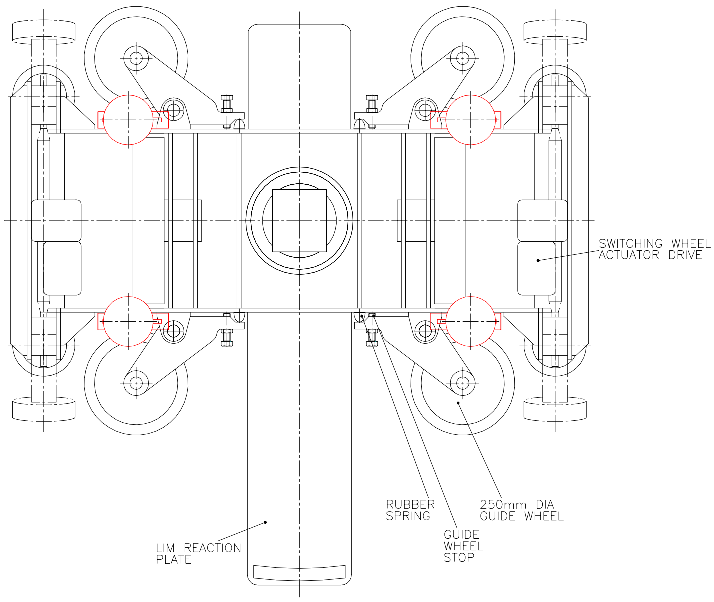


3.9.1 Wheels

Of all the mechanical engineering challenges, the design of the wheels is the most demanding; the major challenge being to minimise tyre wear in an application where vehicles are expected to travel 120,000 Km/year.

RUNNING WHEELS

Steel tyres have not been considered due to their noise generating characteristics, especially with headway frequencies of 2 seconds; the alternative being the use of synthetic tyre materials, which will be inherently quieter in operation.

The large diameter running wheels within a two-wheel bogie arrangement are permanently maintained in line with the track, reducing tyre wear to a minimum, which in turn will extend the LIM air gap adjustment period.

The 400m diameter wheels are manufactured from aluminium and have a low moment of inertia which reduces the acceleration force required from the linear motor.

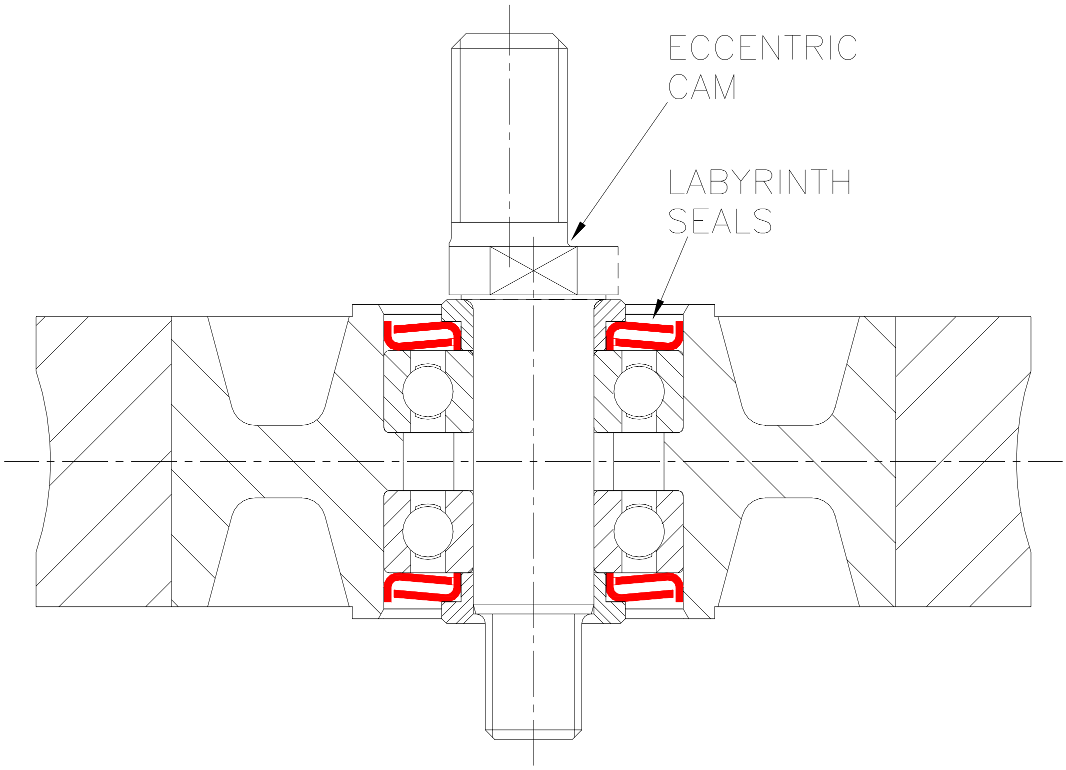
GUIDE WHEELS

These are similar in construction to the running wheels and although subject to less load are required to be kept in constant contact with the track to prevent rapid tyre wear. This contact is maintained by the use of light rubber springs and adjustable stops set to the minimum track gauge.

SWITCHING WHEELS

These wheels are subject to different operating conditions, as they are required to accelerate from zero to full speed rapidly when engaging the guide rail. Therefore the diameter is reduced to a practical minimum in order to minimise wheel inertia.

These wheels will be fitted with labyrinth type seals, to reduce the starting torque normally associated with synthetic lip seals.



3.9.2 Track Switching

Track switching is the central feature of all PRT systems and determins both the track and vehicle design. Primary considerations are the effect on capacity and safety.

In vehicle based switching the guideway has no moving parts and the switching wheels on the bogie determine the direction. The principle safety advantage is that direction selection can be made well in advance of the switch engagement, enabling time for the activation mechanisms to be proven in position and locked.

The bogie design incorporates pairs of electrically activated switching wheels. The safety advantage is that if the wheels are not proven locked into position, the opposite pair can be activated and the vehicle automatically removed from the system at the first convenient exit.

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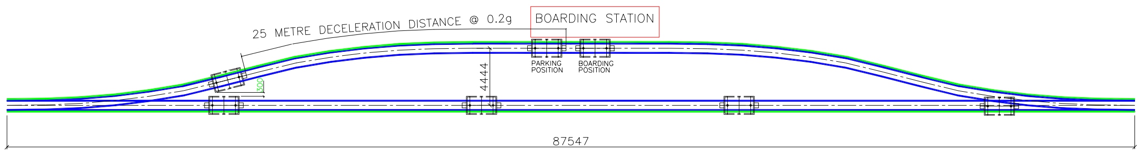
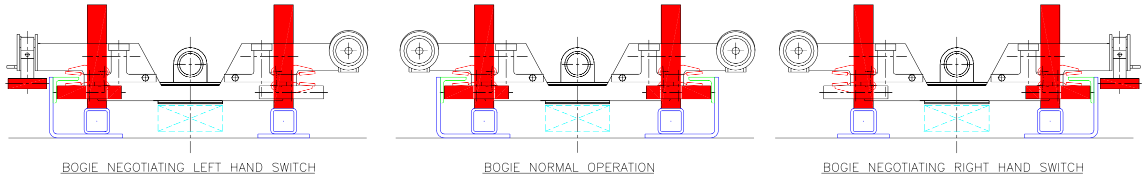
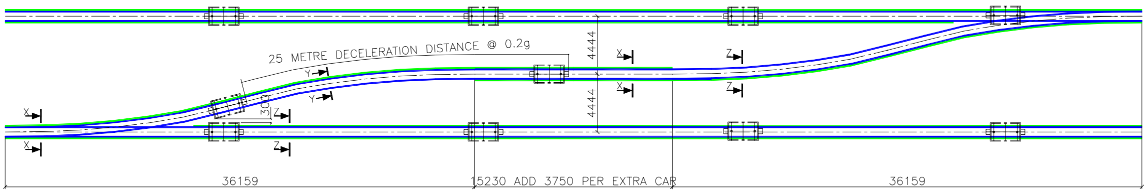
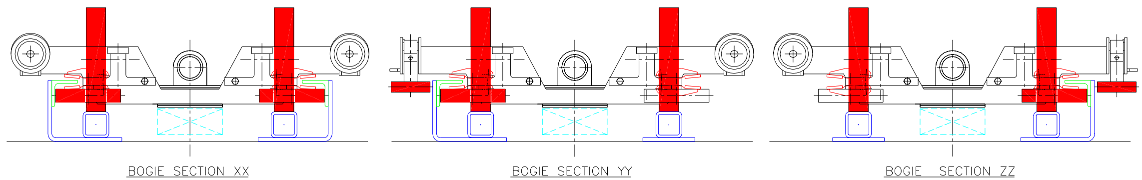








3.9.3 Emergency/Parking Brake Operation

In order to meet the requirements of near constant retardation under all vehicle loading conditions, two pairs of calliper brakes are fitted to each bogie. The brakes are applied in any combination to match the passenger load.

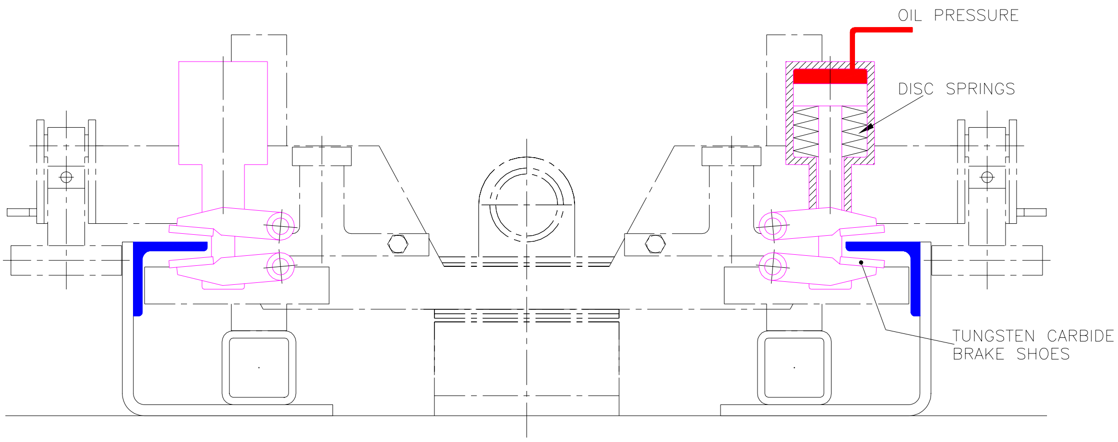
The most effective method of braking is by the use of spring applied calliper brakes acting directly on the guide rail surfaces on which no wheels run. To develop a constant brake force from each calliper under all track conditions prohibits the use of conventional friction materials. Therefore, tungsten carbide tipped pads, similar to those used in mining and the lift industry are used. These pads are not dependant upon friction but cut through any surface debris and deform the steel braking surface resulting in an apparent co-efficient of friction 0.42µ.

To release the brakes, direct electrical operation is not possible due to the high forces required and therefore, a hydraulic system is necessary.

A hydraulic master cylinder operated by a linear electrical actuator forces oil into the brake release pistons. Once the release pressure is reached, a maximum pressure limit switch operates, preventing the actuator raising further pressure. Similarly a low pressure limit switch reactivates the actuator, should the pressure fall.

Each brake cylinder is operated by a DC leak proof poppet valve, thereby providing a system which can selectively apply any combination of brakes.

The system is fully sealed, preventing the formation of condensation and an oil level warning is incorporated.



3.9.4 Service Braking

Service braking and speed control functions are provided by the linear motors and their associated control system.

3.9.5 LIM Reaction Plates

Each bogie is fitted with a 1.5 metre steel reaction plate to which is attached a copper surface plate. The advantage of using two bogie mounted reaction plates rather than a single 3 metre plate, is that the air gap can be more closely controlled when negotiating compound curves as required when approaching super elevated track sections. The air gap is continually monitored by measuring the distance between the bogie frame and running rail and also provides an indication of tyre wear.

When the distance is reduced to a minimum, the on-board vehicle management system arranges for the vehicle to automatically report to the maintenance facility.

Wheel wear compensation and air gap correction is readily re-set by rotation of the running wheel shafts. These incorporate an eccentric feature, which permits up to 10mm of adjustment before the wheels require re-tyring.

3.9.6 Impact Protection

The chassis comprises a central tube with energy absorbing buffers fitted into each end. This arrangement is designed to absorb energy from low velocity impacts which may occur in station areas or when running in un-coupled platoons. The advantage of this through chassis design is that the cabin experiences no impact or compressive forces.

3.10 Vehicle On-board Systems

Below is a list of all the on –board systems

- Power generation by wheel-driven high-output alternator
- Track selection and proving system
- Vehicle to vehicle detection
- Accelerometer indicating brick wall stop
- LIM air gap monitoring
- Battery charging and management
- Vehicle heating
- Air conditioning
- Temperature monitoring
- Interior lighting – fibre optic
- Exterior running lights
- Emergency button – activates 2-way communication link
- Calliper brakes - electro/hydraulic fitted with
    - dual leak-proof poppet valves
    - high and low pressure detection
    - low oil level monitoring
    - non-ventilated reservoir to prevent oil contamination
    - manual release with interlock – service personnel only
- Fault monitoring and management by PLC with duplication for safety critical functions

- Door operation
    - electric actuation
    - auto locking
    - manual external lock release
    - remote lock release

- Manual controls
  - doors open – station only
  - destination selection or start button
- Audio
  - Station announcement – doors opening/doors closing
  - Overload warning
  - Two-way communication

3.11 Maintenance

3.11.1 Lubrication

Generally most bearings will be greased for life. However, routine greasing will have an effect on bearing life, if only to keep the shaft seals in good condition. The ingress of dirt is the most probable cause of failure in similar applications.

Door mechanisms will also benefit from routine lubrication.

3.11.2 Corrosion Resistance

As a design policy all components, where practical, will be manufactured from non-ferrous or non-metallic components:

Chassis	- stainless steel
Bogie frames	- stainless steel
Calliper brakes	- stainless steel/aluminium
Wheels	- aluminium
Shaft	- stainless steel
LIM reactor plate	- copper/galvanised steel
Wheel supports	- cast aluminium
Car body	- plastic
Body and door framing	- stainless steel
Electrical enclosures	- plastic/stainless

3.12 Vehicle On-Board Safety Systems

Passenger safety in the event of fire, vehicle or system failure is of paramount importance and therefore the vehicle and its control system have been engineered to reduce the effects upon passengers during such events.

3.12.1 Fire

To reduce the risk of fire starting and spreading, due to the failure of mechanical or electrical equipment, all components, including the passenger cabin, are manufactured from either non-flammable material or have a high fire rating.

The location of the low voltage electrical systems is external to the vehicle cabin. The exception to this being passenger controls. Lighting is provided by an external fibre optic light source.

If a fire originates within the confines of the cabin, the passenger presses the emergency button which:

a) activates the control system and directs the vehicle to the first station or evacuation platform and stands with its doors open;

b) informs the emergency services or security personnel that a vehicle is due to arrive at a specific station or evacuation point, where the vehicle can be met and the appropriate assistance provided.

3.12.2 Emergency Braking

Unlike other PRT designs, the vehicles in this system will respond, albeit in the unlikely event, to a brick wall stop by the preceding vehicle.

The fundamental issue relating to safety during an emergency stop, is to ensure protection against loss of life and was never intended to provide a comfortable stop. The system, when operating with a headway of 2 seconds at 10/m/sec line speed, exerts a rate of retardation which does not result in injury in other industrial transportation systems with a similar seating arrangement.

In normal emergency braking applications the retardations generated on a lightly loaded car will always be greater than that of a fully loaded car and therefore can be expected to destabilise passengers.

To minimise this effect, the emergency braking system incorporates four pairs of calliper brakes, which act directly on the guideway and can be applied in any combination to match the vehicle load.

This is made possible by utilising the vehicle over load protection system, which weighs the vehicle in the station. The weight of the vehicle is then transferred to the vehicle memory store.

In an emergency the vehicle is then able to select the number of brakes required to produce a retardation force proportional to the number of passengers.

3.12.3 Vehicle Running into a Stationary Vehicle at Line Speed

To enable this situation to occur, a number of failures or combination of failures need to arise simultaneously:

a) The vehicle is stationary due to mechanical failure.
b) The control system has not identified a stationary vehicle.
c) The emergency brakes have not applied otherwise the control system would have been informed automatically.
d) A section of LIMS has failed allowing the vehicle to coast to a halt; a condition which should have been identified by the control system.
e) The vehicle to vehicle detection system has failed.

Upon impact, there would be a rapid transfer of energy from the moving vehicle to the stationary vehicle. In this situation the vehicle's slow speed energy absorbing buffers would be inadequate and severe damage to both vehicles and passengers would result.
The passengers in the stationary vehicle would be subjected to the highest acceleration forces and could expect to sustain the most severe injuries or fatalities on impact.

Such incidents should be prevented by intervention of the vehicle and central control system. Due to the length of the vehicle it is improbable that other additional energy absorbing features would significantly reduce the magnitude of injury to passengers.

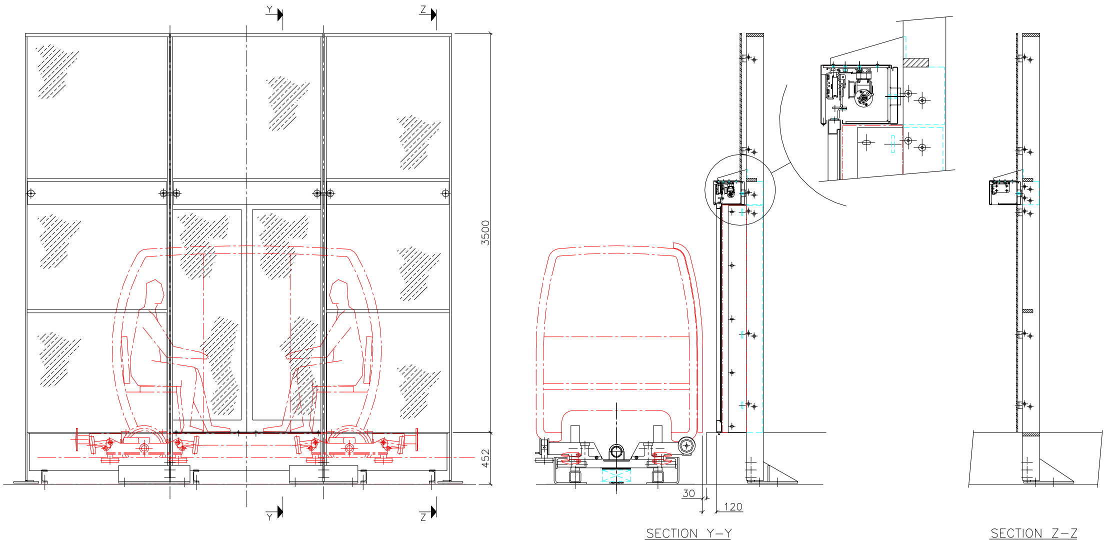
3.12.4 Additional Vehicle Safety Features

- Vehicle to vehicle radar detection
- "Brick wall" stop detection
- Emergency spring applied calliper brakes acting directly on the guideway
- Door safety locks
- Automotive type safety belts (optional)
- Over load detection and announcement
- Low speed energy absorbing buffers
- Contoured seating
- Removable end windows

4 Stations

In principle, the station area should be secure and accessible only to those passengers with tickets and the platform edges being protected by sliding doors. These two features not only provide for passenger safety, but deter vandalism. Fire control and evacuation procedures are subject to local authority and building regulations.

Platform and vehicle interface – DRG.NO. 1123/018



4.1 Platform Doors

Platform doors and screens would be fully glazed and this type of unit is commercially available world wide with full Railway Inspectorate approval.
Entry to the vehicle is unimpeded via doors of a minimum width of 900mm and a vehicle floor, level with that of the platform. (Maximum negotiable gap 35mm).

4.2 Heating

To reduce the heat loss from the vehicle in winter when the doors are open, a heat curtain may be fitted between the platform and vehicle doors. This could be switched on and off automatically upon arrival and departure of the vehicle.

4.3 Provisions for Handicapped people

Access for the disabled and those in wheel chairs will be provided by ramps or lifts dependent upon the station location and usage. Ticketing, call and destination buttons will be located at a height accessible to disabled and able-bodied passengers and all instructions made audible.

5 Safety issues

The most imporant safety related issues are:

- Track switching
- Emergency braking
- Impact protection
- Vehicle stability
- Derailment
- Emergency evacuation
- Door operation
- Communication
- Vehicle merging – operational issue

5.1 Safety Philosophy

As with any passenger transport system, there is always an element of risk. It is therefore the responsibility of those designing, manufacturing and operating the system to identify the risks and take the appropriate actions to eliminate or minimise these to acceptable levels. This procedure will be formalised in compliance with the European Standard EN292 Parts I & II – Safety of Machinery.

To meet the requirements of the Risk Assessment, the most appropriate engineering standards will be identified and applied.

Quality Assurance certification will be a pre-requisite for any company wishing to supply equipment or services to this project.

5.2 Emergency Evacuation

The following situations are those from which evacuation of passengers will be necessary:

a) Vehicle fire
b) Station fire
c) Emergency stop and vehicle failure
d) System failure }
e) Power failure control system intervention

a) Vehicle Fire

To reduce the risk of fire starting and spreading, due to the failure of mechanical or electrical equipment, all components including the passenger cabin, are manufactured from either non-flammable materials or have a high fire rating.

The location of the low voltage electrical systems are external to the vehicle cabin; the exception being passenger controls. Lighting is provided by an external fibre optic light source.

If a fire originates within the confines of the cabin the passenger presses the emergency button which:

- activates the control system and directs the vehicle to the first station or evacuation platform where is stands with its doors open.
- Informs the emergency services or security personnel that a vehicle is due to arrive at a specific station or evacuation point, where the vehicle can be met and the appropriate assistance provided.

b) Station fire

- Evacuation procedures from the station area will be subject to local authority regulations.
- Once fire has been detected the station will be closed to further vehicle arrivals. Other vehicles will be redirected by the central control and the passengers informed by the communication system.

5.3 Emergency Stop and Vehicle Failure

Vehicles subject to an emergency stop:

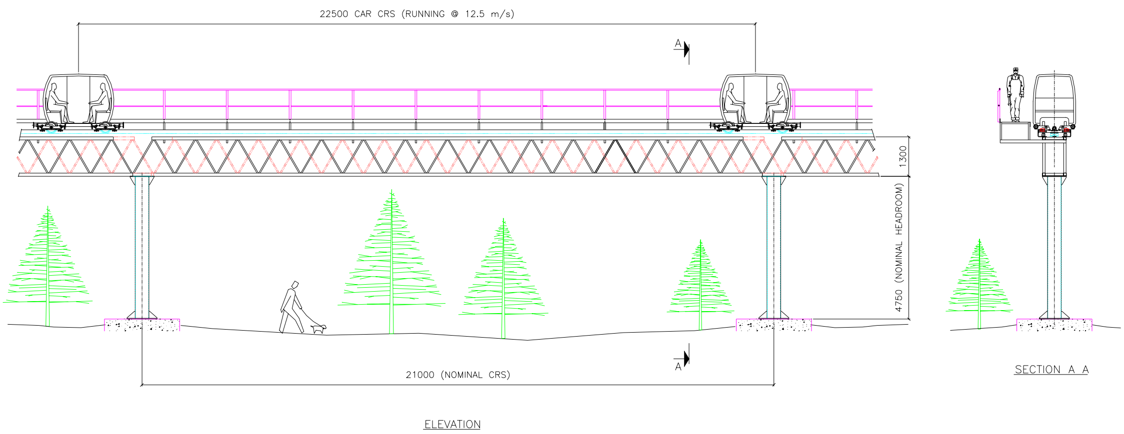
- Central control notified
- Following cars apply emergency brakes proportional to 2m/sec² retardation – central control intervention.
- Preceding vehicles continue to destination
- No further vehicles enter stationary section
- Passengers in vehicles notified of the problem
- Following vehicles reverse to the last station or emergency access walkway, where the passengers disembark under supervision
- If the failed vehicle can be accessed by road, passengers can be evacuated by scissor lift or similar and the vehicles lifted by crane from the track
- If road access is not possible, a special battery power dual-purpose recovery vehicle will be required to recover both passengers and vehicle.

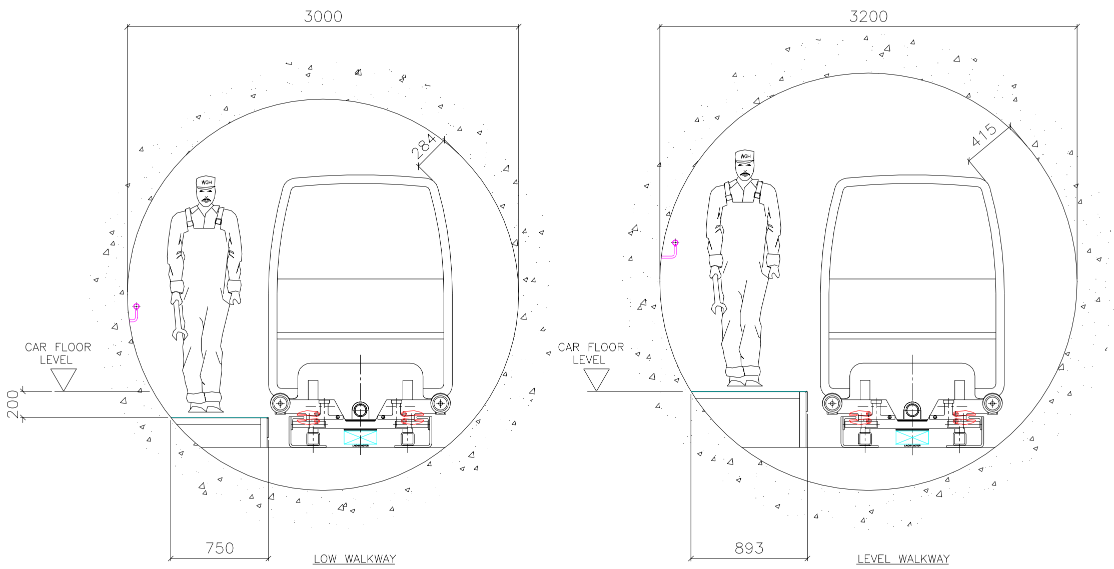
5.4 Evacuation of Passengers in Wheelchairs

In all emergencies other than in a vehicle fire incident passenger assistance will be required. In this situation the vehicle automatically exits the system at the nearest station or emergency walkway, permitting both foot and wheelchair passengers to evacuate directly under their own control.

5.5 Emergency Walkways

- Elevated: Drg.No.1123/013 and 014
- Tunnel Drg.No. 1123/015





5.6 Door Release System

Door locks may be released from both outside the vehicle or remotely, permitting the passengers to open the doors manually from the inside.

6 Maintenance issues

Consideration of future maintenance requirements begins at the initial design stage with the correct selection of materials, components and the development of a design, which are readily maintainable, requiring components to be easily inspected, checked and replaced.

Strategy for Providing an Aggressive and Proactive Maintenance Regime:

Reactive Mode: Otherwise known as fire-fighting maintenance, where the equipment failure dictates the maintenance action and response.

Preventative Mode: Scheduled maintenance usually triggered by hours run or fixed time periods, provides some protection from plant failure, and can often lead to excessive maintenance.

Predictive Mode: Allows the condition of the equipment to be constantly monitored by utilising non-intrusive technologies such as Vibration Analysis, Thermal Imaging and Lubricant Analysis. Evaluation of data allows problematic equipment to be diagnosed the root cause identified and maintenance scheduled accordingly, without incurring excessive downtime.

Predictive maintenance is often used as a baseline for new equipment to confirm that the system design is operating within ISO guidelines and manufacturer's recommendations.

Components and Systems Benefiting from Predictive Controls:

1. **Vehicle Wheels and Bearings** – This area is probably the most important, due to the physical demand and unknown life span of the component.

   The 12 wheels per vehicle could be monitored by accelerometers situated within the wheel axles. This accelerometer would monitor the temperature and overall vibration levels of either velocity, acceleration or both. This information would be interfaced with a PLC which would allow the data to be constantly assessed and any deterioration of the bearing condition, friction build up, or wheel wear could be alarmed.

2. **Hydraulic System –** The most important component of this system is the lubricant and its properties. The cleanliness of this lubricant is paramount in providing optimum protection and performance.

   The hydraulic system can also be monitored on-line, using a special transducer dedicated to monitor both ISO particle count and viscosity. This data can also be interfaced with the PLC for evaluation and alarming. The constant monitoring of these properties allows the optimum life of the lubricant to be used prior to replacement.

3. **Braking System –** Characteristically calliper braking produces pad wear and can be monitored using the automotive method of installing a simple wiring circuit within the pads. The progressive wear becomes a concern, once this wiring circuit becomes "open" and the signal produces an alarm.

4. **Thermal Imaging –** This technology is portable as opposed to the other on-line proposals. All electrical equipment can be thermally profiled and assessed for any components emitting high temperatures. This technology is ideal for diagnosing component defects within electrical control panels and is often used to produce accurate baseline data.

5. **Track Inspections –** Scheduled at fixed time periods when a full evaluation of the tracks and structural supports will be conducted as part of the " Preventative Regime".

7 Operational issues

7.1 Performance

See Project Design Parameters in Appendix 1 in the report 1-ABC-3-4-1.0 Overall System Design.

7.2 Snow and Ice

The uncontrolled formation of snow and ice on the running surfaces will affect performance and ride quality. Each vehicle may therefore be fitted with snow ploughs, scrapers, or brush, as considered appropriate.

In adverse conditions it would be expected to run a number of vehicles in addition to employing special non-passenger carrying, track-clearing vehicles, in order to maintain track performance.

The heating effect of the LIMS will prevent the build up of snow or ice on both the motors and reaction plate surfaces, but may result in the formation of ice where the water cools down.

To avoid build up of snow on vehicles, parking areas have to be covered, and eventually some kind of "gate" with brushes formed similar to the ones at car cleaning stations may be installed and set in operation when strong snowfall.

7.3 Rain

Rain has no effect on the vehicle's performance, although spray may be generated in areas accessible to the public and secondary measures may be required when vehicles run overhead. The enclosed design of vehicle, track and wheels should minimise this effect.

7.4 Direct Sunlight and High Temperatures

These have no effect upon vehicle performance. Passenger comfort will be the principle consideration during extreme conditions.

7.5 Dust and Sand

These have no effect upon vehicle performance, although special attention will be made to the design of bearing seals and electrical enclosures working continually under these conditions. Track will obviously have to be kept clear.

7.6 Vehicle Stability and Wind Effect

The track is designed to allow a vehicle to experience a lateral force of 2.5m/sec^2 in combination with a side load equivalent to a wind speed of 22m/sec.

Under these conditions an empty vehicle has a resistance to over turning ratio of 1.5:1 and a vehicle with two passengers sitting to the outside of the curve has a ratio of 1.7:1.

The linear motors are specified to operate at line speed into a 20m/sec headwind on a 2% gradient.

7.7 Vandalism

Vandalism has two possible outcomes malicious or visual damage. The former resuls in injury or death and the latter in passenger resistance to using the system.

Malicious damage can be inflicted upon both the track and vehicle with devastating results. Passive resistance to vandals gaining access to tracks may take the form of:

- Fitting barriers or enclosures to foot bridges or public access routes that may cross above the guideway.
- Maintaining a minimum track structure height above ground level to prevent easy access.
- Enclosing or guarding any track operating at ground level.

Malicious damage to vehicles will probably take place in unsupervised and little used stations. In these areas, the requirement to have a ticket to enter the platform area is a great deterrent and the case for automatic platform doors becomes apparent in preventing direct access to the vehicle system.

The case for CCTV monitoring at stations is unquestionable.

Damage to the vehicle interior may be limited by the careful design of fittings and panels ensuring that they are flush and are of adequate strength to prevent impact damage; techniques which are applied widely within the lift industry.

The visual impact of graffiti or deliberate soiling of the vehicle's interior must be readily rectified by the use of easily cleaned materials such as polyethylene and stainless steel and the elimination of non-cleanable joints between panels or fittings.

Cleanliness will be subject to an active management regime.

7.8 Noise Supression

On this type of system, where line velocities are relatively low, little noise will be generated by vehicle movement through air.

Noise will be generated at the wheel/rail interface and radiated from that point and may be amplified by the structure on which the track is mounted. This problem increases with vehicle headway.

To minimise the environmental intrusion of vehicle generated noise, the following features are incorporated into the vehicle design.

7.8.1 Wheel Rail Interface

- Non-metallic resilient tyres fitted to all wheels
- Guide wheels are always maintained in contact with the track

7.8.2 Structural Amplification

- The running sections may be filled with polyurethane foam after installation or filled with dry sand during manufacture.
- The guide rail may also be sprayed with a polyurethane surface to dampen any high frequency vibrations.
- Resilient mountings may be fitted between the running rails and the support structure, preventing the transfer of noise into the structure.

8 Concluding remarks

The engineering objective throughout the development of this design has focused on high reliability, low cost of ownership and meeting the performance criteria.

These objectives have been achieved by providing simple and elegant solutions to complex problems by using well proven engineering principles and technology.

The subject of tyre wear has been identified as a necessitating accelerated development. Practical experience is only available from the leisure industry, where such wheels are widely employed on roller coasters, operating at higher speeds and loads, but not having the same duration as that required in this application.

To ensure that tyre and brake engineering proceeds well in advance of the project development, a tyre and brake test facility will be built.

We are therefore confident that at the end of the development phase and test programme, the proposed design will meet its objectives.