Delegate information

Seminars

at the G-MEX Exhibition and Event Centre, Manchester

Mainline Railways TUESDAY 29 SEPTEMBER 1998

Signalling Issues WEDNESDAY 30 SEPTEMBER 1998

Light Rapid Transit THURSDAY 1 OCTOBER 1998

THE INSTITUTION OF CIVIL ENGINEERS

THE INSTITUTION OF RAILWAY SIGNAL ENGINEERS INCORPORATED 1912

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Tuesday 29 September 1998

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D Farrington, British Steel Track Products

0930 2. **Vehicle or Track based lubrication on London Underground**
J Batchelor, Asset Development Engineer, London Underground Ltd

0955 3. **Rail defects on London Underground**
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1020 Discussion
1035 Coffee

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1400 7. **S&C design for the future - BBMC weldable cast manganese crossing development**
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Dr G A Hunt, Team Leader & I Banton,Principal Scientific Officer, AEA Technology Rail

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1640 Discussion
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1710 Close of seminar

Introductory Notes

RAIL SELECTION & STANDARDS

The reasons for rail removal are becoming better understood but are changing continually as many railways turn to higher speeds and axle loads, more intensive use and come under ever increasing cost restrictions.

High Speed Trains Higher Axle Loads Increased Traffic Density
Increased Commercialisation Inter- Modality
Infrastructure Reliability & Availability
Rapid & Mechanised Installation Increased Focus on Logistics
Increased Use of Grade 900 A Rails
Increased Use of Factory F-B Welds Use of Mobile F-B Welds

Table 1 - Trends in Rail Systems

How is the rail supplier responding to these issues, and what information does the permanent way engineer require to help him choose the most suitable rail for his changing environment. The situation may appear confusing when viewed from the world scene as this summary shows:

Country & Railway		Axle Load t	Speed(s) km/h	Profile Supplied	Grade Supplied
Portugal	CP	19.5	140	UIC 54	BS11 A / UIC 900
Italy	FS	20	160	UNI 50	UIC 700
Taiwan	TRA	18	-	UIC 60	MHT
Hong Kong	KCRC	25	120	UIC 54	BS11 A / MHT
UK	Channel Tunnel	22.5	120-160	UIC 60	UIC 900A
Germany	DB	22.5	250	UIC 60	UIC 900A
France	SNCF	22.5	300 (TGV)	UIC 60	UIC 900A
Spain	RENFE	22.5	300(AVE)	UIC 60	UIC 900A
Norway	NSB	22.5	200	UIC 60/ S49	UIC 900A/B
Switzerland	SBB	22.5	200	UIC 60	UIC 900 MHT
India	IRB	22.5	160	UIC 60	India 52 BSA /MHT
UK	RAILTRACK	25	225	BR113A	BS11 N, A, MHT
USA	Amtrak Passenger		200	136	AREA 300 AREA high strength MHT & LAHT
USA	Freight Railroads	29.9-45	<80	136	AREA 300 AREA high strength MHT & LAHT

Table 2 British Steel Track Products Worldwide Supply

As more mixed traffic options arise there will be a greater need to draw on differing experiences world-wide, taking care when making comparisons to be sure that both operational and engineering factors are taken into account.

The Track Engineer's Requirements for rails could be summarised as a good performance for:

Rolling Contact Fatigue,

Wear Resistance,

Fracture Toughness,

Defect Size Tolerance,

Weldability , Weld Integrity, Weld Geometry

These principal factors from a metallurgical point of view are very much interrelated :

As a rail supplier British Steel Plc must attend to the detailed properties shown in this table , many of which relate to the target performance criteria listed above:

Metallugical	Physical
Composition	**Dimensions**
Segregation	**Section Size**
Cleanness	**Crown profile**
Hydrogen	**Straightness**
Hardness	**Line Straightness**
Surface / Near Surface	**End Condition & Twist**
Depth/Distribution	**Flatness**
Tensile Properties	**Surface Quality**
Microstructure	**Rolling Defects**
	Cold Marking
	Residual Stress

Table 3 Rail Properties

By detailed development of the process route over the years, very high standards are being achieved such that hydrogen and inclusion defects are very much a thing of the past. Other aspects such as rolling contact fatigue which is feared to be coming to the fore are very much a combination of material properties and operating conditions so that a co-operative approach with customers is needed for example links between British Steel and Railtrack in what we term **Joint Improvement Projects**, and EC funded studies such as the ICON project which links many operators suppliers and research bodies.

While the above is happening new proposed rail standards are being prepared by railways and manufacturers which greatly expands the choice available – how do these changes fit with the past and how can choice be rationalised?

The grades are to be as identified in this table:

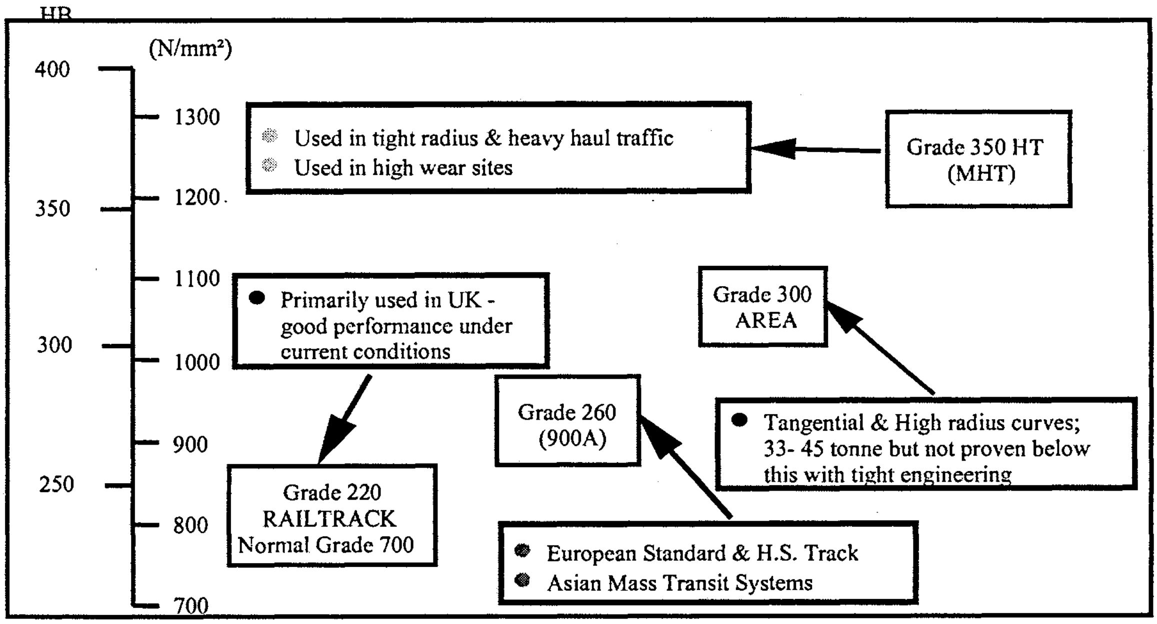
Grade	*Hardness range (HBW)*	*Description*	*Typical Previous equivalent*
200	200 – 240	Carbon – manganese (C-Mn)	UIC 700
220	220 – 260	Carbon – manganese (C-Mn)	BS 11 Normal
260	260 – 300	Carbon – manganese (C-Mn)	UIC 900 / BS11 A
260 Mn	260 – 300	Carbon – manganese (C-Mn) (Higher Mn)	UIC 900B

320 Cr	320 – 360	Alloy (1 % Cr)	UIC 1100 / 1% Cr
350 HT	350 – 390	Carbon – manganese (C-Mn) heat treated	AREA High Strength
350 LHT	350 – 390	Low alloy, heat treated	AREA HS low alloy

Table 4 Rail Steel Grades

This talk is aimed at explaining the choices and reducing the greatly expanded availability within the standards to something much more manageable and in keeping with current knowledge. It provides some guidance on the possible outcomes from different rail selection approaches and indicates where continued monitoring and development is appropriate through supplier – producer partnerships

A breakdown of the applications for the different grades is shown below. Rail selection in terms of both grade and section has evolved into relatively distinct applications ranging from light rail, through to fast passenger and heavy haul. This illustrated by the following diagram:



On the broader front of satisfying rail operator and infrastructure owners a survey has recently been carried out in which the following topics were ranked in order of importance

Rank	Feature	Rating of Rank	
		Average	Range
1	Wear	1.75	1 - 5
2	Fatigue - Ultrasonic failures	3.25	2 - 4
3	Corrugation	3.62	1 - 6
4	Welds - Thermic failures	3.67	3 - 4
5	Fatigue - Rolling contact fatigue	3.89	1 - 8
6	Welds - Flash butt failures	4.50	3 - 7
7	Corrosion	4.50	1 - 10
8	Plain rail fractures	4.80	2 - 6
9	Bolted joints	5.00	3 - 9
10	Formation	5.00	2 - 8
11	S & C failures	6.00	6
12	Fastenings	6.20	2 - 8
13	Welds - maintenance	6.50	4 - 9
14	3rd rail electrified	7.00	7
15	Slab track bearings	8.00	8
16	Drainage	9.00	9

Table 5 Track Priorities Survey

This table is slightly misleading in that the issues of wear, defects detected from ultra sonic surveys and flash butt failures are largely applicable to historical rail now and not to current production. Corrugation is of interest from the point of view of trying to move to design-out through material and profile design based on understanding of the detailed material processes – this is the subject of one of our tasks in the EC funded Silent Track project. Corrosion is relatively high on the list but simple and cost effective solutions are not necessarily easy, unless one accepts that for example coatings help preserve the general state of a rail but cannot guarantee the absence of pitting/corrosion fatigue where any coating is damaged. Plain rail failure reduction is an important target but difficult because it is a mixture of historical effects – for example such that tache ovale defects are declining – and the supplier of good rail steels now has to be innovative to contribute to this area by combining fatigue and other properties in an optimum manner.

Lower down the list joints are of particular interest and a further element of rail selection that this relates to is that of welding. British Steel's major contribution to writing of the new proposed European rail and welding standards has proved to be a good vantage point to assess and optimise for customers the benefits of the improvements to rail geometry by better understanding of the control possible. This talk is to give a better insight into the options now available and it should allow a more informed response to standards / choices and use of the new specification options.

Future Developments

Heavier Axle Loads

In anticipation of the possible introduction of heavier axle loads, the effect on existing rail section and grades is under evaluation using Track System models and observations made on heavy haul experience worldwide

Topics for Heavy Rail under new traffic regimes:
Rolling contact fatigue
Wear
Corrugation
Rail grade selection
Grinding regime
Crown profile
Lubrication
Increased lateral loads
Vehicles/suspension design
Track stability
Sleeper design
Sleeper spacing
Maintenance regime
Structures
LWR train

Vehicle or track based lubrication on LUL

John R Batchelor BSc, MSc, DIC

Asset Development Engineer - District Line
London Underground Limited

Synopsis : The paper summarises London Underground's work over the last seven years to manage friction at the wheel/rail interface. The history and key developments, over this period, is presented referencing how each fits into the broader development of a complete wheel/rail management strategy. LUL continues to operate relying on track based lubrication and makes continued effort to maintain the competent attention to detail required during the maintenance of rail mounted devices. In parallel, initiatives to prove train based systems are fit for purpose, are able to control both rail head and gauge face friction levels in a reliable, safe and cost effective manner are being developed. The best business option is not yet clear - many systems work - but which gives the best value ? LUL's preference is for a train based system based on either solid lubricant (both tread and gauge corner) or grease spray of the track from the train.

1.0 Introduction

The wheel/rail interface has been the subject of numerous studies by numerous administrations over many years. London Underground has joined in this drive for improvements in wheel and rail life and all the effects that are unpleasant to our customers and local environment. Specific focus on the wheel/rail system started in 1991 when it became apparent that several of LUL's lines were suffering an increase in wheel and rail wear, increased noise and ground-borne vibration, some evidence of an increasing rate of rail defects and increased signal failures due to wheel and rail wear material bridging block joints. This paper looks at the developments made in the management of friction and particularly friction control with various track and train based lubrication techniques.

2.0 Scoping the challenge - Technical and Commercial

There are three factors which all have to be managed in conjunction with each other to optimise the performance of the interface. These are:-

- Rail profile and condition
- Wheel profile and condition
- Lubrication - which contains the friction within desired limits

The key lesson learned from all the London Underground experience to date is that the combination of the three factors is a delicate balance and slight deviation or modification in any factor can impact on the other factors and cause the equilibrium to be lost. Significant cost and operational impact result. When the subject of friction management and the 'wheel/rail interface' is discussed it is easy to assume that this either means too high friction or too low friction without being specific. The thrust of this paper is only concerned with activities which lower friction coefficients and improve wear regimes. London Underground does experience adhesion problems in some areas, in common with other administrations in the industry, but these are not covered here.

London Underground is using the desired target ranges for coefficient of friction (μ) as shown in table 1. Targets have been widely communicated to the line business units but methods to economically measure and manage the railway using these target figures are not common across the network. The only equipment used for friction measurement by LUL in the Salient Systems™ tribometer with most lines using only staff experience, visual inspections and 'calibrated glove' techniques.

Location	**Friction Coefficient (μ)**	
	Desired target	Unacceptable
Gauge corner, gauge face and check rail / flangeback	$\mu < 0.1$ (ALARP)	$\mu > 0.2$
Rail head	$0.25 < \mu < 0.35$	$0.2 > \mu > 0.6$

Table 1 - Wheel/Rail friction coefficient ranges

From a wear perspective it is widely accepted over 60% of the contribution is due to friction management (or lack of lubrication). So the need to maintain optimum lubrication is critical to the interface.

It has been estimated that the poor management of the wheel/rail interface costs the company in excess of £10 million p.a. The cost estimate is based on reduced asset life; damage to other assets; containment measures; additional maintenance and inspection works; wasted energy and lost income.

3.0 Conventional Approach

London Underground has managed friction relying on track mounted grease and oil dispensers. These are used for gauge corner and check rail (wheel flange back) lubrication and the network has installed approximately 1000 of these devices (see figure 1). There are several variants of grease lubricators within this 1000 but all are based on the same basic principle - vehicle wheels driving mechanical plungers pumping lubricant. Oil boxes consist of less moving parts and rely on felt pads acting as 'wicks' from a oil reservoir wiping against passing wheels (gauge corner and flange back). In addition to the automated grease and oil delivery other sources of lubricant are:

- from naturally occurring materials, such as water and leaves
- hand applications of grease - usually during 'crisis management' recovering the delicate balance when another factor is outside tolerance, when setting up the original equilibrium after introduction of new assets or in depots/sidings

The effectiveness of track-mounted lubricators is sensitive to the following factors

1. Track layout and geometry (including gauge and rail inclination)
2. Position of the lubricator in the curve
3. Type of lubricator (i.e. the lubricant delivery mechanism)
4. Type of lubricant
5. Lubricator maintenance and adjustment
6. Wheel and rail profiles (inc. surface finish)

7. All other factors that influence vehicle curving behaviour (inc. vehicle speed)
8. Interference from other materials (water, dust and leaves)

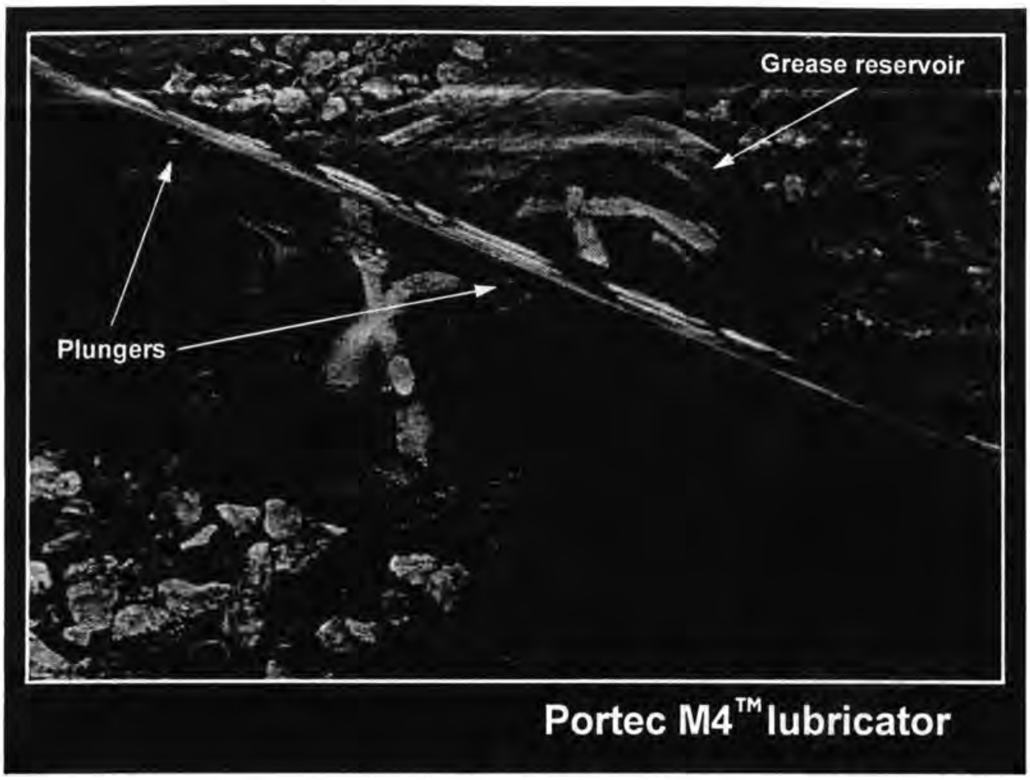


Figure 1 - Typical rail mounted lubricator

Experience has shown the two largest effects being (i) the position of the lubricator for a particular curve and vehicle type and (ii) maintenance and adjustment.

Figure 2 gives an indication to the performance of this type of lubricator. The data was collected over a year for a particular running rail lubricator. The lubricator was inspected every three weeks and the consumption of grease used since the last inspection recorded and reported as a day average. Line, lubricator model and maintainer remain anonymous.

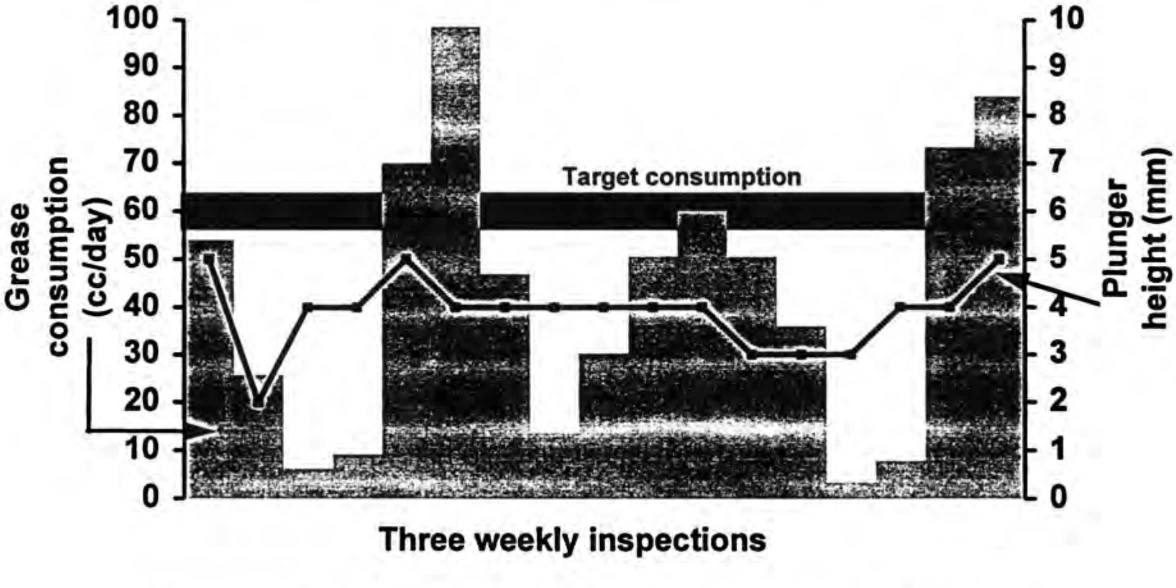


Figure 2 - Grease consumption of a typical rail mounted lubricator.

The graph shows how sensitive this type of lubricator can be. Very small changes in the plunger setting can have large and unpredictable effects on output. London Underground's engineering standards require the maximum period between preventative maintenance of:

- 14 days in sub-surface and tube sections
- 28 days in open sections

These are minimum acceptable conditions and it is current advice to plan to inspect critical lubricators on a weekly cycle.

An adequate lubrication regime can be obtained using combinations of track based greaser but it is totally reliant on constant inspection by competent trained staff and careful attention to detail during maintenance. This has had varying levels of success across the network. Pockets of expertise exist on some lines and improvements in performance have been measured following targeted staff training programmes but London Underground is still working to change the underlying culture to promote the importance of lubrication to the wheel/rail interface.

4.0 Vehicle based systems

Vehicle based lubrication systems started to be investigated by London Underground during the early 1990's. At that time a team was set up to assess industry best practice, with a view to making a step change in the performance of the wheel/rail interface.

Solid stick lubricants that were train mounted were in early stages of development and in use on a handful of fleets world-wide. The Docklands Light Railway (DLR) had introduced solid sticks by the time LUL had started to research the application. This had been a change from a lubrication strategy of operating two vehicles with wheel flange grease spray.

In 1991 London Underground started development work on both a solid stick application system and a wheel flange spray system - LUL doing the design and test work. Designs were focused on Victoria line rolling stock as a line that continually showed signs of being unstable with respect to wheel/rail wear and had the benefit of being a self contained line.

Figure 3 - Prototype (left) and Production (right) LCF™ applicators for Victoria line

Initial trials consisted of fitting one Victoria line bogie with a proprietary non-metallic circular cassette, on an LUL designed fixing. This contained Centrac® LCF and stick wear rates and fixture and cassette endurance was monitored. No change was made to track based greasers - see figure 3 (left). After one weeks running it was clear the cassette was not robust enough to survive the environment and the test was stopped. Very little stick wear data was obtained but enough confidence was gained in the system potential to develop a longer term trial on the East London Line (ELL).

Objective of the ELL test was to demonstrate the ability of Centrac® LCF to adequately manage friction on LUL without track lubrication. A robust axle mounted applicator was designed also to use the non-metal circular applicator sandwiched between alloy plates. Track lubricators were turned off and the test ran between July 1992 to December 1992 with Centrac® LCF lubricating 12.5% of axles. Applicators were fitted on leading and trailing axles of the 'A' stock units. Results showed a decreased rate of wear on wheel flanges over track based grease lubrication.

A production cassette was then developed for the Victoria line stock, see figure 3 (right), and fitted to one side of all Victoria line units. Axle coverage remained at 12.5%. The line ran with one rail track lubricated and one rail LCF lubricated from 30 January 1994.

The single side trial demonstrated, with 95% confidence, that gauge corner wear on the solid lubricated rail was 8 times less than on the conventionally lubricated rail over the years duration of the test. This led to cassettes being fitted to both sides of the train. The line turned off all track lubrication on 10 February 1995.

On the back of the Victoria line project actions were taken for Central line vehicles to be fitted with solid lubricant. Solid lubricant options were also built into the specifications for Jubilee and Northern line rolling stock.

During these trials a prototype wheel flange spray system was developed for Victoria rolling stock to ensure the project had another train mounted option should solid lubrication run into any technical or commercial difficulties. Work was carried in conjunction with Engineering & General Equipment Ltd although this was shelved after the design phase.

In the latter half of 1996 and early 1997 LUL were faced with a further outbreak of problems on the Victoria line. Noise complaints were increasing, incidents of rail defects increasing with no apparent change to the wheel /rail system. Subsequent investigations showed heavily worn wheel treads (hollow) and wide spread corrugation over the line. Rail head friction was consistently measured in excess of 0.5. Gauge corner friction and resulting wear was still low and resulting in wheels staying in service longer (owing to no thin flanges) expect high wheel tread friction had caused an aggressive wear regime serious hollowing the treads and in some cases causing second flanges. To contain the situation a decision was taken in January 1998 to recommission track based greasers and run with both LCF™ and track grease. This state continues today with all other lines using solid lubrication also running with track greasers active.

It is not clear why this rail head / wheel tread wear was not picked up during the year trial running or in the first year of full operation. It is now believed the loss of migration of small amounts of grease (not quantified) to the rail head had forced a high friction condition to develop with the resulting high wear regime

5.0 Current trials

Options to develop track and train based solutions continue.

5.1 Track based
Our Central line track team are working with industry to look at applications of low coefficient of friction coating for running rails. Specifying the friction coefficient as in table 1 the gauge face can be coated

A number of lines are looking at Various non-contact activated rack greaser are being researched and Central, Northern and District have installed A.T.S. Electro-lube Electro-luber™. Figure 4 shows an trial installation in Ealing Common depot with the Electro-luber™ feeding a Portec MC-3® Grease Distribution Unit (GDU). Trials continue to assess:

- grease carryover
- performance with fluctuating temperature

Figure 4 - Electro-luber™ installations at Ealing Common Depot

Electro-luber™ works by a electro-chemical reaction generating nitrogen gas which builds up inside a sealed gas chamber. Pressure in the gas chamber forces lubricant out of the container. This can be used for a number of different applications.

5.2 Vehicle based - Grease spray
In May 1997 LUL commenced a programme to trial a lubrication system working in conjunction with Villy Vogel AG Ltd. The system concept was a vehicle mounted track spray which was different from the previous work carried out in the early 90's and was based on similar methods currently in operation in Hong Kong. The system, activated by monitoring curvature, produces a pulsed output which deposited lubricant directly on the gauge corner of the rail. The reasons for developing this technology :-

1. It gave a system which put the lubricant directly where it was needed.
2. Grease consumption would be lower than the corresponding wheel flange spray owing to reduced wastage
3. The system offered greater flexibility for future development - especially concerning control systems and only lubricating part of the railway that need it.
4. Only a few units per line would be needed.

LUL designed, using CAD and rapid-prototyping technology, support bracketry to mount spray nozzles (see figure 5). These were designed in carbon fibre composite because of its strength to weight ratio and resistance to the harsh environment experienced by axle mounted structures.

Figure 5 - LUL designed spray mounting bracket - CAD representation (left) and actual installation (right)

During the development of the scheme one 1983 tube stock was fitted with a prototype system and run on the main line (and analysed using Automated Video Inspection (AVI) techniques) to check kinematic gauge calculations and operation of the curve sensing system. No lubricant was deposited during this trial but it demonstrated gauge clearance, lateral movement of spray nozzle to gauge corner of rail under dynamic conditions and proved performance of the curve sensing kit as adequate for a full lubrication trial. Some development needs were noted concerning issues such as the vehicle stopping on canted track and intermittent sensing of shallow curves.

A test was carried out under controlled conditions to evaluate performance with the system depositing lubricant. This was carried out on the access road to our train modification unit at Acton (the old Acton train overhaul works, road 27 - see figure 6). This lightly used track gave a 250m section of 90m radius track. Eleven survey stations were set up on the curve with full profile and friction measurements taken before and after the lubrication runs.

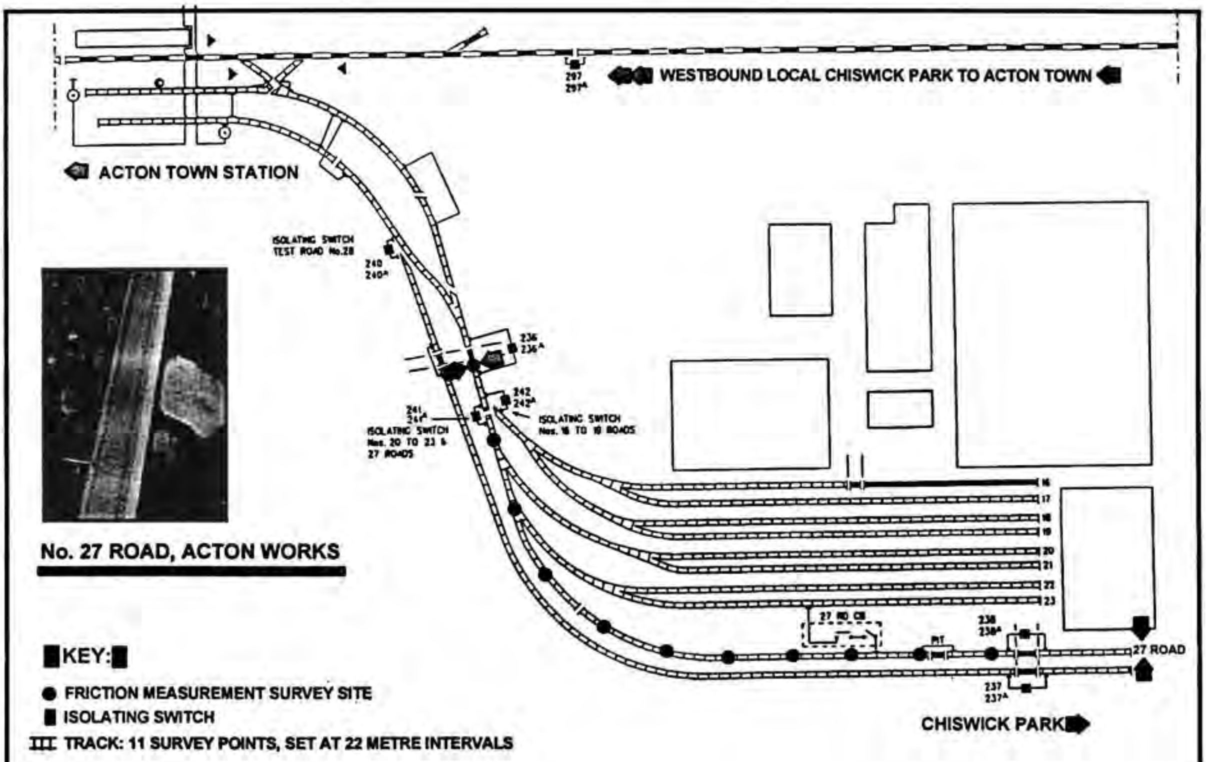


Figure 6 - Plan of Acton site (27 road)

The friction results taken during the trial (see figure 7) indicate that gauge corner friction was lowered from 0.45 (average) to 0.2 (average). This required 8 passes of the vehicle with 3.0 cm^3 (total) of lubricant used. This equates to a rate of $0.012cm^3/m$ which has become the target deposition rate. This requires the system output to be speed dependent so the target friction reduction can be obtained in a single pass.

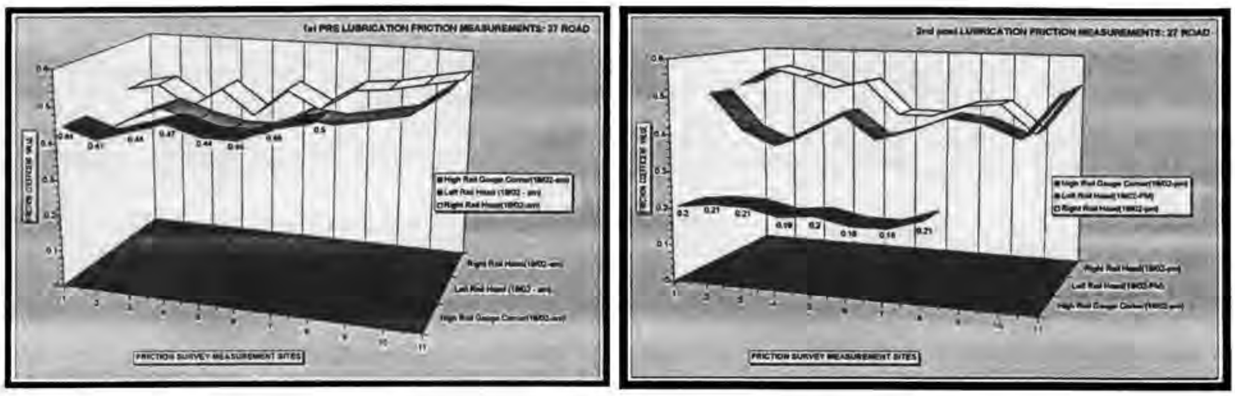


Figure 7 - Rail head and gauge corner friction pre and post spray

This system is showing very good potential as a controllable reliable lubrication provider. A further round of design and test has already started with the objective of having a vehicle fully equiped and tested ready for in service running, on the Jubilee line, starting April 1999.

5.3 Vehicle based - Solid lubricant

Following the rail head and wheel tread wear experienced on the Victoria line London Underground has lost confidence in use of just a solid flange lubricant to manage the whole wheel/rail interface. The LCF™ product used has good performance in controlling flange wear (as described above) but owing to its physical nature is not designed to migrate to the rail head. Rail head conditioning has been shown to be as important as flange wear - especially if the rail does not experience contamination from the environment (i.e. its all in tunnel such as the Victoria line). For a solid system to work both a tread friction modifier and flange lubricant are required. This impacts the business case as the implication is twice the number of sticks are required with addition bracketry to mount them resulting in additional maintenance cost. This impact must be determined over the whole asset life and there is considerable further work to do in this area to understand the benefits compared with today's, track based, lubrication regime.

London Underground is in discussion with Kelsan Solid Lubricants (Europe) Ltd suppliers of LCF™ and HPF™ (tread friction modifier) with a view to:

1. Demonstrating HPF™ is complaint with signalling compatibility tests
2. Finding ways of testing HPF™ on the operational railway to gather just enough information to generate the business case.

6.0 Wheel/rail management strategy - The future

London Underground's emerging strategy will be to reprofile wheels on condition against more rigorous and well defined maintenance standards. This will be managed by more regular turning of wheel using underfloor wheel-lathes and TreadView™ used as the preferred profile condition monitor. Projects are in place to deliver the necessary plant over the next two years. Programmes of rail grinding are currently being developed, with the lines, to combat known trouble spots. Our intention is monitor rail profile condition using a system supplied by E H Reeves & Associates Inc. and fitted to LUL's Track Recording Vehicle (TRV). A new wheel profile has been developed (LT5) as part of the work to deliver a complete wheel/rail improvement. This will be rolled out across the network by incorporation into normal wheel reprofiling activities over the next three years. Lubrication will be supplied by selecting the most business attractive option from the range described in this paper, current preference is for a train mounted system.

7.0 Conclusions

A simple sounding subject that has already swallowed up massive resources to find the 'best' lubrication system and management strategy. London Underground is concluding the seven years of investment using the methods described in the paper.

Some keynotes for any organisation wishing to embark on the wheel/rail journey would be:

- Do not expect quick wins - it is all about changing the culture even when one has found an adequate technical solution.
- There is more than one adequate lubrication system - pick the one that has the positive business case but also consider the one that facilitates the fastest and easiest culture change.
- Remember the rail head - need friction modifier or some migration of grease from gauge corner to rail head. This may need further quantification depending on the environment.
- Strive for an integrated asset management system to co-ordinate the huge amount of data generated by the wheel/rail interface. This crosses the function divides between track, rolling stock and the environment.

8.0 Acknowledgements

The author wishes to pass on his thanks to his colleagues in the District line engineering organisation for their assistance with production of this paper. Particular thanks go to Enver Mehmet and Paul Brown of the Track/Train interface team for supply of friction measurement and train spray data. The content this paper has been reviewed by David Crawley - Trains and Stations Delivery Manager and Malcolm Dobell - The Rolling Stock Engineer.

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9.6 Structures & Dynamics section internal report: **Results from Miniprof wheel and rail profile meter for Centrac LCF™ solid flange lubrication trial**: ©LUL 8/94

ICE Seminar: Infrarail 98

Rail Defects on London Underground

John Sinclair and Mark McDonough

1 Introduction

Rails on the London Underground network experience up to 24 million gross tonnes of traffic every year. This is a severe environment that requires careful rail management to avoid the problems caused by rail defect development. Only limited time is available for rail inspections and maintenance, as the rails encounter up to 19 hours of traffic each day.

In modern rail, most defects are generated by fatigue loading in service. If no action was taken, some of these defects would grow and cause rail breaks. Under certain circumstances this could lead to a derailment caused by the wheel not being supported and guided by the rail. London Underground Limited (LUL) manage this safety risk by a rail defect management process, where the rails are inspected regularly and actions are carried out upon the detection of particular defects. Rail defects also have important financial implications due to the reduced rail life and emergency rail replacement which is expensive and disruptive to service operations.

2 The LUL rail defect management process

LUL rail defect management is a controlled process that has three essential elements:

1. Rail inspection to detect defects
2. Minimum actions upon detection of defects
3. Analysis to improve defect management and reduce the number of rail breaks

2.1 Rail inspection to detect defects

The types of ultrasonic inspections used on LUL are the same as defined in Rail Track line specification RT/CE/S/055. The routine Ultrasonic inspections used by LUL are listed below;

Procedure	Probes used	Item tested and defects found
U1	0° and 40°	Rail ends at fishplated joints, horizontal cracks and cracks at holes.
U2	0° and 40°	Switch and Crossings (0° probe) and holes other than fishplated joints, horizontal cracks and cracks at holes.
U3	0° and 70° (070 Rail Testing System - RTS)	Continuous rail test except where the 070 trolley cannot pass, e.g. wing rails and crossing vees. "Tache Ovale" and tache ovale type defects, together with horizontal cracks. Monitoring of loss of rail bottom signal (LORB).

The extract below lists the special test procedures on LUL used normally as a result of problems indicated by U1, U2 or U3 procedures part of the routine ultrasonic inspections.

Procedure	Probes used	Item tested and defects found
U5	0° and 70°	Testing for the length and depth of squats and inspection of rail head repairs, wherever they occur, except in cast manganese crossings. Also used at locations identified by visual inspection or after U3 LORB.
U6	0° probe and two each detachable 45° probes in a rig and a miniature 70° probe	Testing for the lack of fusion in thermit (alumino-thermic) welds and weld repairs.
U8	0°	Testing on the side of the head and web of the rail for vertical longitudinal defects, and shattercracks.

The inspection interval is dependent on type of test, track category and construction type as defined in the following table;

	Inspection Interval (months)					
	Full depth 070			Rail end 040		
Track category	Open	Tube	Sub-surf	Open	Tube	Sub-surf
A	6	6	6	3	2	2
B	6	6	6	3	3	2
C	12	12	6	3	3	3
Depot entrance	6	-	-	3	-	-

The track categories are defined against perceived damage to the track based on a combination of speed and tonnage expressed by a factor L where;

$$L = T \times V^2 / 1000$$

The annual tonnage T is in millions of gross tonnes and V is in miles per hour. The track category is determined from this loading factor:

Where for	A	L	>	30				
For	B	L	<=	30	&	L	>=	15
For	C	L	<	15				

The inspection interval is also influenced by the construction type; "Tube" consists of deep level lined segment tunnels with the track supported on concrete, "Open" would consists of track supported on ballast and "Sub – Surface" consists of track supported in ballast but constructed using a "cut and cover technique"

With effectively 12 lines on the LUL network often with mixtures of track category and construction type this results in a very complicated inspection programme with breaks down into 162 discrete work packages per year.

The inspection programme is carried out entirely using a manual team who are dual skilled to be able make their own access arrangements to the railway and licensed to carry out the Ultrasonic test procedures. The Ultrasonic inspections are carried out during "Engineering hours" with traction current discharged and at locations with no trains running. Typically Engineering hours would offer at best a 4 hour time slot from nominally 01-00 hrs to 05-00 hrs. The manual inspection technique also has the advantage of being able to work around other work activities on the railway not requiring exclusion zones. For U1 and U2 inspections hand probes are used and for U3 inspections a trolley is used. (See figures 1 & 2 below).

Figure 1

Figure 2

A number of trials have been conducted using motorised trolley based systems but to date the challenges of the logistics of operating these types of trolleys on LUL system have out weighed the potential productivity benefits.

There is also the concern regarding the ability to rectify large numbers of defects identified within short time scales by high productivity techniques without seriously impacting on the train service.

2.2 Minimum actions upon detection of defects

The minimum actions are dependent on the severity of the detected defect in terms of the:

- Probability of the defect causing a rail break (For example large cracks in highly stressed parts of the rail are more likely to result in a rail break).
- Risk of a derailment from a broken rail (For example multiple defects detected over a short rail length are more likely to cause a derailment due to part of the rail becoming detached).
- Consequences of a derailed vehicle (For example a higher speed derailment is likely to be more serious).

Minimum actions include:

- Removal of the defective rail within a specific time after defect detection
- Additional rail inspections
- Fitting emergency or temporary fishplates to prevent derailment even if the rail breaks
- Imposition of speed restrictions to reduce the consequencies of a derailed vehicle and reduce rail loadings.

2.3 Analysis to improve defect management and reduce the number of failures

It is essential that rail defect management is working effectively. Failure to detect significant defects or taking inappropriate actions after a defect has been detected can increase the probability of a rail break. Process auditing and analysis of the failure statistics are used to monitor the effectiveness of rail defect management and act as a feedback loop to improve the process and adapt the process to changing circumstances. This proactive approach allows actions to be taken BEFORE serious problems occur.

3 Rail head defects on the Victoria Line

3.1 The problem

The rail failure statistics from the Victoria Line were examined as part of the rail defect management process,. This showed that the number of rail head failures were progressively increasing. Metallurgical examination of these failures showed that they were caused by cracks initiating from either the gauge or field corners and growing into the head to form transverse defects. Well developed defects look like "tache-ovale type" failures.

The Victoria Line has a vehicle mounted lubrication system that deposits small amounts of solid lubricant onto the gauge corner and gauge face on the high rail of curves. The system is very effective in reducing rail sidewear and wheel flange wear, but does not protect the top of the rail. This is believed to be caused by the lack of lubrication on the crown due to the lubricant not migrating from the gauge corner.

The absence of crown lubrication increases the lateral and longitudinal forces at the wheel / rail interface and can generate excessive plastic flow of metal across the rail head. The resulting profile change can cause closely conformal contact conditions, with almost identical wheel and rail profiles at the contact position. Such contact is highly deleterious, as it causes higher forces, increased wear and can lead to a "spiral of decline" in the profile geometry. It also forms sharp notches near the gauge corner on the high rail of curves (figure 3) and lips on the extremely "mushroomed" heads on the low rail of curves (figure 4). These stress concentrating features are the initiation sites for cracks that grow under the fatigue loading from passing trains.

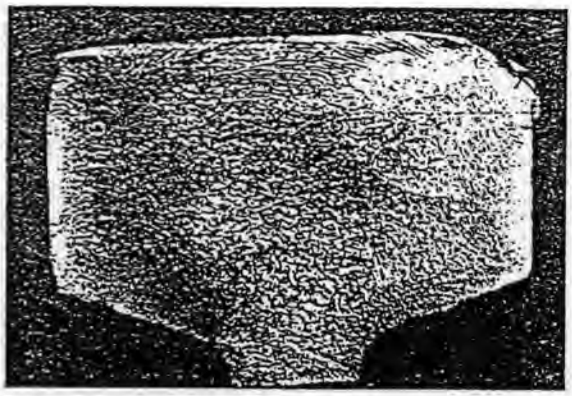

Figure 3

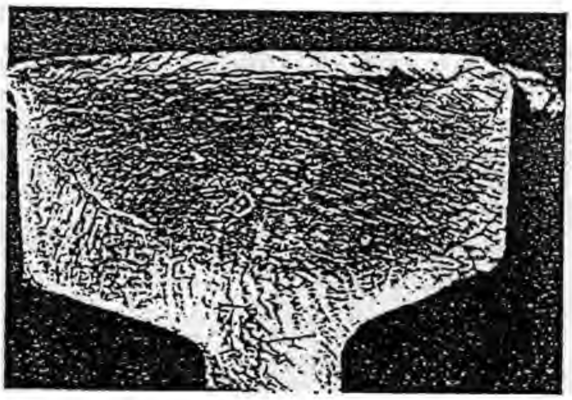

Figure 4

LUL's existing rail defect management system will detect well developed defects using the U3 procedure, and the application of minimum actions for "taches-ovales" will remove rails with significant defects. However, cracks growing from the gauge or field corners will normally be larger than "tache-ovale" defects before they can be detected by the U3 process and therefore, have a higher probability of causing a rail break and potentially reduce the safety reserve.

3.2 The solution

The first priority is safety. Urgent action was required to adapt the rail defect management system to ensure that the safety reserve was maintained. After this, actions to control the underlying cause of the failures were addressed.

The rail defect management system was adapted to include the special U14 ultrasonic inspection procedure that can detect smaller cracks and to introduce revised minimum actions.

The U14 inspection is essentially a variation on the U3 procedure with the probe pack offset by 9mm from the centre line position to enable "tache ovale" type defects propagating from the gauge or field corner of the rail to be detected earlier than by the U3 procedure.(See figure 5 below)

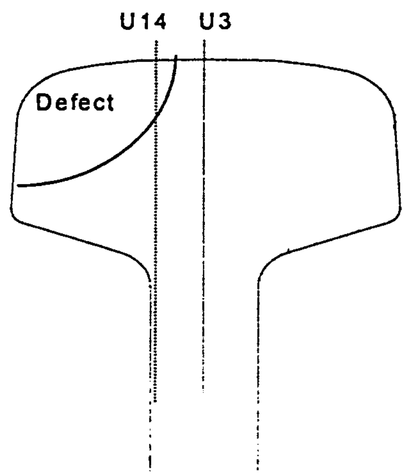

Figure 5 Detection of gauge corner cracks

Application of U14 Inspections to the Victoria Line

The inspection programme has been based on targeting areas of the Victoria line with similar probability of discovering U14 type defects.This was achieved by dividing the Victoria Line into 100 metre sections and reviewing the historical occurrence of defects together with the average cant which had been found to be a strong driving factor for the occurrence of defects. An initial mapping exercise (see figure 6 below from LUL TRV Datascope) of the incidence of defects and geometry recorded using the LUL Track Recording Vehicle indicated that 78% of defects occurred where the cant was 30mm or greater.

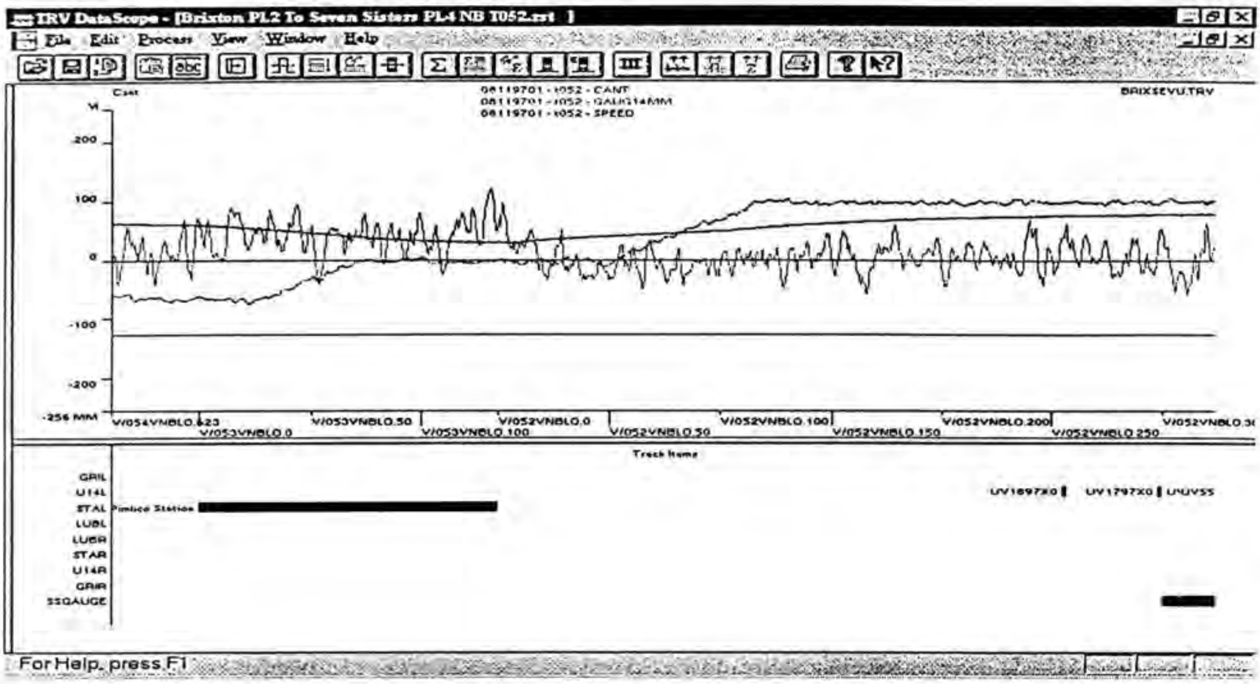

Figure 6 TRV Datascope view mapping defects against geometry

It was also necessary to consider the importance of the areas to the operation of the line so the critical areas were inspected at weekends when service disruption would have a reduced impact and more time is normally available for rectification work.

To enable the timely rectification of defects to avoid service delays the Ultrasonic inspection teams have worked closely with the line maintenance teams who are prepared with equipment to affect rail replacement or repair.

The current inspection programme is very intensive being carried out at a 6 week frequency over 6 shifts using a team of operators for each shift and therefore creates a high resource demand. Initially the programme has involved simultaneously inspecting both the gauge and field corners of the rail. Following a recent analysis of the failure statistics the standard U3 inspections are being alternated with the field side U14 programme to make best use of the testing resources.

Work is also being done with an American Company Sperry Rail Service to apply wheel probe technology to a conventional type of rail inspection trolley to enable U3 and U14 gauge and field inspections to be carried out simultaneously by a single operator. Figure 7 below indicates the trolley which has been operated twice now on the Victoria line in tandem with conventional equipment with promising results.

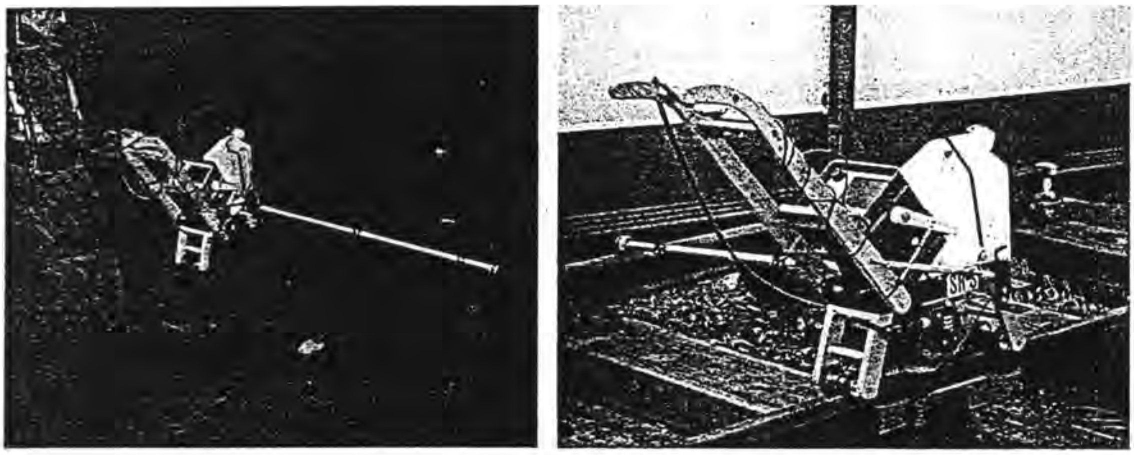

Figure 7 Sperry Wheel Probe Trolley

The U14 inspection intervals were based on the results from service trials and were consistent with fracture mechanics modelling of the relative crack growth rates of gauge corner cracks and "tache-ovale" defects

The minimum actions to be taken upon defect detection were based on Quantified Risk Assessment (QRA) using risk equivalence with the existing minimum actions for "taches-ovales". The QRA considered the following factors:-

- The probability of a rail break (For example, a defect detected by both U3 and U14 procedures is likely to be larger and require a more stringent minimum action)
- The probability of wheel guidance and support being interrupted (For example, a section of rail is more likely to become detached or displaced if a defect is detected close to a bolted joint)

- The probability of a collision following derailment (For example, a serious collision is more likely if a defect is detected near a tunnel headwall)

This resulted in a layered response, with more stringent minimum actions being specified for defects with a greater potential safety risk. Overall, this represents a similar or lower risk than the well-established management system for "tache-ovale" defects. However, it is only treating the symptom and not the cause. In the medium term, a safer and more effective solution is to stop the gauge and field corner cracks from forming.

The following actions have been considered:

- Removing the stress concentration features by grinding off the lips and notches. Although it eliminates the crack initiation site, the relief is only temporary if the lips and notches quickly reform due to unsatisfactory lubrication and wheel/rail profile interactions.

- Reducing the tangential forces by slightly lubricating the rail crown. This was achieved using track mounted lubricators that provide protection from excess rail sidewear and wheel flange wear and allows trace amounts of grease on the rail crown. Considerable care was taken to ensure their reliable operation.

- Improving the compatibility of the wheel and rail profiles by additional wheel turning and rail profile grinding.

The last two activities may offer a long-lasting solution to the cracking problem, and an extensive trial has just started on the Victoria Line to monitor its effectiveness.

4 Conclusion

Rail defect management is an essential element in the LUL safety management process. It is not a fixed process, but evolves through structured evaluation to adapt to changing conditions experienced at the wheel rail interface.

Eliminating Rail-End Bolt Hole Cracking by Cold Expansion - The Technology and Logistics of Implementation

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Introduction

Improving service reliability while optimizing track maintenance has been the subject of many studies. Implementing cost effective methods of reducing maintenance and inspection of rail is a priority of maintenance departments to minimize disruptions to rail operations and improve safety. An important part of track maintenance is the inspection for and repair of defects at bolt holes. While the total number of defects at bolt holes is relatively small the impact of these defects can be quite large. The costs to the operation from schedule delays associated with the repair often far exceed the repair cost. Additionally, identified cracks waiting for repair may impose speed and weight restrictions; further adding to cost of operations

This paper describes a hole treatment process called split sleeve cold expansion, developed by Fatigue Technology Inc. (FTI) to virtually eliminate fatigue cracks in holes in aircraft structures. It describes how this technology is being used to significantly reduce the incidence of rail-end bolt hole cracking resulting in tremendous long term cost benefits to rail operators and improved safety. The technology can also be applied to other rail structures and components such as wheels and bridges.

Joint Failure Mechanism

Cracks originating from rail-end bolt holes are the result of the repetitive loads applied from each wheel as it passes over the joint as shown in Figure 1. The shear stress in the rail caused by the bending moment from the force of the wheel and the impact of the advancing wheel on the joint, is concentrated at the bolt hole. Additionally, the shear stress associated with dynamic wheel/rail forces generated by a dynamic dip at the joint, combined with high cyclic stresses, eventually cause cracks to initiate in the lead bolt hole and grow, i.e., classic fatigue failure. Loose or poorly supported joints can further increase the magnitude of the stress at the hole and any scratches or corrosion pits that may be present in the hole can further exacerbate crack initiation. Undetected rail-end bolt hole cracking can lead to the separation of a significant piece of track, Figure 2; potentially causing derailment.

Figure 1. Fatigue Loading of Typical Rail Joint

Figure 2. Example of Separated Piece of Track

Rail-End Bolt Hole Cracking Problem

Bolt-hole cracking is not unique to any specific railway, region or country, but it is recognized as a worldwide problem. In the United Kingdom during the early 1980s, more than 3000 cracked and broken rails of different types were reported each year. The highest number of defects were reported on middle-speed-range, heavily loaded track. Of these, about 25% were caused by cracks originating at rail-end bolt holes, or about 750 per year. Between 60 and 70% of rail-end cracks were detected before they had grown completely through the track. From these statistics one can calculate that over 200 rail-end bolt holes completely failed before detection or repair. In 1974, the U.S. National Transportation Safety Board identified broken rails as the largest single cause of train accidents. Between 1982 and 1988, track related accidents represented between 30 and 40% of the total number of reported accidents. U.S. Federal Railroad Administration statistics for 1988 showed that derailments caused by bolt hole failures accounted for 10% of the total cost of rail and joint bar defects.

More recently, tests were carried out as part of the Heavy Axle Load (HAL) program for the U.S. rail industry to investigate the effect of increased axle loads and speeds on existing track. It was found that an increase in axle load of only 20% precipitated serious cracking in bolt holes at turnout frogs and switches.

Fatigue Life Improvement of Rail Joints

A number of significant attempts have been made over the past 30 years to overcome the problem of rail and bolt-hole cracking from increasing the web thickness of the rail to "work-hardening" the hole surface to increase the fatigue resistance locally. None of these methods proved to be effective.

The U.S. Department of Transportation (DOT) sponsored a study in 1975 to investigate the application of several promising fatigue life enhancement techniques to rail bolt holes. These methods included pad coining, interference fit bolts and split sleeve cold expansion. The lives of specimens treated with split-sleeve cold expansion showed a remarkable life improvement over non-cold expanded bolt holes and the other methods investigated. Figure 3, from the DOT study, shows the dramatic improvement in rail life after the application of cold expansion. Independent British Rail trials and evaluation of the cold expansion process, including laboratory and in-service tests, confirmed the results and concluded that the process increased the life of a bolted rail joint by a factor of 10 or more by reducing or eliminating bolt hole fatigue failure.

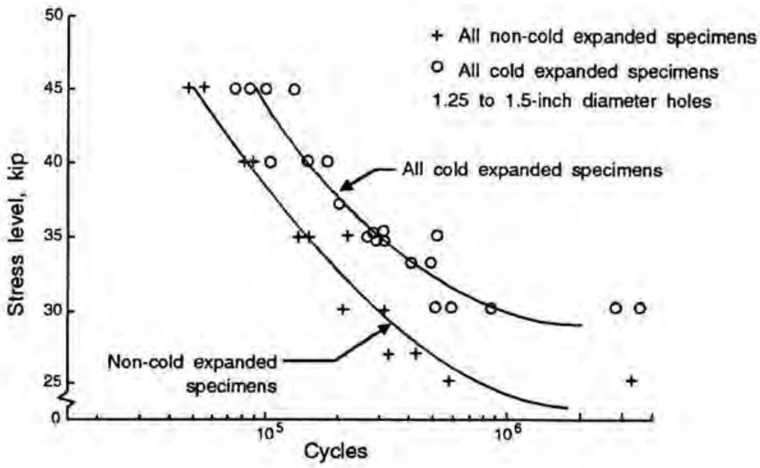


Figure 3. Increase in Fatigue Life for Cold Expanded Holes (U.S. DOT Rail Fatigue Results)

The Split Sleeve Cold Expansion Process

The split sleeve cold expansion process is accomplished by pulling an oversize tapered mandrel, pre-fitted with a dry-film lubricated split sleeve through the bolt hole using a specially designed hydraulic puller, as shown in Figure 4. The sleeve remains in-place in the hole during the expansion process and is afterward discarded. The sleeve protects the hole from sliding metal contact and ensures the hole is radially expanded. The dry-film lubricant in the sleeve minimizes the pull force required to pull the mandrel through the hole.

The combination of the mandrel diameter and the sleeve thickness creates enough radial expansion to significantly yield the hole. The expansion for the process in rail applications range from 2 to 4% of the hole diameter depending on the material properties of the steel and the hole diameter. The peak magnitude of the residual compressive stress is roughly equal to the compressive yield strength of the steel and extends about one diameter from the hole edge. See Figure 5. A balancing zone of tensile stress, about 10 to 20% of the tensile yield stress, surrounds and "locks in" the beneficial compressive stress. The residual compressive stresses lower both the mean and maximum cyclic stress at the edge of the hole.

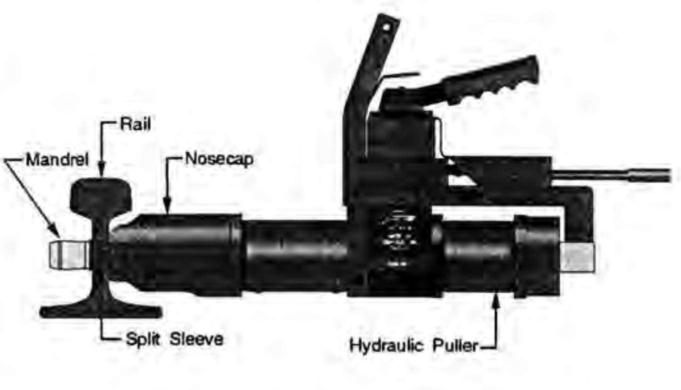


Figure 4. Schematic of Split Sleeve Cold Expansion Process

The residual compressive stress also reduces the effective crack opening displacement and retards crack growth by reducing the stress intensity factor range (ΔK) as shown in Figure 6. This was also reported in British Rail studies of the process. Additionally, the presence of residual stresses may change the critical crack length for unstable fracture. The lower crack growth rates and greater critical crack length can be used to extent non-destructive inspection intervals for rail joints.

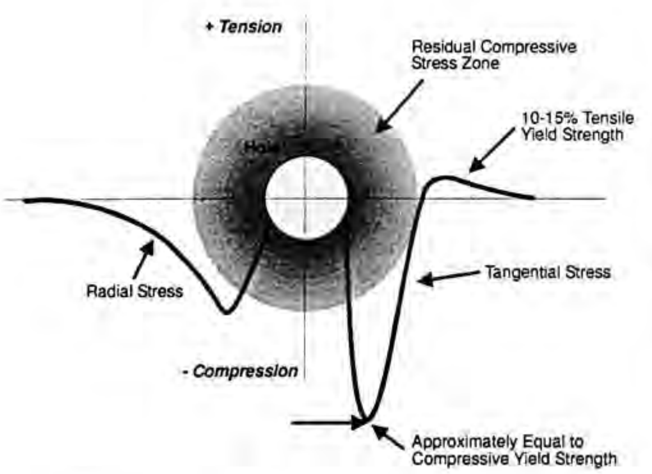


Figure 5. Distribution of Residual Stress Around a Split Sleeve Cold Expanded Hole

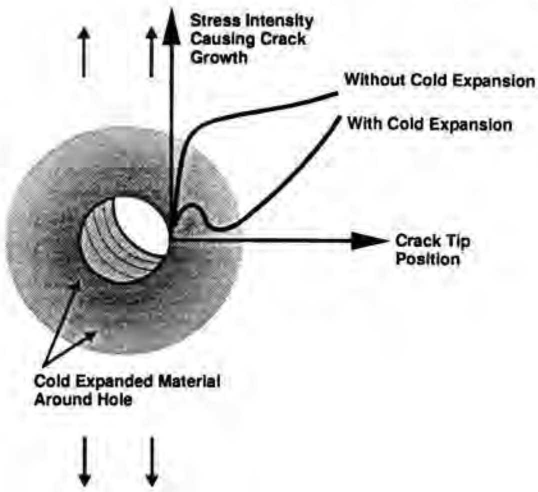


Figure 6. Reduction in Stress Intensity Factor Range (ΔK) in a Cold Expanded Hole

The residual compressive stress also reduces the effective crack opening displacement and retards crack growth by reducing the stress intensity factor range (ΔK) as shown in Figure 6. This was also reported in British Rail studies of the process. Additionally, the presence of residual stresses may change the critical crack length for unstable fracture. The lower crack growth rates and greater critical crack length can be used to extent non-destructive inspection intervals for rail joints.

FTI RailTec Process

To facilitate cold expansion of rail-end bolt holes FTI developed the RailTec™ cold expansion system of tooling to incorporate the process in existing track as well as new production rail. This rugged system of tooling was designed for a range of standard rail bolt holes and for the demands of the track environment. In a typical field application, as used by rail crews, each joint is dismantled, followed by cleaning of bolt holes and adjacent areas. Holes are measured and cleaned up with a bridge reamer to a nominal size and then each hole is cold expanded using RailTec tooling. Finally, the joint is re-assembled. Trained operators can process around 40 holes per hour. For new production the bolt holes are reamed to the appropriate diameter and cold worked using equipment similar to the field repair equipment.

In-Service Results

In-service evaluations of cold working show the dramatic effects of the process on rail-end bolt hole cracking. In the UK, the Exeter to Sherbourne route comprises 38 km of track. Prior to a cold working maintenance action that started in 1987, the line was plagued with rail-end bolt hole cracks in the form of star cracks. By 1991 the entire route was treated and the number of incidences of star cracking reduced from 25 in 1987 to just 1 in 1991 as shown in Figure 7. A similar result came from a study of the Plymouth to Penzance route shown in Figure 8. Again, the high incidence of star cracking was reduced by cold expanding holes. These results justified the widespread use of cold expansion in the UK.

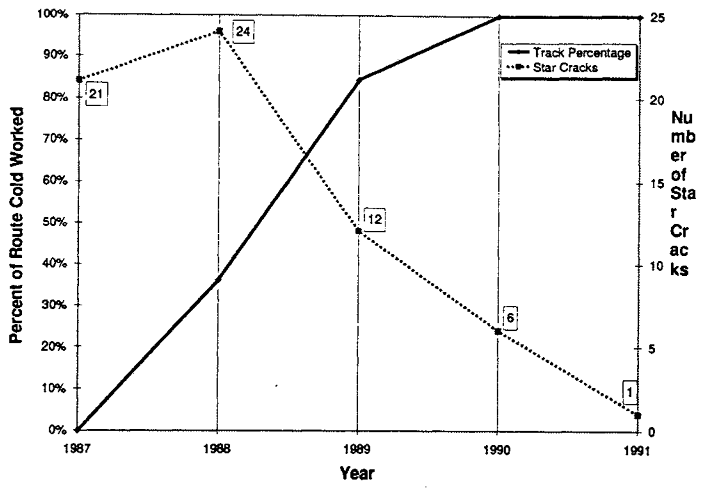


Figure 7. Survey of Results After Cold Expansion - Plymouth to Penzance Route

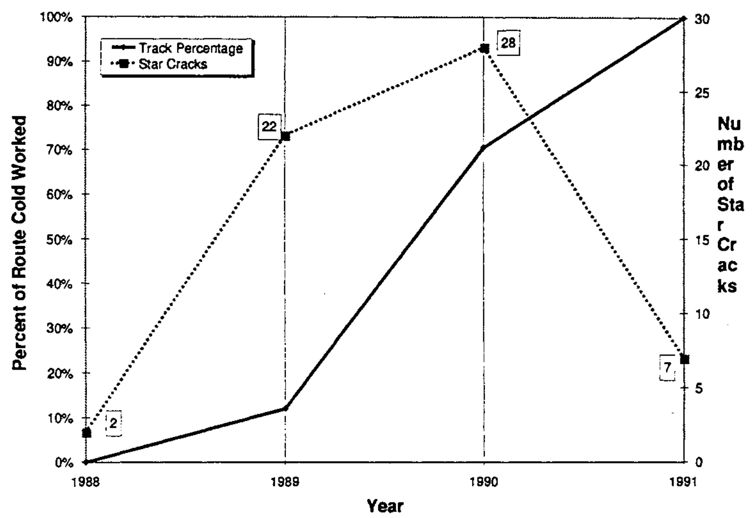


Figure 8. Survey of Results After Cold Expansion - Exeter to Sherbourne Route

Summary

The problem of rail-end bolt hole cracking can be virtually eliminated by the use of split sleeve cold expansion as verified by laboratory studies, carefully controlled field surveys and in-service results. The residual compressive stress induced by the RailTec process, effectively reduce the local stress levels and inhibit crack growth. The process is used in routine maintenance in the United Kingdom and the United States and is applied to existing track; new or replacement bolted track, switches, crossings and insulated joints, and has also been successfully used to prevent cracks emanating from balance weight holes in rail wheels. Studies show that increased axle loads and speed increase the probability of rail-end bolt hole cracking. Cold expansion of these joints reduces susceptibility by allowing the joint to operate at higher stress levels. The overall result is a greatly extended fatigue life of bolted track, safer and more economical rail operation by eliminating a potential cause of derailment, reduced routine or special maintenance costs and extended joint inspection intervals.

The standardized RailTec cold expansion tooling is readily available from FTI. Expertise, assistance with tooling and training on the RailTec™ system are available from both FTI and from Cold Expansion Management Systems Ltd. (CEMS) in the UK.

A Change to UIC60 Rail For High Speed Lines in the UK

DAVID VENTRY
Railtrack PLC, London, UK

Railtrack has been considering changing to the use of UIC60 rail for new installations on high speed and heavy axle load routes. This paper considers the reasons why such a change may be appropriate, the benefits and the implications.

The privatisation of the British Railway Industry has raised expectations and provided a clearer focus on the value of train path availability and the cost of delay. It has also accelerated demand from train operators for higher speeds, tilting trains and higher axle loads. There is therefore a need to consider changes in the track to enable it to economically carry greater forces and tonnage more reliably, and with less intervention.

One might also consider why the United Kingdom's standard rail section (113A) is smaller than the UIC60 section used by the other major European railway administrations when our maximum permitted axle load is higher. 113A is effectively only a minor improvement on the section adopted by the Railway Executive in 1949.

UIC60 is appreciably stiffer than 113A and therefore acts as a more effective load spreader. This leads to either a reduction in the rate of geometry deterioration and hence less maintenance intervention, or the ability to carry greater loads with the same maintenance. Higher standards of geometry can also be maintained more easily. It is also anticipated that the incidence of certain rail failures will be reduced.

There are obvious procurement advantages in moving to a product produced by numerous suppliers. There may also be knock on benefits with other track components.

AEA Technology Rail have assisted Railtrack by calculating the theoretical performance of an number of rail and sleeper options. This work has shown clear advantages from the use of UIC60 rail and has given clarity in the optimum sleeper type and spacing.

Halcrow Transmark were also engaged by Railtrack to define the practical issues to be addressed in a change of section and to identify methods of managing them. This work was particularly important in ensuring that there were no hidden costs which could distort or undermine the business case.

One of the physical differences between UIC60 and 113A is the foot width. UIC60 is wider and therefore will not fit existing sleeper designs. It would have been possible to used UIC60E which has a foot similar to 113A. Whilst this has some short term advantages, the longer term benefits of using a European standard section are considered greater and this option has been excluded.

As can be seen from the attached diagram, the major differences between UIC60 and 113A are depth and width. There are also minor differences in the head. These have implications for some rail handling equipment. Thimble equipment will need to be provided for UIC60 and the long welded rail trains will require modification. Transition arrangements to other rail sections will also have to be provided, probably through the use of transition rails.

Sleeper designs for UIC60 are available although new designs suitable for higher axle loads are being considered. Railtrack has recently changed its installed nominal gauge from 1432 to 1435mm and this will be retained with UIC60 although there may be a case for further widening in future.

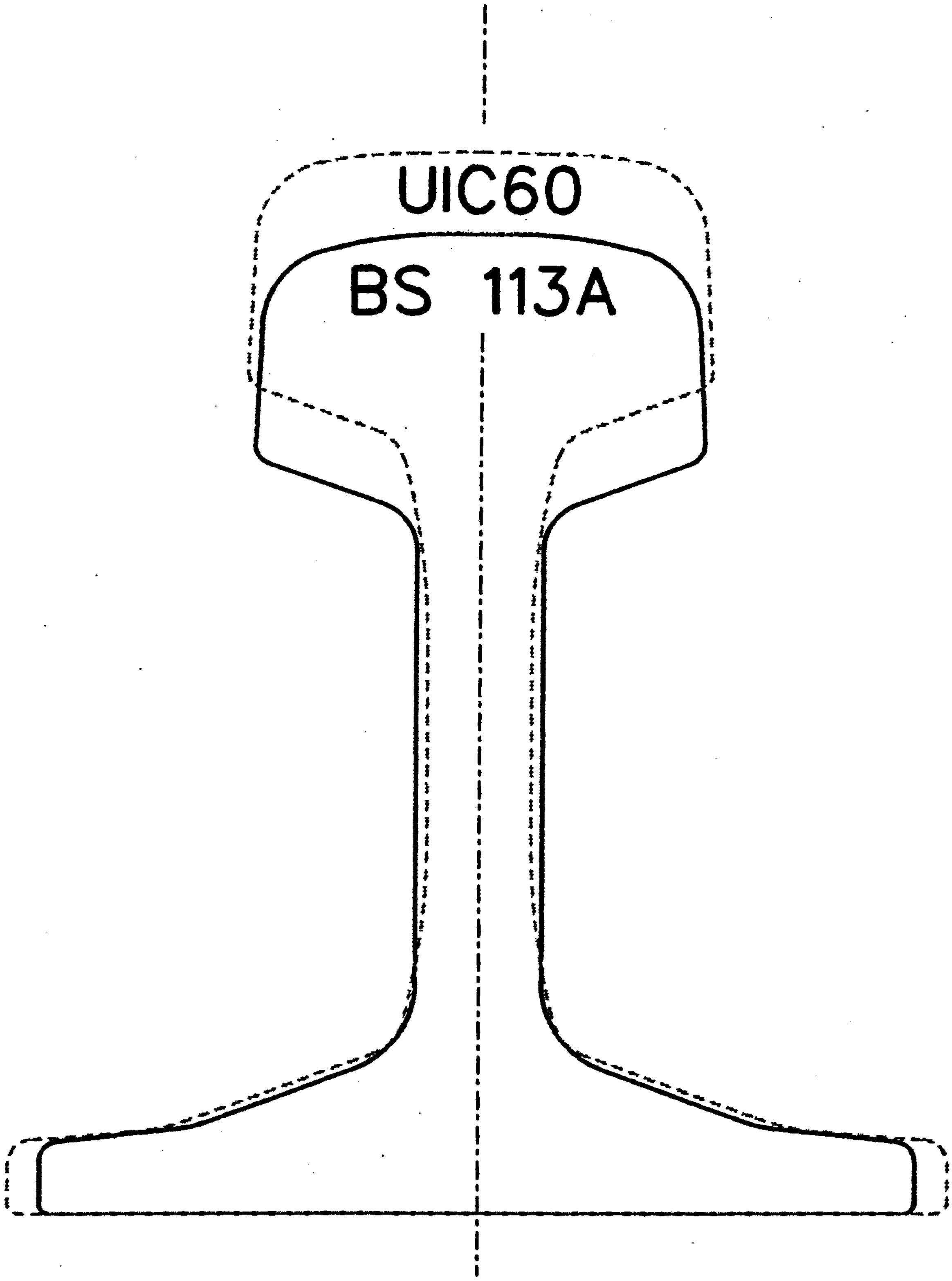
With installation of UIC60 confined to locations where the sleepers are also being renewed the benefits will only come from a route by route strategy. The benefits are also long term as Railtrack currently sees no business benefits in significant premature renewal of track.

This paper has considered plain line implications of changing to UIC60. A move in that direction for S.&.C. is only a matter of time. With it will come a change back to Inclined rails and reliability will be the most important feature.

A change to UIC60 rail will have implications for Railtrack and its Contractors which are currently being considered. The business case is being produced but, if approved, implementation will be carefully staged to ensure a trouble free transition and is likely to be mid 1999 at the earliest.

Diagram - Comparison of UIC60 and 113A sections.

Acknowledgements - Dr. Roger Allen, Railtrack for assistance in producing this paper.


UIC60
BS 113A

S&C DESIGN FOR THE FUTURE BBMC (BALFOUR BEATTY MANOIR CROSSING) WELDABLE CAST MANGANESE CROSSING DEVELOPMENT

Tony Lockwood
Technical Sales Manager Balfour Beatty Rail Engineering Limited.

The Development

To meet the ever increasing demands for higher operating speeds, increased axle loads and to attain lower levels of maintenance, Balfour Beatty Rail Engineering Limited (BBREL) and Manoir Industries (MIO) have jointly co-operated in the design and development of a comprehensive range of cast 11-14% Manganese Centrebloc Crossings with weldable leg ends.

The development has been focused in providing a range of crossings from angle 1in4 to 1in28 to suit Railtrack's existing geometrical and concept requirements and suitable for installation on either timber or concrete bearers.

For the developed range of crossings options are available for splay, left or right hand parallel wing rails, double parallel wing rails and special junction applications, all combined with flexibility within the pattern to cater for special geometry requirements away from the recognised standard alignments.

The current range also includes a series of obtuse crossings from 1in4.75 to 1in8 again with full flexibility within the pattern to cater for varying layout requirements.

In developing the product BBREL and MIO have identified the optimum crossing parameters for each angle and type of crossing. This study was vital in order to reduce the overall pattern requirement whilst retaining maximum flexibility in their application. A further key element in the development was the intent to reduce the manganese centrebloc to a minimum without effecting the structural integrity of the crossings.

For crossing angles utilised in mainline applications i.e. 1in8 to 1in28 the wing rails are an integral part of the manganese monobloc element. Crossings below 1in8 and all obtuse crossings incorporate a rolled rail wing extension due to the standard parameters for undertaking the rail to manganese weld falling within the limits of the wing rail cover.

Options are available for securing the wing rail extensions to the manganese element. This can be achieved by either blocked and butt jointed, the use of F2 fishplates or, if required, in special circumstances, supplied as a welded joint.

The most innovative feature of the crossing development has been the design of the modular pattern concept essential to reduce the quantity of patterns and is a critical feature in achieving the levels of flexibility required to support the product range. Applying modern foundry and moulding techniques in association with the use of patterns manufactured in resin has secured a high standard of finish and dimensional quality. Utilisation of modular patterns allows for a fully flexible approach to the manufacture of cast crossings.

The Product

Within the Railway Industry there is a recognised advantage in using crossings manufactured from work-hardening austenitic manganese steel. They are a key component in the rail system and are situated in the areas of highest stress. Through work hardening, austenite changes into a thin layer of very hard martensite. As wear takes place the hard surface layer is constantly replaced. The non work hardened area retains its ductility, thus avoiding the possible propagation of fatigue cracks. The cast manganese content is manufactured in accordance with Railtrack Line Specification RT/CE/S/012 to UIC866-0.

The crossing has primarily been developed for fully welded installations with the option for standard or insulated standard mechanical rail to rail jointing if required.

The BBMC range of crossings, fully approved by Railtrack, offer proven manufacturing technology and are totally compliant with Railtrack's current specifications and standards for both casting and machining profiles.

Due to the incompatibility of such widely different metals as cast manganese steel and the carbon steel used in rail manufacture a welded joint between the rail and the manganese crossing was not initially feasible. Fishplates and bolts have therefore been used to join the rail to the manganese mechanically. This has been justifiably an area of concern to both railway operators and maintenance organisations as it causes a discontinuity in the crossing - rail joint, leading to premature wear and requiring increased levels of maintenance.

Using the latest welding technology, a process patented by Manoir, manganese steel can be welded onto carbon rail steel resolving the problems created by mechanical manganese to rail jointing. The rail to manganese welding process consists of a tri-metalic link double flash-butt weld fully in accordance with international standards.

The high integrity welding process is undertaken in the factory using state-of-the-art machinery, specially equipped to ensure perfect alignment of the joint rails (straight or curved) and control checked by graphic recording of the welding process to guarantee the structural integrity. Welded manganese crossings have been adopted by SNCF, Eurotunnel, SNCB, Germany, Finland, MTRC, Italy, Sweden and major railroads within the USA. There are in excess of 80,000 welds currently in track internationally, including the existing Railtrack network, with no failures reported.

The design element of the current range of crossings for flangeways, nose profile, nose topping, wing throat and wheel transfer zones are fully in accordance with current Railtrack standards. For future developments with change in rail profile and concept, full analytical studies will be undertaken to optimise these critical characteristics.

The Benefits

The BBMC crossing offers the following benefits whether the application be for a new layout, renewals project or maintenance requirement. Although the current product has been focused at the Railtrack market, the technology is universal and can be adopted to suit alternative rail sections and specification requirements.

- Austenitic manganese offers a high ductility, allowing the crossing to be cold pressed within the manufacturing process to suit varying track alignment.
- Austenitic manganese offers operational work hardening and longevity in performance. A greater ability to resist impact shock as a consequence of support from rail to leg end of the casting gives longer life.
- High impact and wear resistance with hardness levels across the crossing ranging to more than 450HB after work hardening has occurred while the crossing retains its ductility.
- Monobloc structure promotes reduced levels of maintenance.
- Weldability eliminates mechanical joints reducing track circuit failures improving safety and ride comfort with reduced maintenance.
- Welded legs can be either standard 900A grade or Mill Heat Treat (MHT).
- Welded legs can be manufactured to suit the client's specified requirements for length and curvature.
- Welded leg extensions can be drilled for Insulated Rail Joints, offering the benefit of a rail to rail joint not a rail to casting joint.

BBMC has been developed with interchangeability in mind. With recognition of the various types of crossings currently utilised by Railtrack it is physically impossible to develop a product having a footprint that is singularly compatible with all the crossing variants. However, in order to standardise where possible, bearer centres through the crossing are fully compatible with existing crossings. Baseplates fitted within the manganese element are also compatible with existing monobloc crossings. In minimising the length of the manganese centrebloc, the cast to rail interface i.e. the weld , occurs closer to the crossing nose. As a consequence of this, where rail replaces what would have been manganese for the conventional cast monobloc crossing there is a change in baseplates to suit conventional rolled rail legs.

To support our clients in identifying the interface requirements for crossing types, application, geometry, bearer centres, baseplate types or alternatively concrete bearer coding, a full BBMC Crossing Schedule has been produced. The schedule will be an appendix within the Railtrack Line Specification track Design Handbook RT/CE/S/049.

Balfour Beatty Rail Engineering Limited and Manoir Industries are committed to providing the highest quality of service to the railway industry at all times, together with the latest state-of-the-art technology, to ensure the most effective and economical solutions.

Management of Welded Track

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Introduction

Over the last 30 years, modern railway systems have moved away from jointed track to continuously welded rail (CWR). Most high speed lines today comprise rail that is continuously welded by either flash welding or alumino-thermic welding. Not only does CWR improve the vehicle ride, it also reduces the dynamic loading of the rail joints reducing the number of rail joint failures and, therefore, significantly reducing the cost of track maintenance. In addition, both types of welded joint have higher structural integrity than bolted joints. However, CWR is not without its problems. A proportion of welded joints break in service or are identified as being defective, resulting in high costs to Railtrack and its maintenance contractors as a result of the remedial work required, and the associated train delay costs. Critically, one must consider the safety of rail users with the risk of derailment from broken rail joints.

The 1998 Railtrack Network Management Statement gives a commitment to reduce the annual number of broken rails from 700 to 600 within a year, and further to 450 within three years. It is also more cost-effective if defective welds can be identified before failure so that they can be replaced with minimum disruption to services. This paper explores ways in which welded track can be managed to achieve these objectives.

Rail Failures

Studies of historic weld failure data have shown that the number of broken and defective flash and alumino-thermic welds initially increased in number from 1969 until 1979 at which point the numbers have remained reasonably constant. The initial sharp increase in the total number of failed welds reflects the rise in the total population of welded rail joints during the years of change from jointed track to CWR. For the Railtrack network, details of the classification of these failures are provided in the Rail Data database. Analysis of the failure data shows that the most common type of failures for both flash and alumino-thermic welds were classified as being internal/non-running surface vertical transverse defects.

This is a rather non-specific classification that covers a multitude of defect types. The definitive classification of the type of failure is a complex task requiring specialist knowledge and facilities, not always available to the staff faced with the task of inputting the data. This has meant that, although we can calculate the annual numbers of defective and broken rail joints, and break this number down into different approximate classifications, it is not always possible to definitively classify the type of failure.

Factors That Increase The Risk Of Failure

In general, the priciples of fatigue apply to the rail defect initiation, growth and fracture. The number of defects and rail failure risk increases with the number of stress (axle loading) cycles. This effectively determines the useful life of the rail, which can be significantly reduced where the stresses are high. It should also be remembered that a large number of broken and defective welds fail as a result of process or procedural defects. This is particularly true of the alumino-thermic welding process, which is very operator- sensitive being a manual process (unlike flash welding which is automatic). Even when joints are made which contain defects, the structural strength of the joint is such that a large proportion remains in service undetected for many years without any problems. However, other factors which result in higher service loadings can result in premature failure of welded joints, even those which are defect- free joints. The main culprits comprise the following:

- Poor Joint Geometry - If the running surface or gauge face alignment of the joint is poor it will result in higher dynamic loadings under traffic. The worst case is when the running surface at the joint is dipped. Studies have shown that the profiles of all welded joints progressively dip under traffic, this effect is predominantly driven by the dynamic loading under traffic which results in ballast degradation and voiding of the sleepers adjacent to the joint. As the dip increases, so do the stresses at the joint, leading to an increased probability of failure.

- Wet Spots - In areas where there is poor drainage due to contamination or degradation of the ballast, the ballast and formation are pumped hydraulically causing voiding beneath the sleepers, which in turn leads to higher stresses at the joint. This problem is compounded if the running surface profile is poor to begin with.

- Stress Free Temperature - To avoid track buckling due to the thermal expansion of CWR, the rails are laid at a stress free temperature (SFT) of 27°C. At this temperature, the axial stress in the rail, as the name implies, is at zero. At rail temperatures above 27°C the rail is in compression and at temperatures below this the rail is in tension. The problem arises during particularly cold spells, where the axial tensile stresses are high, therefore increasing the risk of failure of the welded joint. This problem is compounded at locations where either the SFT is incorrectly installed at too high a temperature or the installed SFT has locally increased due to rail creepage under vehicle braking and acceleration.

- Wheel Flats - The impact forces from wheel flats introduce significantly higher stresses into the rail. The relationship between the magnitude of these forces and the speed of the vehicle is non-linear. In general, the vehicle-induced forces rise steeply reaching a maximum at around 30mph, levelling out until around 70mph, where the forces start to rise again.

Identifying High Risk Joints

It is important that defective joints are identified as soon as possible so that replacement can be planned to minimise costly unplanned train delays. It is not possible to identify reliably, internal defects within both flash and alumino-thermic welds using conventional pulse echo ultrasonic inspection (USI). Internal defects within the weld metal of alumino-thermic welds are very difficult to detect with USI as the sound waves are scattered due to the coarse grain structure of the weld metal. Defects within the parent rail up to the weld fusion faces can be detected in alumino-thermic welds using standard USI procedures. However, this will only identify a small proportion of the total number of defective welds. Specialists from Swedish State Railways claim to be able to identify internal defects within the weld metal of alumino-thermic welds by using conventional pulse echo USI with a modified technique. Another method which it is claimed can size and detect defects within the weld metal of alumino-thermic welds is time of flight diffraction. These techniques need to be fully evaluated before any decisions can be made on implementation of these methods of non-destructive testing of welds.

Surface breaking defects can be readily identified by a combination of visual inspection and magnetic particle inspection. However, this does not enable any sizing of the defects.

The surface profile of the joint can easily be assessed by use of a straightedge and feeler gauges or one of the many commercially available joint geometry measuring gauges.

Destructive tests carried out on alumino-thermic welds, removed from track due to the presence of visible surface defects, have shown that a number of these welds would have survived in a track environment and had been removed unnecessarily. This evidence combined with the large number of welds that break in service, only goes to demonstrate how subjective the current procedures are in terms of accurately identifying defective welds.

Reducing The Number Of Broken Rail Joints

The first step towards developing a strategy to reduce the number of in-service weld failures is to positively identify the causes of the defective joint. Once the modes of failure have been identified, it will be possible, in consideration with the factors known to increase the risk of failure, to develop a rail joint failure risk model that will enable the location of rail joints with the highest probability of being defective to be predicted. From this information it will be possible to determine appropriate inspection regimes, which may be more frequent than the minima currently specified. Specimens of welds identified as being defective can be fatigue tested to determine the relationship between size and type of defect and the respective reduction in mean fatigue strength of the joint. This will enable the current minimum action criteria to be reviewed to determine more appropriate actions for dealing with defective welds to reduce the total number of broken rail joints.

By carrying out remedial work to correct the faults known to increase the risk of rail joint failure, it will be possible to achieve an immediate reduction in the number of welded joints failing in service. This work would comprise the following:

Joint geometry - Joints identified as being excessively dipped, hogged or laterally misaligned should be straightened by pressing to bring the joint back within tolerance. In-track four way presses are available and are currently undergoing service testing in the UK with one of the IMC,s. If it is found that the adjacent sleepers are voided, this must be rectified by either measured shovel packing or hand held stone blowing.

- Wet spots - Any wet spots should be rectified in accordance with the instructions given in the Track Maintenance Handbook GC/EH005. It is essential that the primary cause behind the formation of the wet spot must be rectified at the same time or the problem will reoccur.

- Stress Free Temperature - If the SFT is suspected as being incorrect, the actual SFT should be confirmed. Indication that the SFT may have changed since installation, such as out of square sleepers, should alert P-way staff to the need to check the SFT. The AEA Technology Rail, Vortock VERSE® system provides a quick and cost effective non-destructive method of determining the SFT. If the SFT is found to be incorrect then this will need to be rectified. SFT's higher than 27°C will significantly increase the risk of welded joint failures during extremely cold weather, and as such should be corrected before the onset of winter.

- Wheel Flats - Installation of the AEA Technology Rail WITMS (Wheel impact transportable monitoring system) systems will enable vehicles with wheel flats to be detected. Once a vehicle is identified as having wheel flats, it should undergo the necessary maintenance to its wheel sets at the earliest opportunity to remove any flats.

Conclusions

This paper has identified some of the key factors that have to be taken into account for the successfull management of welded track.

Rail defects associated with welded joints can be kept to a minimum,and some relevant maintenance techniques and strategies have been highlighted to achieve this aim, which are compatible with other aspects of permanent way maintenance for minimum cost.

The latest in rail pads and fastenings for international use.

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In this paper I will describe some of the ways in which the evolution of resilient rail pads has driven the development of the latest rail fastening systems, and how these new developments meet the needs of construction and maintenance contractors, as well as railway operators, in the modern permanent way industry.

If I had been making a presentation on this subject twenty years ago, an opening paragraph like that would have made absolutely no sense at all! Rail pads were considered to be a minor part of the rail fastening, and those independent contractors that did work in our industry simply followed the instructions of the railways. Since then, both the technology and the business environment have changed beyond recognition. Twenty years ago, the P. Way Engineer of each railway would select a rail clip that offered the performance that he required at a price that he could afford, and then - perhaps as an afterthought - ask for confirmation that the rail pads that would be supplied with his concrete sleepers would give sufficient insulation to maintain his track circuits, prevent the rail from damaging the concrete surface, and not wear out too quickly. Today, all that has changed:

Resilient Rail Pads.

Although resilient rail pads have existed since the 1950s, their significance in reducing damaging dynamic forces throughout the track structure was not fully understood until the 1980s. Much of the work done at that time stemmed from the discovery that fast trains with imperfect wheels and rails could do more damage to concrete sleepers, ballast and rails than slower heavier trains. In particular, the Battelle Institute in the USA, studying problems on Amtrak's North East Corridor, and Cambridge University in the UK, looking at the West Coast Main Line, both concluded that resilient rail pads could alleviate the problem. The hunt was then on for a design of rail pad that would be very resilient, but also durable and affordable.

Significantly, independent work in the UK, France and Japan all led to the same conclusion - that natural rubber compounds moulded as pads 9 - 10mm thick, with suitable surface shaping, would meet the requirement. However, in order to function effectively, they had to allow the rail to move relative to the sleeper by 1 - 2 mm under each passing wheel. This leads to three problems:

- The clip and insulators are subjected to greater displacement amplitudes, and could fail by fatigue or wear.

- The rail is more free to "roll" relative to the sleeper, and the resulting dynamic gauge widening could result in vehicle guidance problems.

- The greater displacement amplitudes could result in an increase in the levels of noise emitted from the rail foot and web.

Thus the simple questions about rail pads posed by the P.Way Engineers of twenty years ago are now supplemented by a host of others - Is the clip fatigue limit matched to the pad stiffness? How is dynamic gauge widening controlled? How significant is the noise increase? In short - Has the design of the integrated rail fastening system been properly built around the rail pad characteristics?

Taking these three questions in turn:

All fastening systems introduced before about 1990 were designed to work with relatively stiff rail pads. In most cases, this meant that the maximum amplitude of dynamic clip deflection in track would have been less than 1mm. Consequently, clip fatigue limits were typically set at 1.2 - 1.5mm to minimise the risk of failure. Improvements in steel making and heat treatment control have allowed this limit to increase slightly, but in general it was necessary to use rail pads of greater than optimum stiffness in order to limit the fatigue stresses in the clips. Similar arguments applied to the nylon insulating elements used in all mainline concrete sleeper fastening systems, which were more likely to wear away, or fracture, under greater rail movements. Fastenings developed more recently have been designed from the outset to have fatigue limits of around 2mm, and to have insulating pieces engineered to withstand the more severe loading environment associated with very resilient pads.

Limiting dynamic gauge widening is a more difficult problem. With resilient pads, even in curves it is likely that the rail will move downwards under load - on a soft 10mm pad the field side edge of the rail could compress the pad so much that the rail head movement would become excessive, even if the gauge side edge did not lift off the pad. Consequently, traditional means of rail roll protection, which are designed to prevent excessive uplift of one edge of the rail, are useless. The most effective solution to the problem is the use of a rail pad with highly non-linear load-deflection characteristic. This is achieved by careful selection of materials, and design of the surface shaping.

The question of noise is a very complex one. Although there is a tendency for more resilient pads to cause an increase in noise emitted from the rail with a given surface condition, that is only one element of the noise heard as a train passes. Lower frequency noise emitted from the sleepers, and secondary noise resulting from ground- or structure-borne vibration, will be reduced. Noise from the wheels, aerodynamic noise, and motor noise, are - of course - not affected. It is also reported that the rate of development of rail corrugations decreases when more resilient pads are used, and that noise from the rail increases dramatically as corrugation depth increases. Thus, in the longer term, resilient rail pads may not increase noise from the rail, after all. A European research project ("Silent Track") is currently in progress to investigate this issue. Until the results of that work become available, it appears that the only place where it may be necessary to use stiffer rail pads to reduce noise is in sharp curves. In such curves, train speeds are inevitably low, and thus the dynamic forces that resilient pads would mitigate are also low.

Total system design.

It is clear that any new rail fastening system must be able to work with very resilient pads, but must also be able to function well with stiffer pads where the track and traffic situations demand it. The fastening system must also perform as one element in the total track system, which must be economical to construct and maintain. Here, too, there have been changes in emphasis over the last two decades. Increasingly, railways and their contractors are looking for minimum whole life costs of the track system - not simply low cost components.

Once again, resilient pads have a part to play. By reducing the transmission of dynamic forces into the track structure, settlement rates are reduced, and lining and levelling cycles extended.

At another level, it becomes important to be able to build, renew or maintain track at low cost, and with minimum disruption to traffic. The days of delivering sleepers, clips, pads and insulators to track seperately, and assembling them with hand tools, are numbered in many countries. In the USA in 1992 virtually all track was built in this way; by 1997 some 40% of new concrete sleepers were delivered to track with all of the fastening components pre-installed. The figure in Northern Europe is probably similar. Some track laying machines now incorporate fastener application modules - at least one incorporates rail heaters, so that the track is laid and clipped up at the required stress free temperature with little or no manual intervention.

The fastening system is also critical in operations such as de-stressing. Using traditional fastenings, most of a possession period can be taken up by a track gang removing and then replacing the loose fastening components - the actual de-stressing process is relatively quick. With modern captive fastenings, and mechanised equipment, it is possible for one operator to unfasten, or re-fasten, over 250 metres of track in less than 10 minutes.The significance of this kind of improvement is that it may make it possible to carry out work in short (e.g. mid-week) possessions, rather than waiting for longer and more expensive weekend working periods.

Concluding remarks.

Rail pads are now understood to be one of the most critical elements of the track structure. Modern rail fastenings are designed as integral systems, incorporating the rail pad. The system must be durable to provide long, maintenance free service but also be amenable to handling by automatic machinery.

RAIL GRINDING FOR EUROPEAN RAILWAYS

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1 INTRODUCTION

Rail ginding is a versatile maintenance activity which is used worldwide on all types of railway: high speed passenger lines, mixed passenger and freight, metros and dedicated freight and heavy haul railways. Although the types of traffic on these different types of railway differ significantly, giving rise to a variety of damage, rail grinding has been found to be an effective treatment, and in many cases the most effective or only treatment. It is nevertheless worthwhile occasionally to ask the fundamental question, "Why grind?", particularly at a time of tight financial constraints, such as exists at present in the UK and more generally throughout Europe.

The most convincing, indeed perhaps the only reason, to grind rail is to save money. Ways of doing this are primarily by extending rail life and by reducing other types of track maintenance, particularly tamping. Another reason, which in some circumstances may also be motivated by saving money, is to reduce noise, and thereby broaden acceptability of the railway amongst its neighbours, and perhaps even allow it to operate where complaints otherwise might restrict or halt operations. This is particularly important for new high speed rail systems, and also for underground railways and tram systems which operate in heavily populated areas. Although this may not often be perceived as an "economic" reason for grinding, there may well be such an economic case where there is legislation limiting noise levels and alternative measures to reduce noise may be prohibitively expensive.

This paper considers different reasons for grinding which are relevant primarily to European railways. Where possible, reference has been made to quantifiable benefits of the operation, economic and otherwise.

2 WHY GRIND?: problems, benefits and costs

2.1 extension of rail life

The life of rail is shortened for several reasons, but most commonly because of excessive side wear in curves and because of fatigue. An increasingly common reason for taking rail prematurely out of service is rolling contact fatigue (RCF): "squats", "head checks" and "spalls", "tache ovales" and, primarily on heavy freight railways, "shelling". The differences between these types of RCF, their development and treatment, are discussed in ref. [1].

Grinding can be of some help in alleviating side wear in gentle curves, where it may be used to profile the rails asymmetrically, thus increasing the rolling radius difference between the two wheels on a wheelset, enabling it to steer better around the curve. However, in general the most effective way of reducing side wear is to lubricate the rails adequately. Side wear is also reduced with harder rail, but this is no substitute for good lubrication: whereas the former may reduce the wear rate by a half or slightly more, good lubrication can reduce the wear rate by an order of magnitude.

Grinding is the principal treament of rolling contact fatigue, particularly head checking, squats and shells. These arise largely as a result of high normal and tangential stresses at the wheel/rail contact, with cracks initiating either at the rail surface (squats and head checks) or at sub-surface inclusions (shells). RCF damage is particularly severe in tight curves (typically 600m radius or less), where the gauge corner of the high rail is loaded extremely heavily. Grinding is effective for two reasons in particular:

- It helps to achieve a rate of metal removal which exceeds the rate of fatigue crack development. The critical rate of metal removal is typically about 0.5mm/50MGT in tangent track, with a substantially higher rate required in curves.
- It can reprofile the rail, thereby moving the point of wheel/rail contact away from the gauge corner of the high rail or, in fewer cases, removing contact between the "false flange" of heavily worn wheels and the field side of the low rails.

The effectiveness of grinding in treating RCF defects and extending rail life is demonstrated clearly by experience on heavy haul railways in North America and elsewhere. The experience of CP Rail in Canada is illustrated in Figures 1 and 2, which show respectively the track mileage of rail replaced per annum from 1982 to 1995, and the track miles ground each year [2]. The order of magnitude of savings which may be possible from increasing rail life on a European railway may be appreciated from the comparative figures presented in Table 1. Although clearly the operating conditions on CP Rail and on the European railway are very different (and early rail replacement on the European railway probably occurs as a result of wear and other factors, as well as RCF defects), operating and traffic conditions on CP Rail should be more conducive to wear and RCF than those in Europe.

On the Tokaido Shinkansen in Japan, where "squats" are the principal type of RCF defect, grinding has also proved to be an effective treatment of the problem [3]. There has been a substantial and steady decrease in the number of rail breakages as the quantity of grinding has increased steadily. On the Shinkansen and on CP Rail, "preventive" grinding is undertaken, in which a small amount of metal is removed frequently, before the damage is evident. In Japan, an interval of 40MGT is believed to be optimum for grinding, whereas in North America the interval is often considerably shorter: 15MGT or less in tight curves, 25MGT in less severe curves (600m and greater) and about 35MGT in tangent [4]. Preventive grinding in North America is commonly undertaken with large machines (88 stones) achieving the desired transverse profile and metal removal in a single pass, typically at speeds of 10km/h or more in tangent track.

Relatively little work has been done to date in Europe to examine the effectiveness of grinding to forestall fatigue cracking and extend rail life. However, Loram Rail are at present engaged in a cooperative test with the Banverket in northern Sweden in which the effectiveness is being examined of different transverse railhead profiles for reducing rolling contact fatigue defects.

The results of this test to date are extremely encouraging, and suggest that significant savings should be possible by extending rail life.

	CP Rail	European railway
total track km	17,000	40,000
rail replaced per annum (track km)	160 (a) (0.9% of total track km)	1,300 (3.3% of total track km)
track km ground per annum	15,000 (88% of total track km)	2,000 (5% of total track km)

Note (a): On Burlington Northern (where similar "preventative" maintenance is undertaken), 2-3% of the high rail in sharp curves (R<600m) is replaced p.a.. The projected life of this rail is 600-950MGT [4].

Table 1 Annual rail replacement and grinding requirements for a North American and European railway

2.2 Reduction in track maintenance

Tamping (or perhaps also in the future, stone-blowing) is necessary when the track geometry deteriorates, bringing about poor ride in vehicles on the track. After many cycles of tamping, or where the ballast otherwise deteriorates, ballast cleaning or even reballasting may eventually be necessary. Track geometry deteriorates largely because of dynamic loads on the ballast, which cause it to break up and settle rapidly. The rate of ballast settlement and consequently also the maintenance requirements have been quantified as functions of the amplitude of sleeper (and thus ballast) vibration by Sato [5,6]. By reducing the rate of ballast settlement, the tamping cycle can be extended significantly.

Grinding is an effective means of reducing the rate of deterioration of track geometry, and thus tamping and other requirements, because it removes the railhead irregularities, such as corrugation, ballast spalls and wheelburns, which excite vibration and dynamic loads. The French Railways (SNCF) are one of the greatest exponents of the virtues of regular grinding to reduce the requirement for tamping. On the high speed TGV line between Paris and Lyon, they have observed an average reduction in tamping requirements of 50% as a result of grinding [7]. To obtain the greatest benefit, grinding is undertaken immediately after tamping.

In an earlier cost/benefit study of grinding based on German data for maintenance requirements and costs, it was concluded that grinding should be undertaken when the depth of corrugation was about 0.3-0.4mm [8]. The economic benefits of grinding and the optimum intervention interval vary from one railway system to another depending on maintenance requirements and costs.

2.3 Reduction in noise

Every vehicle except, perhaps, a bicycle or glider, gives rise to significant noise. For railways, noise in the 60-300km/h speed range is primarily wheel/rail rolling noise. At lower speeds, "machinery" noise is more significant, while at higher speeds, aerodynamic noise becomes dominant. Wheel/rail rolling noise arises largely from vibration of vehicle and track components which is excited by the wheels rolling over irregularities on the wheels (corrugation, wheelflats etc.) and rails (corrugation, ballast spalls, wheelburns etc.). For disc braked rolling stock, a 50 micron deep corrugation gives rise approximately to a 10dB increase in noise, whereas for tread-braked vehicles, such a corrugation would give rise to about a 4dB increase from a rather higher noise level [9]. This different behaviour occurs because tread-braked wheels themselves are rougher, with more irregularities to excite vibration (typically equivalent to a corrugation of about 30 micron depth), so irregularities on the rails are relatively less important.

Clearly if longitudinal irregularities on the rail are removed, wheel/rail noise is significantly reduced. Moreover, if care is taken to reduce the residual longitudinal irregularities on the rail in typical corrugation wavelength ranges, corrugation recurs more slowly. Rail is now ground routinely in Europe so that longitudinal irregularities which are very much shallower than 10 microns remain on the rail in the 10-30mm and 30-100mm wavelength ranges, which are critical for corrugation and wheel/rail noise. Indeed, so tiny are these residual irregularities that routine measurement is not possible with current grinder-based measuring equipment from any grinding contractor. For these reasons, Loram has developed sufficiently accurate state-of-the-art manual equipment which is used to monitor grinder performance [10,11], while grinder-based equipment is under development.

Routine grinding can sometimes be used as an alternative to noise barriers, particularly where legislation limits allowable noise levels, as is the case for most new railways in Europe. In such circumstances grinding can be extremely cost effective, although there is clearly a limit to what can be achieved by such means. Figures for Switzerland indicate a cost of about £2.5 million per route km for 5m high noise barriers [12]. One kilometre of noise barriers would cost considerably more than the annual rail grinding budget of several European railways.

3 SPECIFICATION, STANDARDISATION AND QUALITY CONTROL

It is important in general to grind rail to some standard of longitudinal and transvere profile, and in most of Europe it is particularly important also to demonstrate this by routine measurement. These issues are being addressed at present in development of a European Standard for rail grinding. This is a process in which Loram Rail is actively involved.

Our experience as contractors operating throughout Europe is that supposedly objective specifications are often made, but implementation of those specifications is extremely subjective. Other critical questions also arise, such as how to audit whether a specification has been met when the measuring equipment which is conventionally used has inadequate accuracy.

One possibility which Loram have pursued with some customers is first to specify limits on the amplitude of allowable longitudinal irregularities and the deviation of transverse profile from the desired profile. Equipment is also agreed which is available to both parties and which is used to assess acceptance. The critical component of deciding whether the finished rail is acceptable is to specify a percentage of measurements of transverse profile, or percentage of the total track length for which the specification must be met. Specific allowance for some measurements to be outside tolerance is required to allow for both the inaccuracy of measuring equipment and the difficulty of grinding rail with initially varying profile economically to a uniform final profile. Such a specification can in principle be monitored independently by both the client and the contractor.

4 CONCLUSIONS

Rail grinding is an extremely versatile maintenance activity, not only for treating rail damage but also to reduce noise and general track maintenance. By comparing rail replacement requirements for one European railway for which figures are available with the requirements of a North American railway, there would appear to be considerable potential for reducing the cost of rerailing and overall track maintenance by regular, preventive grinding combined with more general attention to wheel/rail interaction. Major savings are possible by extending tamping cycles as a result of the lower dynamic loads on track with a good longitudinal profile achieved by grinding. Noise is an obvious benefit from grinding, and although the benefits of a quiet railway may be difficult to cost, grinding can be extremely economical if legislation exists to limit noise. In all cases, the greatest benefits are obtained by grinding relatively little but regularly.

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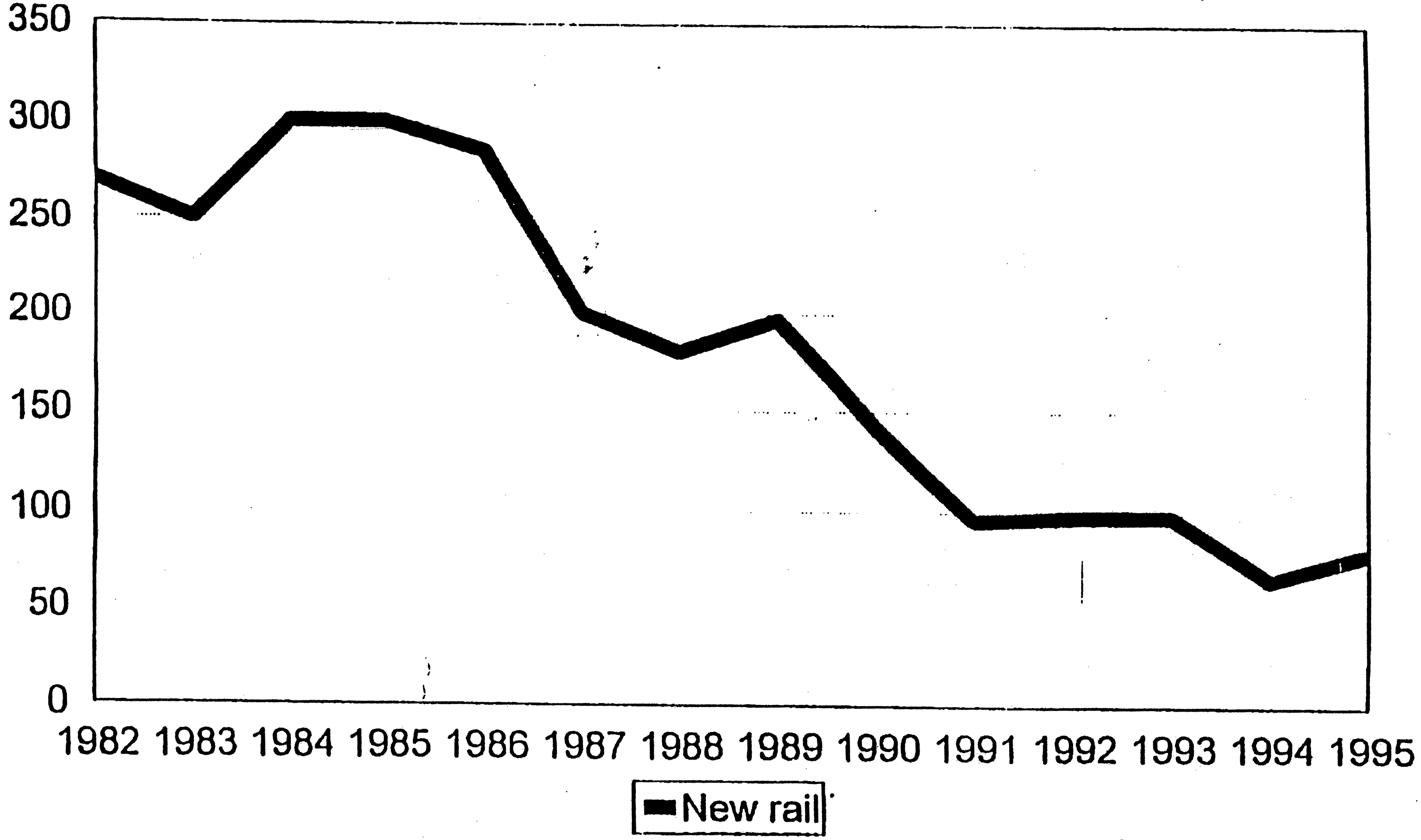
Rail Replacements - CP Rail

Track miles of new rail laid

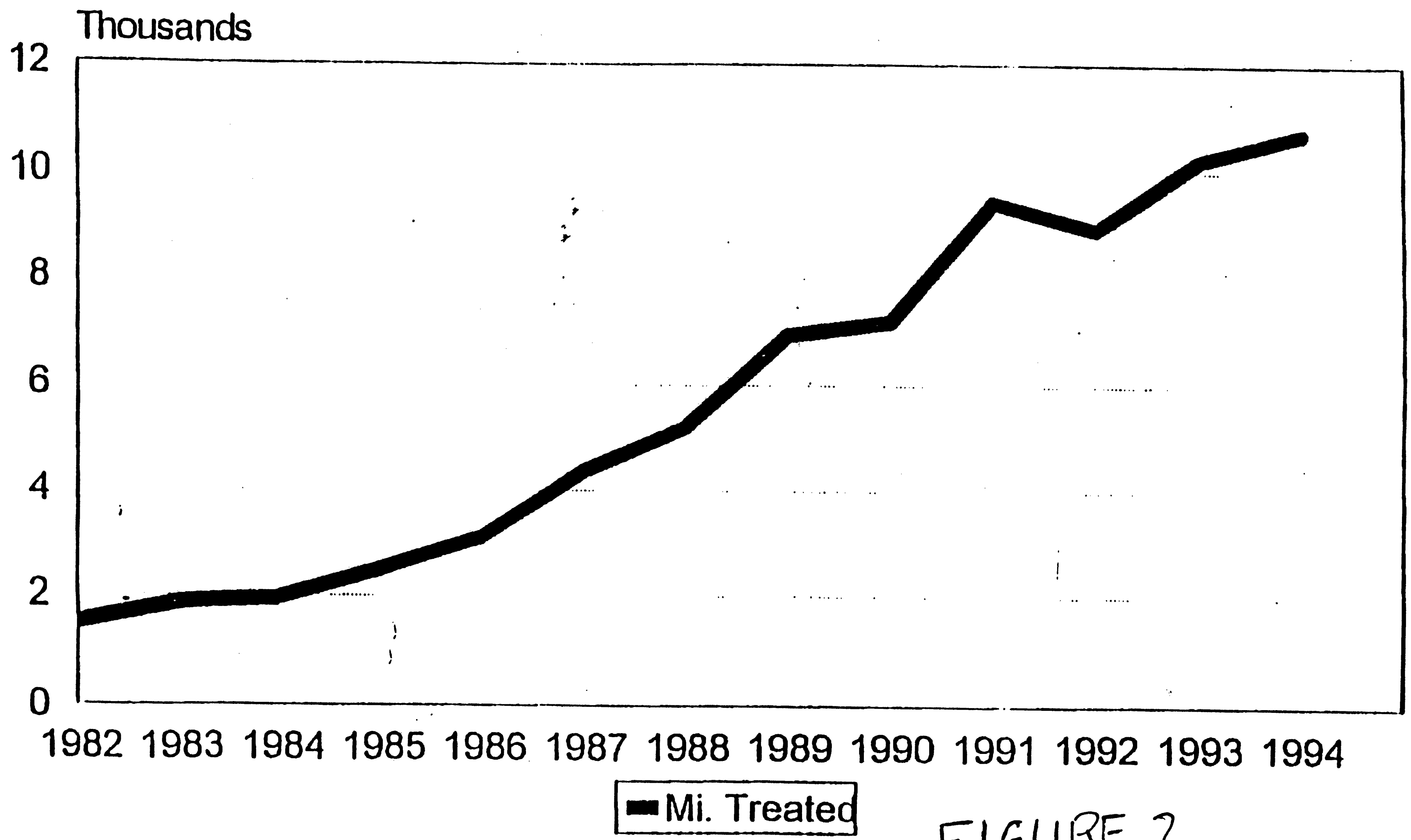


Canadian Lines

FIGURE 1

Track Miles Treated by Grinding

By Year



Canadian Lines

FIGURE 2

"RAIL PROFILES TO GIVE A STABLE RIDE AND GOOD CURVING"

RICHARD CHARLES & RICHARD HARVEY

AEA Technology Rail, rtc Business Park, Derby, England.

1. Introduction

There are two sets of rail profiles which have an influence on the behaviour of railway vehicles, longitudinal and transverse.

The basic function of the longitudinal rail profiles is to present a smooth vertical track profile for wheels to run along and, in certain circumstances, a smooth lateral track profile to provide guidance for the wheels. The influence of the longitudinal rail profiles in fulfilling these functions is direct and any roughness within the geometry of the rail profiles will degrade the ride of the vehicle and in turn that of the payload or the passengers.

The shape of the transverse profiles of the rails (as shown in Figure 1) has a less direct, but equally important, effect on vehicle behaviour through its influence on vehicle stability and curving. It is the effect of the transverse rail profiles on stability and curving that this paper addresses.

The transverse rail profiles influence vehicle stability and curving through their effect on wheelset conicity. The contribution of wheelset conicity to the dynamic behaviour of vehicles has been appreciated from the early days of railway operation when it was realised that designing wheels with conical treads would minimise the time that the flanges of the wheels spent in contact with, and rubbing against, the rails.

The influence of rail profiles on vehicle behaviour is not straight forward because wheelset conicity, as well as being influenced by rail profiles, is also affected by the shape of the wheel profiles and the position of the rail head in relation to the position of the wheel treads. In addition to this, the effects of conicity on stability and curving performance conflict. A high value of conicity will benefit vehicle curving performance but will have a detrimental influence on stability performance. In turn, rail profiles which promote good vehicle curving will degrade vehicle stability performance.

In this paper wheelset conicity is defined, the influence of rail profiles on conicity is described and the effects of conicity on stability and curving are discussed.

2. Conicity

As can be seen from Figure 2, when a conventional railway wheelset is positioned centrally on a pair of new rails the rolling radius of each wheel will be the same. If the wheelset is displaced laterally, the rolling radius of one wheel will increase and the rolling radius of the other wheel will reduce and a rolling radius difference will develop across the axle.

If such a displaced wheelset were to be rolled along the track the rolling radius difference would cause the wheelset to turn and roll back towards the centre line of the track. As the wheelset crossed the track centre line, it would be yawed, and hence move towards the rail on the opposite side of the track. As the wheelset approached this rail, a rolling radius difference would develop in the opposite sense and the wheelset would turn and move back towards the centre line to complete one cycle as shown in Figure 3. If the wheelset continued to roll the cycle would repeat and the wheelset would follow a path which was approximately sinusoidal in shape.

For any wheelset the relationship between rolling radius difference and lateral displacement will define the **"CONICITY"** of the wheelset and the wavelength of this kinematic motion will be inversely proportional to the conicity of the wheelset.

For a wheelset fitted with new coned tyre profiles, the rolling radius difference will be directly proportional to the semi-cone angle of the tyres and the amount by which the wheelset is displaced laterally. Therefore for this wheelset the semi-cone angle will be the conicity of the wheelset.

However, for wheelsets with hollow treads, either by design or as a result of wear, an alternative means has to be derived to define their conicity.

If a wheelset is placed at a number of lateral positions between two rails and the rolling radius difference established at each position, a graph can be plotted of the rolling radius difference against lateral position as illustrated in Figure 4. As is shown in this example, for a wheelset with new P1 tyre profiles which have a semi-cone angle of 1 in 20, half the slope of the linear section of the graph will be 1/20 or 0.05 which is the conicity of the wheelset.

Figure 5 shows that, for wheelsets with hollow treads, a rolling radius difference graph generated in the same way will be non-linear. For such cases, it is necessary to fit a straight line to the graph and the conicity of the wheelset will be half the slope of this straight line.

3. The Influence of Rail Profiles on Conicity

The slope of the straight line fitted to the rolling radius difference graph, and hence the conicity of the wheelset, will be a function of the fit between the wheel and rail profiles.

Rail profiles influence conicity through the shape of the rail head, their inclination and the separation of the rail profiles i.e. the track gauge. If the head of the rail profile is flat and is combined with wheels which have hollow treads, this can cause the wheel/rail contact to become conformal. Under these circumstances, for a given lateral shift, the point of contact between the wheel and the rail will move by a greater amount than the lateral shift and this will cause a greater change in rolling radius and an increase in conicity to occur.

Reducing track gauge and reducing rail inclination cause the wheel/rail contact point to move towards the flange root radius and the more conical section of the tyre profile which increases conicity. An increase in flange back spacing or the thickness of the wheel flange will have a similar effect on conicity.

4. Effects of Rail Profiles on Conicity and Stability

At lower speeds, the conicity of the wheelset and the kinematic motion keep the wheelset in the centre of the flangeway clearance. However, for every vehicle design there will be a

"critical speed", above which the kinematic motion will contribute to an instability and the vehicle will **"hunt"**. In such circumstances, the wheelset displacements will increase and ultimately be limited by wheel flange/rail gauge corner contact. This hunting produces a deterioration in the ride of the vehicle and an increase in the dynamic lateral track forces. The critical speed will depend on the suspension parameters (stiffness, damping etc.) and the conicity of the wheelsets.

For a given design, the higher the conicity the lower will be the critical speed. Modern vehicles are designed to accommodate conicities in a given range (typically 0.05 to 0.4) and the suspension parameters are selected to ensure that the critical speed of the vehicle is greater than the maximum operating speed for that conicity range.

Figure 6 shows the relationship between vehicle speed and wheelset conicity on the lateral displacement of the leading wheelset of a two axle freight vehicle on a 180m section of straight track. The second half of the track section is perfectly smooth.

It can be seen that when the speed has increased from 20 to 50.0 m/s and the conicity has increased from 0.05 to 0.4, a high frequency instability occurs in the lateral wheelset displacement response.

Stability performance can be improved by increasing the plan view stiffness of the suspension and reducing wheelset conicity. Hence any feature of the rail profiles which increases conicity (e.g. flat heads, tight gauge or reduced rail inclination) can have a detrimental effect on the stability performance of a vehicle.

Vehicles which perform satisfactorily on the majority of a given route have been known to hunt and generate a rough ride at locations where the rail inclination is reduced such as at S&C, on lengths of new track laid tight to gauge or where the rail heads are particularly flat.

Prior to 1988, primarily as a result of the way in which rails were rolled, it was not unusual for rail to be produced with a head radius which was towards the limit on flatness. When such rails were combined with head wear, this lead to premature rise in conicity and an increased incidence of vehicle stability problems. This trend was arrested, however, by the introduction of a revised design rail profile.

The original and the revised rail profiles are superimposed in Figure 7 which illustrate the increased rail head curvature of the revised profile. For a wheelset with moderately tread worn P8 tyre profiles, the conicity on the original 113A rail profile is 0.53 which compares with a figure of 0.28 for the revised 113A profile. This demonstrates the beneficial effect of the new profile. The introduction of this target profile reduced the proportion of rail rolled towards the minimum flatness limit and the number of high conicity sections of track. If any new profiles are introduced into a system, such as the UIC 60, then measures should be taken to ensure that the rails are not rolled to the lower limit on head curvature.

The example above involved increased conicity, brought about by flat rail heads, and the effect of a new rail profile shape. Significant increases in conicity can also occur when worn rail profiles are transposed in curved track. Figure 8 shows that one of the effects of transposing rails is to produce a sharp corner which can make contact with the root of the flange and an increase in conicity to occur. For the same wheelset used to compare the conicities of the original and revised 113A rail profiles above, the conicity on the rails in the original position is 0.31 whereas on the transposed rails the conicity is 1.05. This demonstrates the importance of adhering to the rules for transposing side worn rails in high speed curves.

The two examples just shown demonstrate the effect that the shape of the rail head can have on conicity. However, as indicated above, the distance between the two rail profiles (i.e. the track gauge) also has an effect on conicity as shown in Figure 9.

Reducing track gauge below 1435 mm has a dramatic effect on the conicity generated by wheelsets with an advanced amount of hollow tread wear.

The increases in conicity described above will have an unwanted effect on stability performance. In the next section the effects of rail profiles and conicity on curving behaviour are considered.

5. Effects of Rail Profiles on Conicity and Curving

When any railway vehicle enters a curve the wheelsets will be at an angle to the rails. However, under favourable conditions the conicity of the wheelsets contributes to a wheel/rail interaction and the development of tangential forces which can steer the wheelsets and reduce this angle.

If this steering effect is sufficient, the wheelsets can align themselves radially on the curve and the vehicle will roll freely round the curve. If this steering is not sufficient, the wheelsets will remain at an angle to the rails (i.e. a yaw angle will exist). As the wheelsets rotate, lateral forces will develop between the wheels and the rails and these lateral forces will contribute to the harmful effects of poor curving i.e. rail sidewear, gauge spreading forces and wheel flange climb. In simple terms, the greater the angle between the wheelsets and the rails the greater will be the lateral forces and the magnitude of the harmful effects. It is possible to imagine that the greater the wheelset conicity the greater will be the turning moment, hence steering effect. Added to this, the lower the plan view stiffness of the primary suspension of the vehicle the more the wheelsets will move for a given turning moment. Curving performance can be improved by reducing the plan view stiffness of the suspension and increasing wheelset conicity. Hence there is a conflict between stability performance, where a stiff plan view stiffness and low conicity are beneficial, and curving performance, where a soft plan view stiffness and high conicity are beneficial.

The effect of conicity on curving forces is demonstrated in Figure 10 and 11. Each figure shows typical wheel/rail forces, longitudinal forces generating the steering effect and lateral forces derived from the residual angle that the wheelset has with radial alignment. The first figure shows the forces developed on a 500 m radius curve by a four wheel passenger vehicle fitted with new P1 tyre profiles which generate a conicity of 0.05. The second figure shows the forces on the same radius curve by the same vehicle fitted with new P8 tyre profiles which generate a conicity of 0.177.

The increased turning moment, the reduced angle and the reduced lateral forces are clear to be seen.

5.1 Rail Profiles Designed to Improve Curving Performance

The results presented in the previous section demonstrate how increased conicity can improve curving performance. However, in this case the increase in conicity was derived from the wheel profiles. So how can the Permanent Way Engineer manage the shape of the rail profiles to improve curving behaviour ? One way that this can be achieved is by asymmetric rail grinding and this has been used as a technique to improve curving and hence reduce rail side wear on curves. Although the experience in the UK is very limited, the literature indicates that it can be cost effective on heavy haul lines i.e. dedicated lines which employ one type of high axle load wagon.

The principle of asymmetric grinding, as demonstrated in Figures 12 and 13, is that it increases the rolling radius of the wheel on the outer, high rail and reduces the rolling radius of the wheel on the inner, low rail. In theory this should increase the effective conicity of wheelsets which use the curves.

Serious claims have been made for the benefits of the technique through the reductions achieved in rail sidewear.

However, there are disadvantages which can be associated with the technique, such as increased rail head wear, increased contact stresses and additional (grinding) costs. The reduced rate of side wear combined with the higher contact stresses can also lead to an increase in the risk of rolling contact fatigue occurring.

Notwithstanding the possible disadvantages, studies undertaken have indicated that there may be benefits from employing asymmetric grinding, but there is no clear case for universal adoption on the mixed traffic, convention axle load railway which operates in the UK.

6. Controlling Rail Profiles

There are a number of problems associated with controlling the shape of rail profiles for stability and curving. In the real world the variation of conicity can be extremely large as it is influenced by both the population of wheel shapes and the population of rail shapes. Included in these populations will be new profiles and profiles worn to maintenance limits. The variation in conicity will also be influenced by changes to track gauge and the design shape of wheel and rail profiles. Wheels worn to a particular pattern on one route can generate quite different conicity values on another route which has a different gauge, range of curvature and/or distribution of rail profile shapes.

Traditional design has concentrated on ensuring that selected wheel profiles generate lower conicities on the rail shape population to ensure satisfactory stability performance. For certain vehicles on particular diagrams, the conicity values generated by these new wheels can degrade the curving performance. However, as wheel tread wear and rail head wear develops, conicity increases and this can lead to an improvement in curving but a degradation in stability performance, hence the need to monitor wheel and rail profile shape.

7. Rail Profile Limits for Stability

If limits are to be placed on rail profile shapes, to ensure that sections of excessive conicity do not occur, it is necessary to know if the contributions to conicity, from wheel and rail profiles can be separated. This question has been investigated by AEA Technology Rail for Railtrack and it has been established that the contribution of the wheel and rail profiles correlate with measurable geometric indices. The use of these indices and appropriate limits offers the opportunity of preventing the occurrence of excessive conicity values.

8. Summary

Rail profiles can have a profound effect on stability and curving performance.

The change in the standard track gauge from 1432 mm to 1435 mm will eventually result in a reduction in the incidence of excessive conicity and hence an improvement in stability performance.

If the UIC 60 rail profile is adopted measures should be taken to ensure that the rails are not rolled to the lower limit on head curvature.

The lower conicities of new wheel profiles can degrade curving performance.

Asymmetric grinding can benefit curving performance, however, there is no clear case for universal adoption of this process on the mixed traffic railway in the UK.

Progressive rail head wear improves curving behaviour but degrades stability performance.

The correlation between a geometric rail index and conicity will enable limits to be set on rail profile shape to ensure satisfactory stability performance.

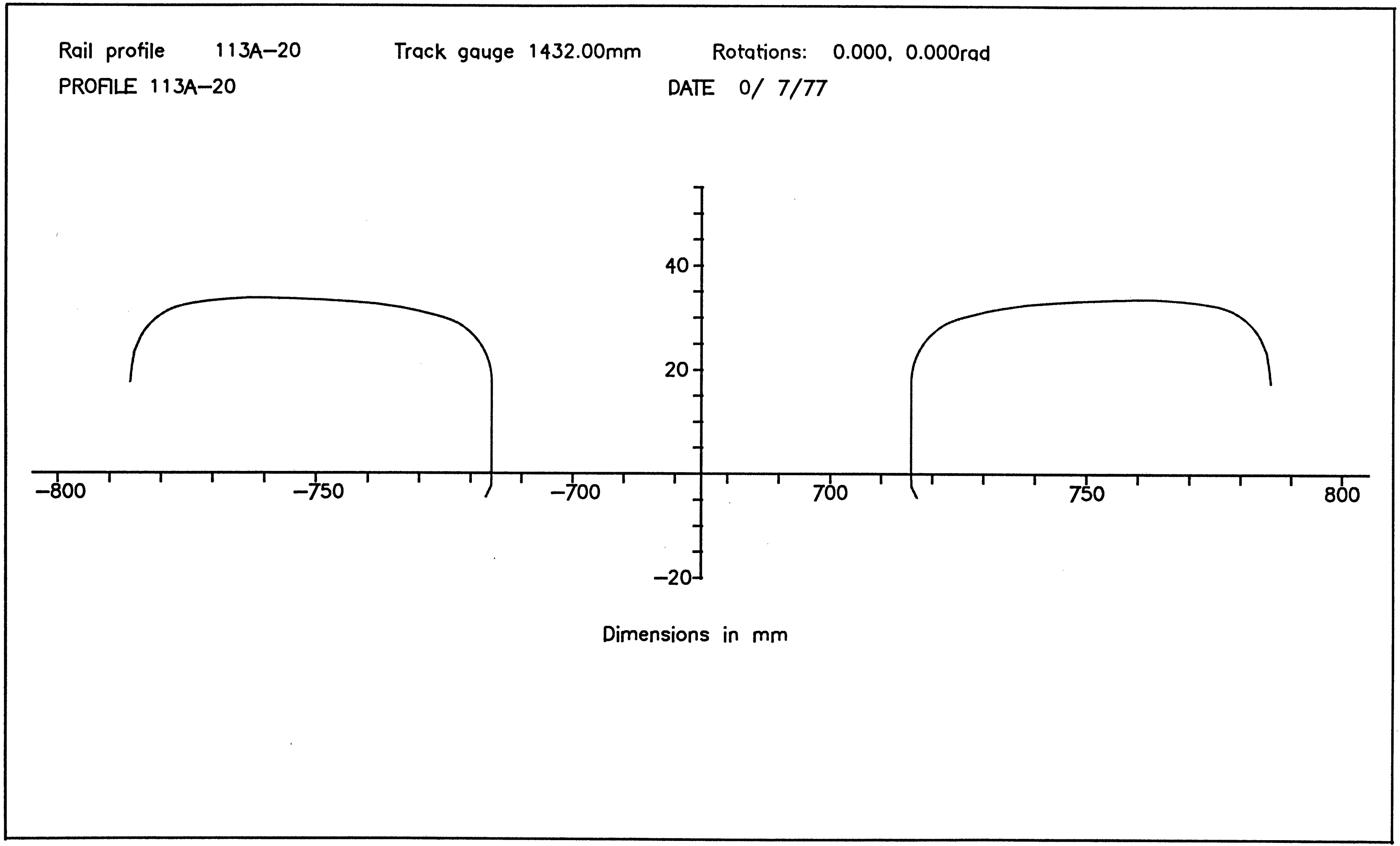
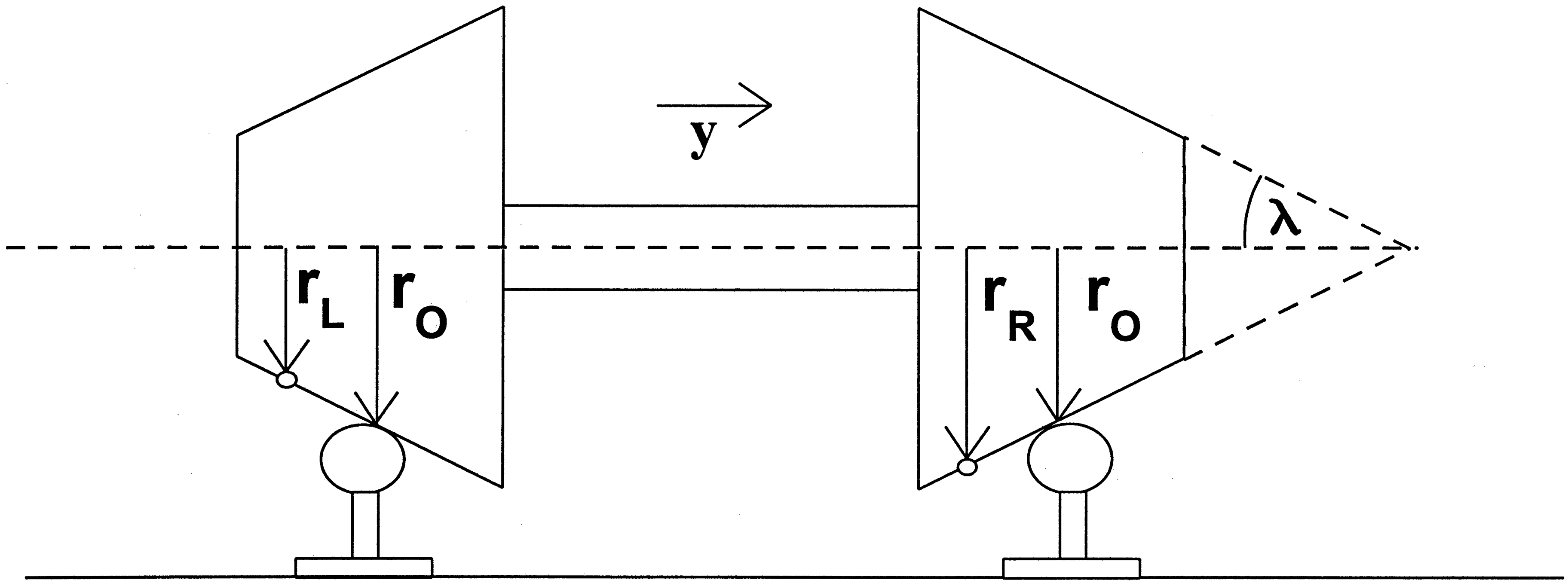

Rail profile 113A–20
Track gauge 1432.00mm
Rotations: 0.000, 0.000rad
PROFILE 113A–20
DATE 0/ 7/77
40
20
–20
–800
–750
–700
700
750
800
Dimensions in mm

Figure 1

WHEELSET CONICITY

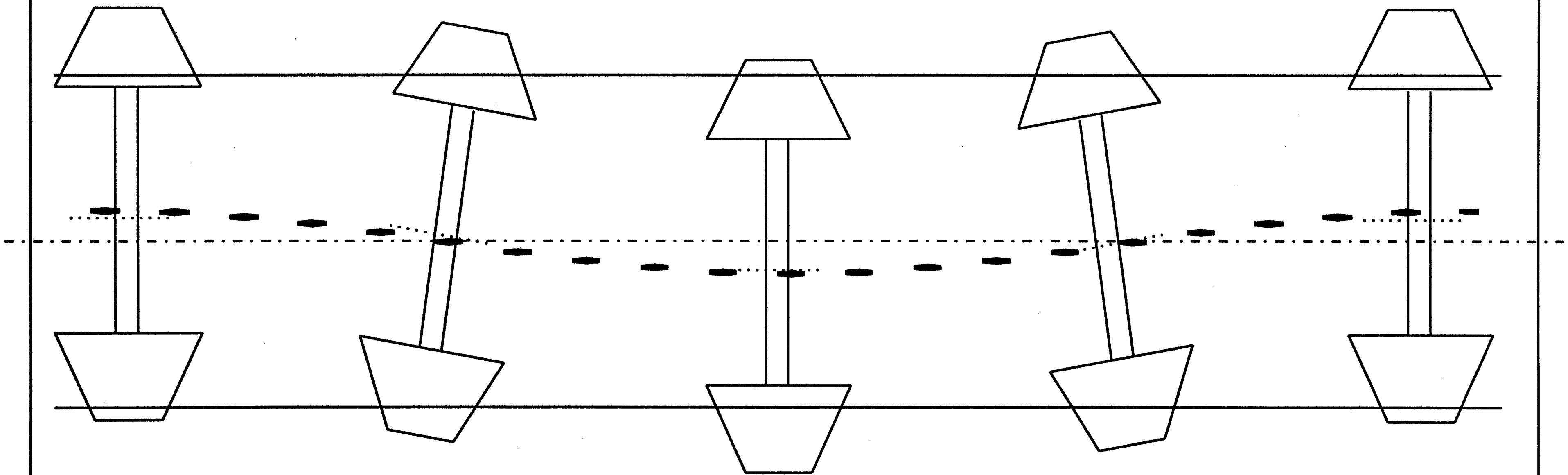


Rolling Radius Difference = r_R - r_L

AEA TECHNOLOGY
RAIL

Figure 2

Slide serial no 2



Kinematic Motion

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Figure 3

Slide serial no 3

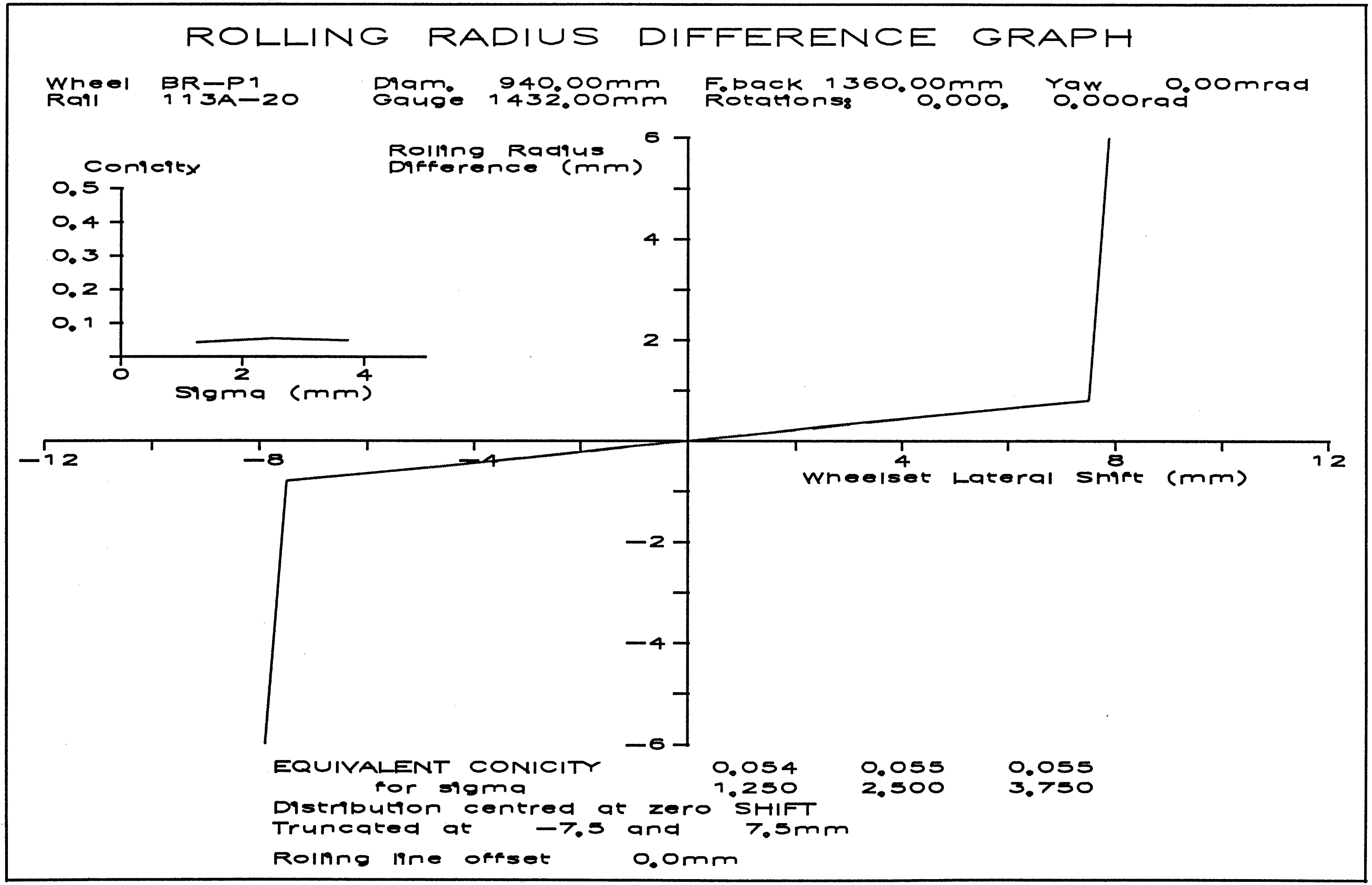

ROLLING RADIUS DIFFERENCE GRAPH
Wheel BR—P1 Diam. 940.00mm F.back 1360.00mm Yaw 0.00mrad
Rail 113A—20 Gauge 1432.00mm Rotations: 0.000, 0.000rad
Conicity
0.5
0.4
0.3
0.2
0.1
0
2
4
Sigma (mm)
Rolling Radius Difference (mm)
6
4
2
−2
−4
−6
−12
−8
−4
4
8
12
Wheelset Lateral Shift (mm)
EQUIVALENT CONICITY 0.054 0.055 0.055
for sigma 1.250 2.500 3.750
Distribution centred at zero SHIFT
Truncated at −7.5 and 7.5mm
Rolling line offset 0.0mm

Figure 4

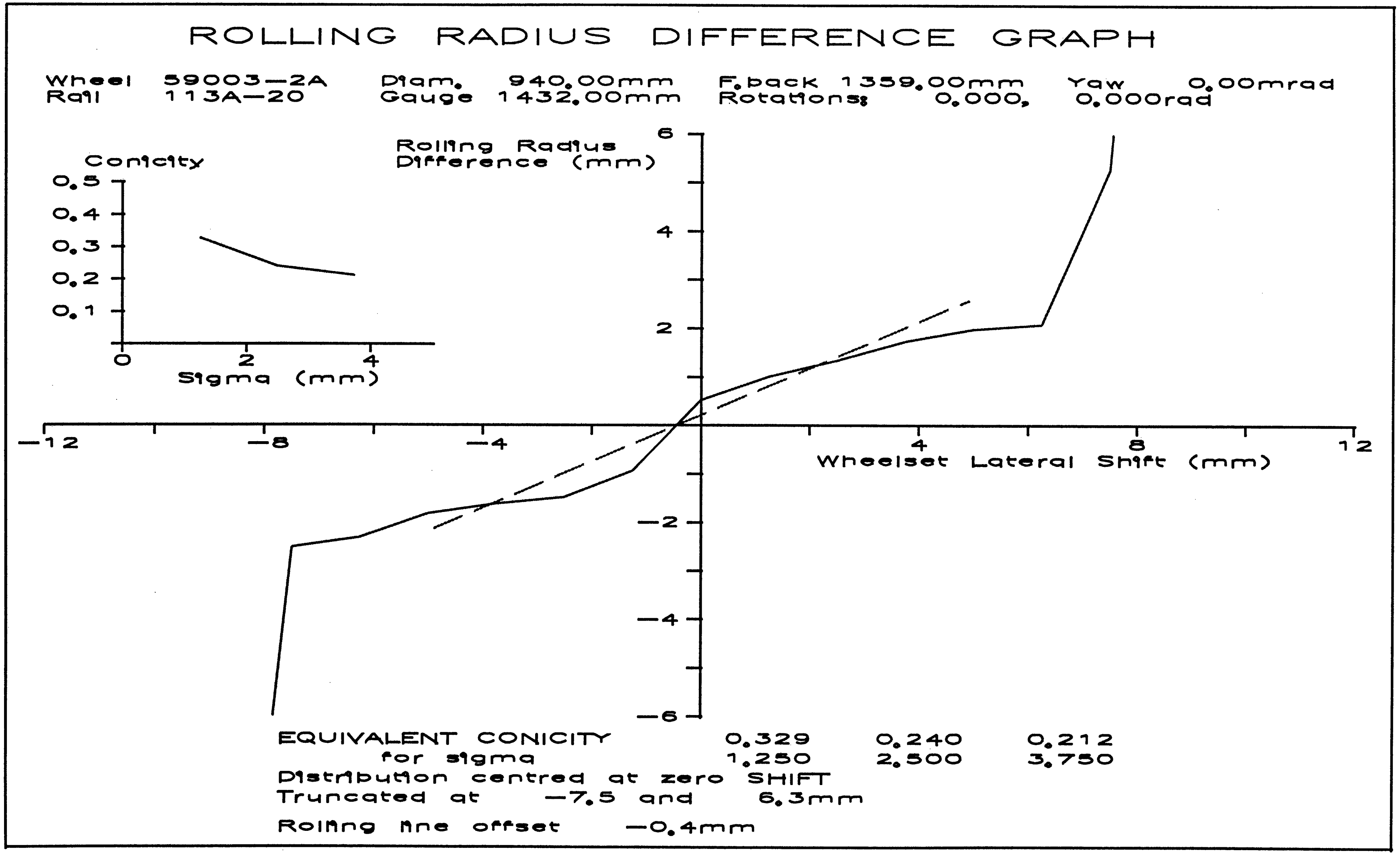
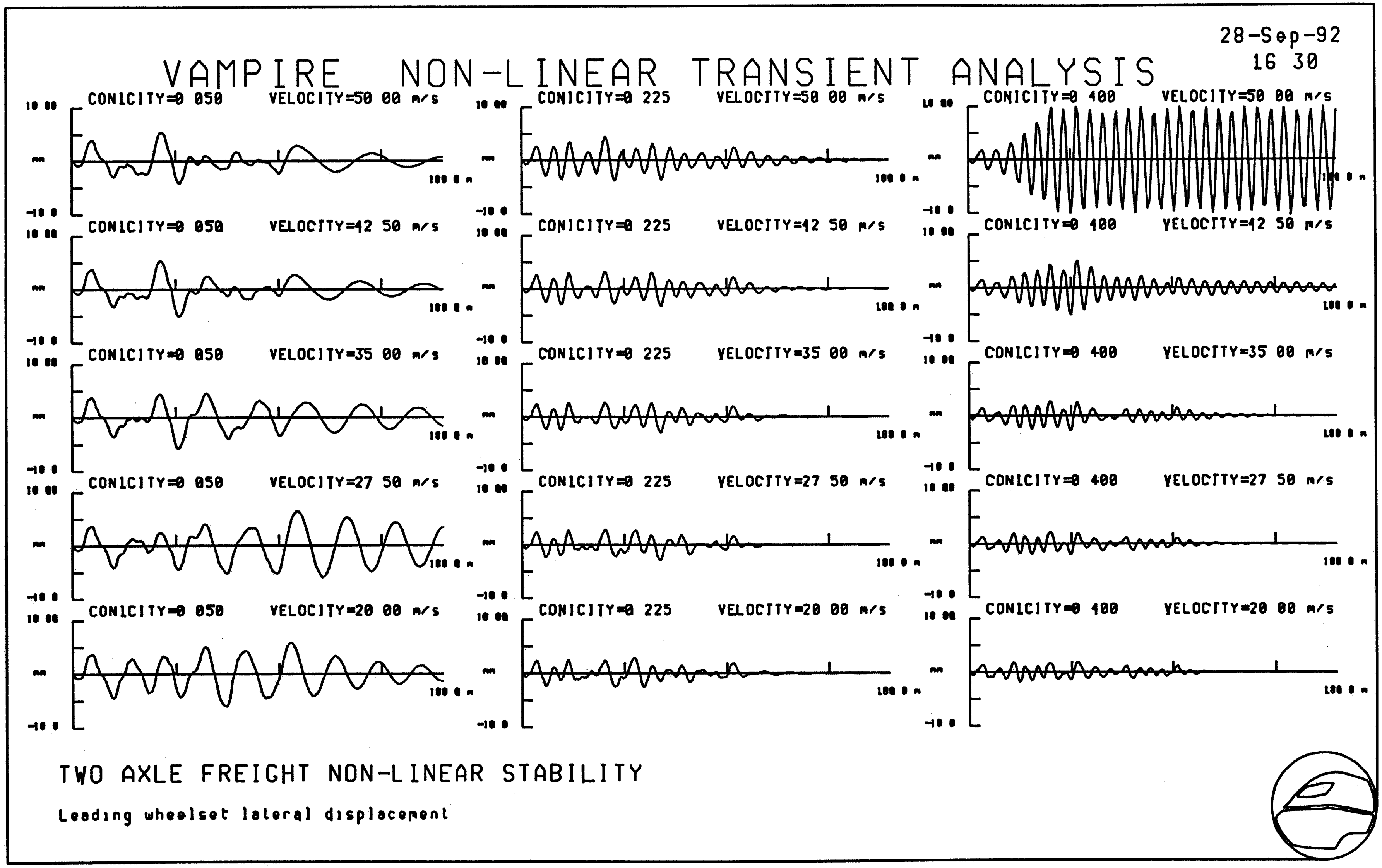

ROLLING RADIUS DIFFERENCE GRAPH
Wheel 59003-2A Diam. 940.00mm F.back 1359.00mm Yaw 0.00mrad
Rail 113A-20 Gauge 1432.00mm Rotations: 0.000, 0.000rad
Conicity
Sigma (mm)
Rolling Radius
Difference (mm)
Wheelset Lateral Shift (mm)
EQUIVALENT CONICITY 0.329 0.240 0.212
for sigma 1.250 2.500 3.750
Distribution centred at zero SHIFT
Truncated at -7.5 and 6.3mm
Rolling line offset -0.4mm

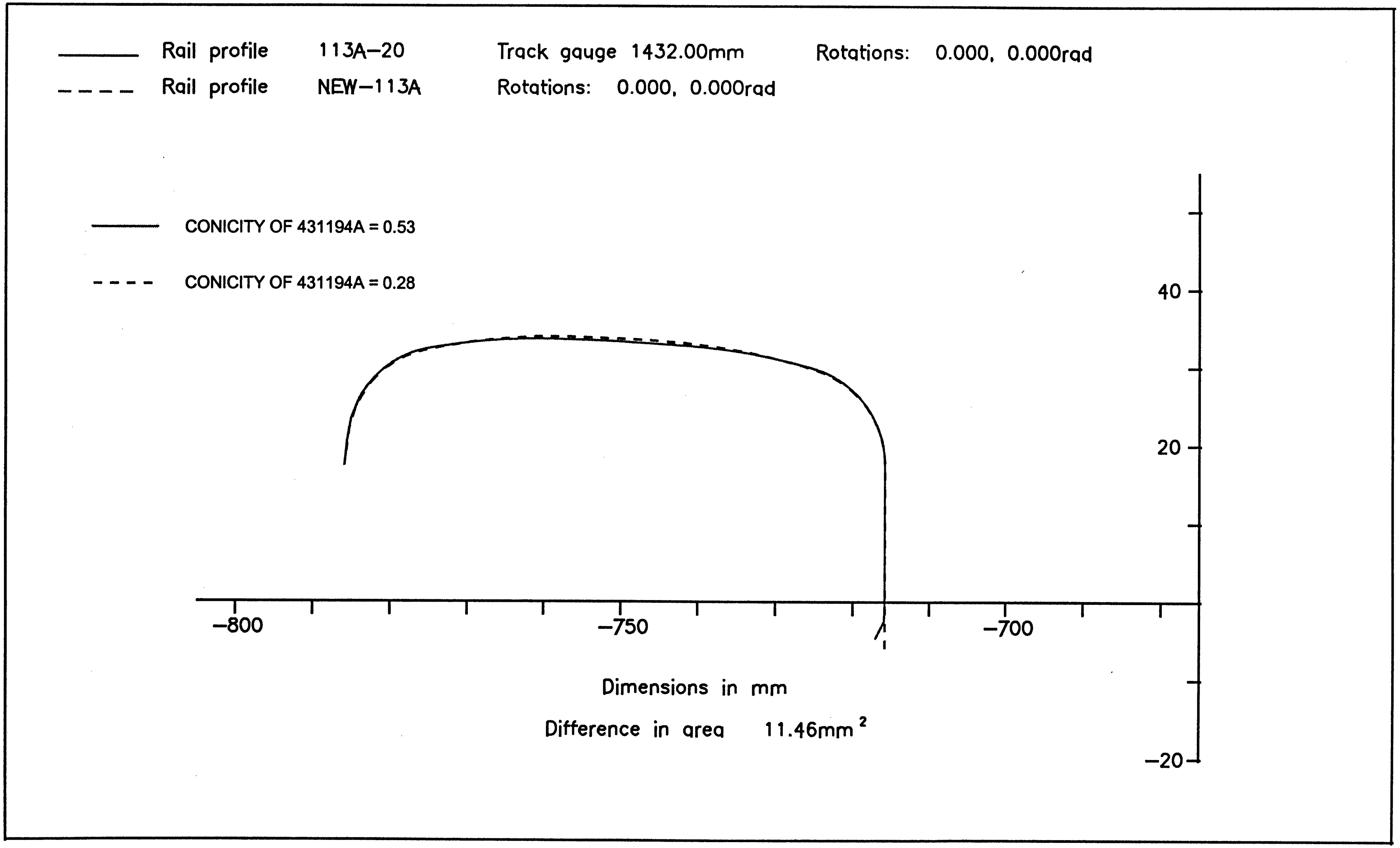
Figure 5



AEA TECHNOLOGY RAIL

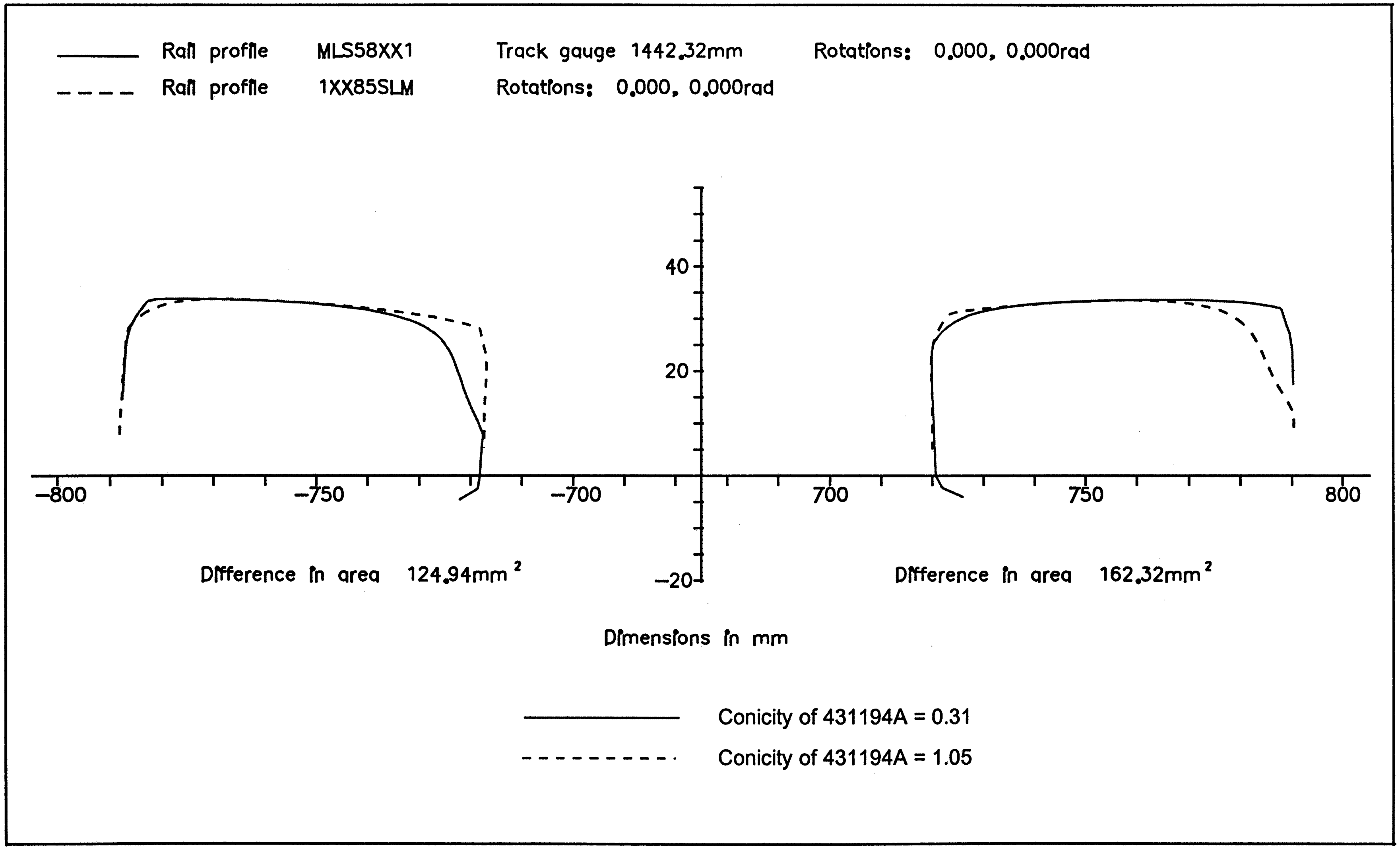
Figure 6

Slide serial no 6



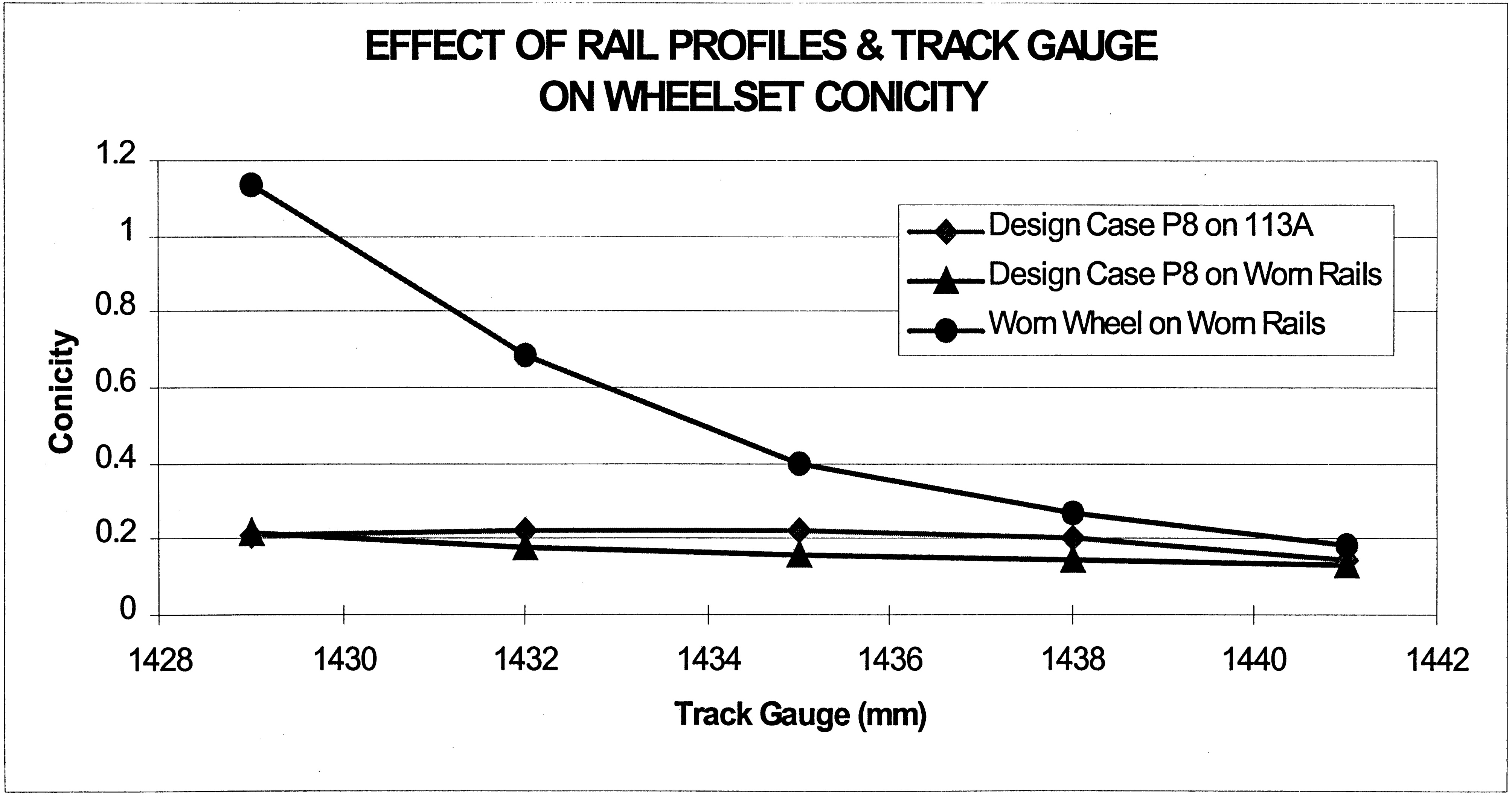
Rail profile 113A-20 Track gauge 1432.00mm Rotations: 0.000, 0.000rad
Rail profile NEW-113A Rotations: 0.000, 0.000rad
CONICITY OF 431194A = 0.53
CONICITY OF 431194A = 0.28
40
20
-20
-800
-750
-700
Dimensions in mm
Difference in area 11.46mm²

Figure 7



AEA TECHNOLOGY RAIL

Figure 8



AEA TECHNOLOGY RAIL

Figure 9

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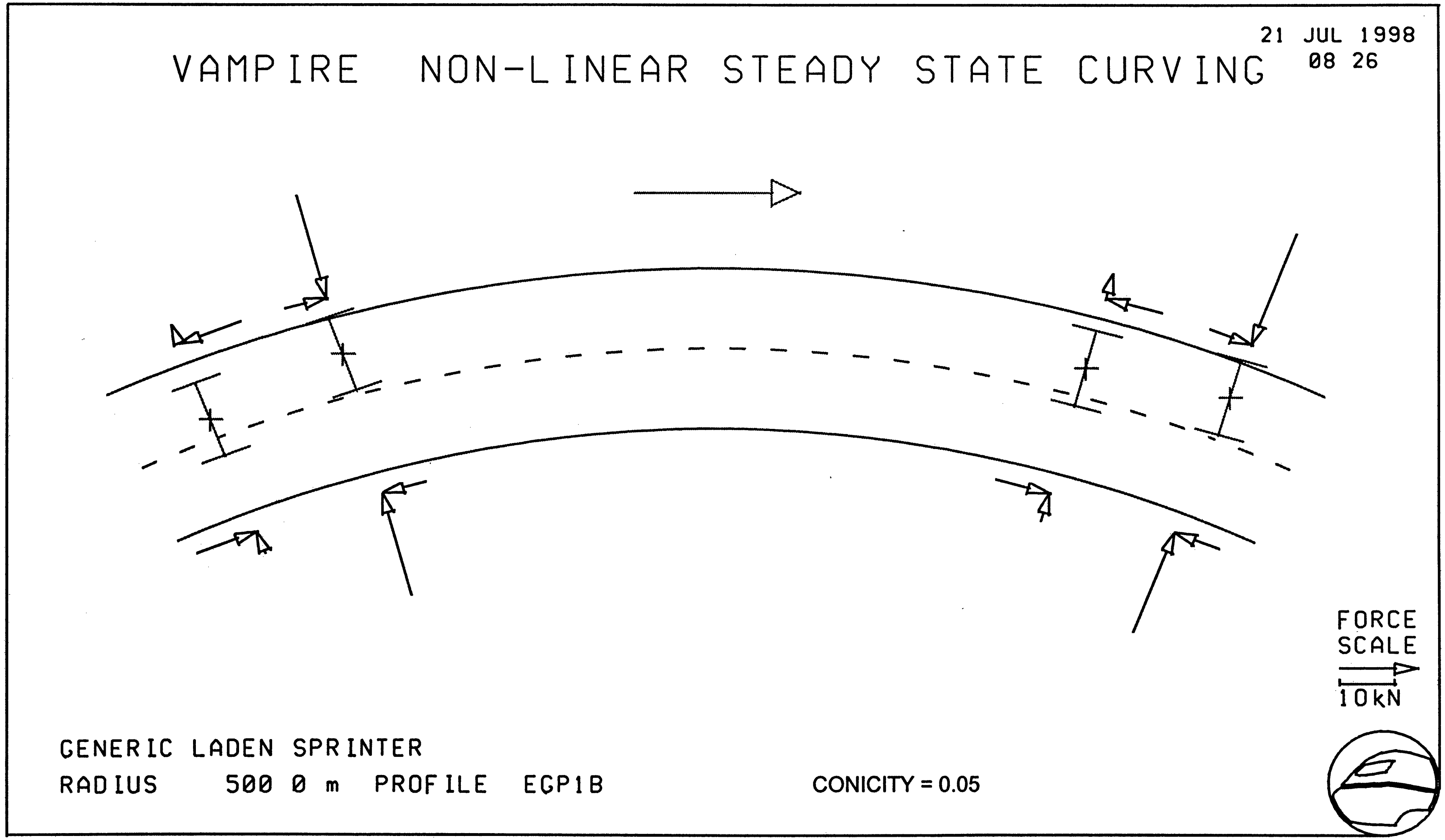
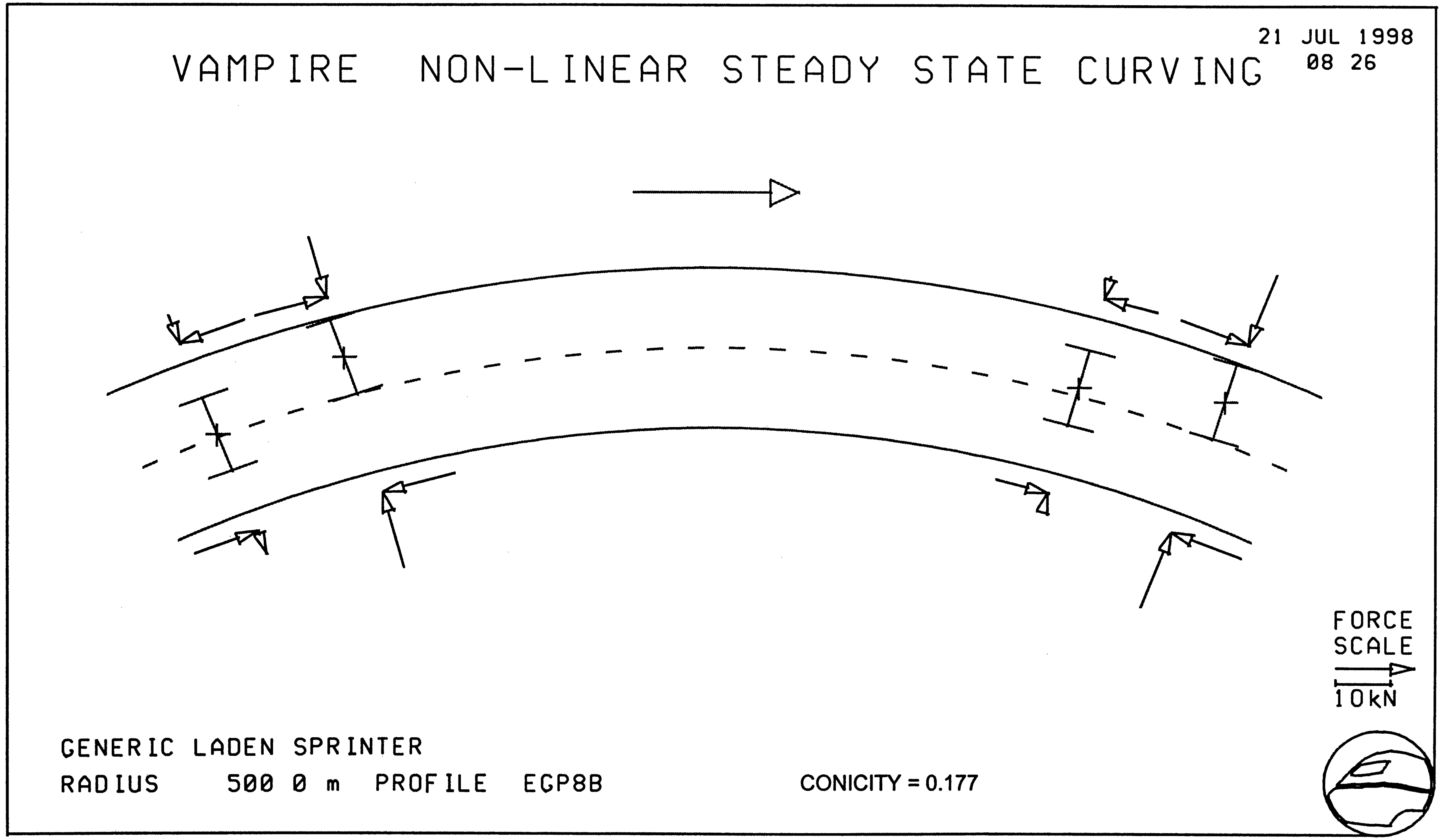


AEA TECHNOLOGY RAIL

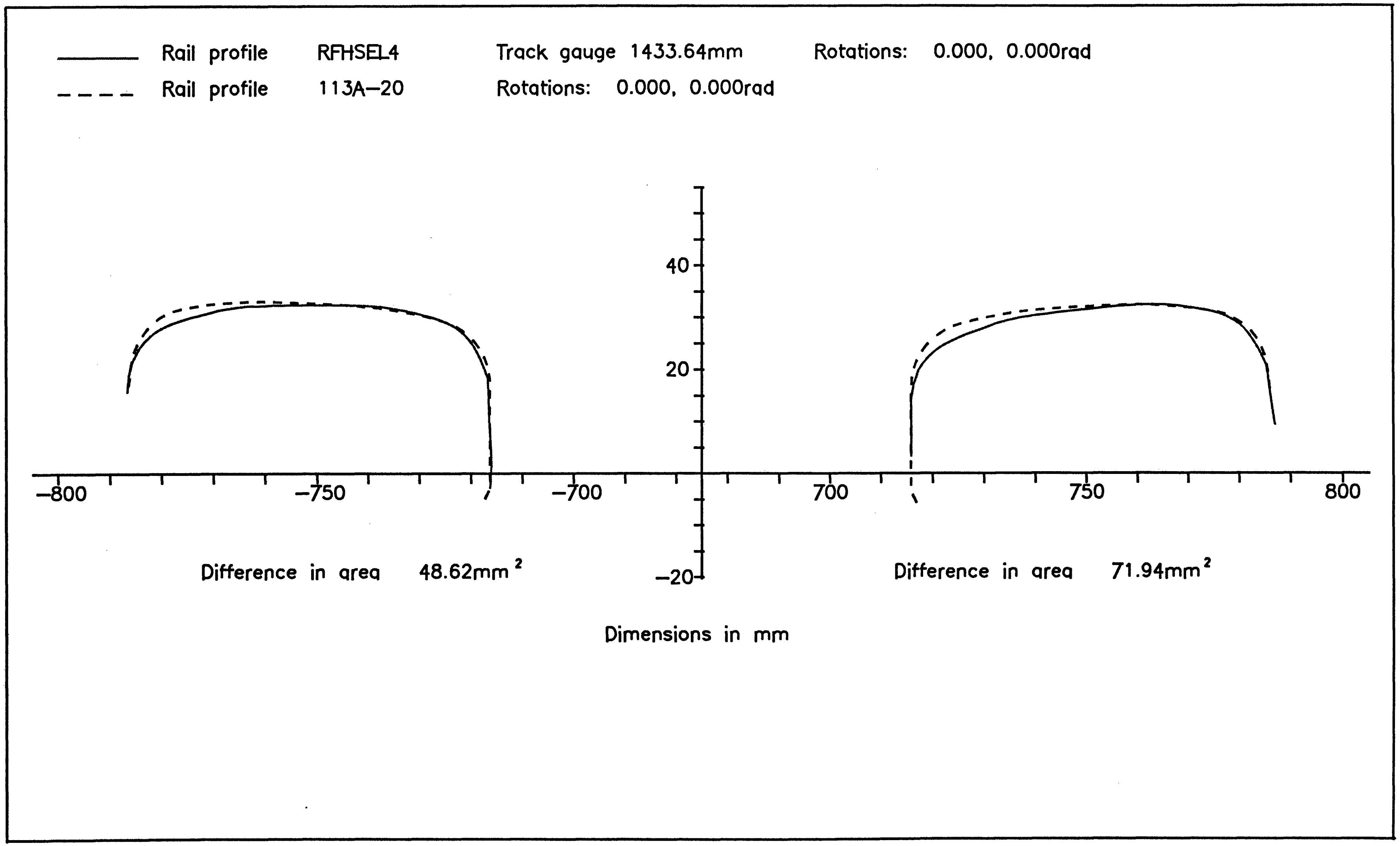
Figure 10

Slide serial no 10



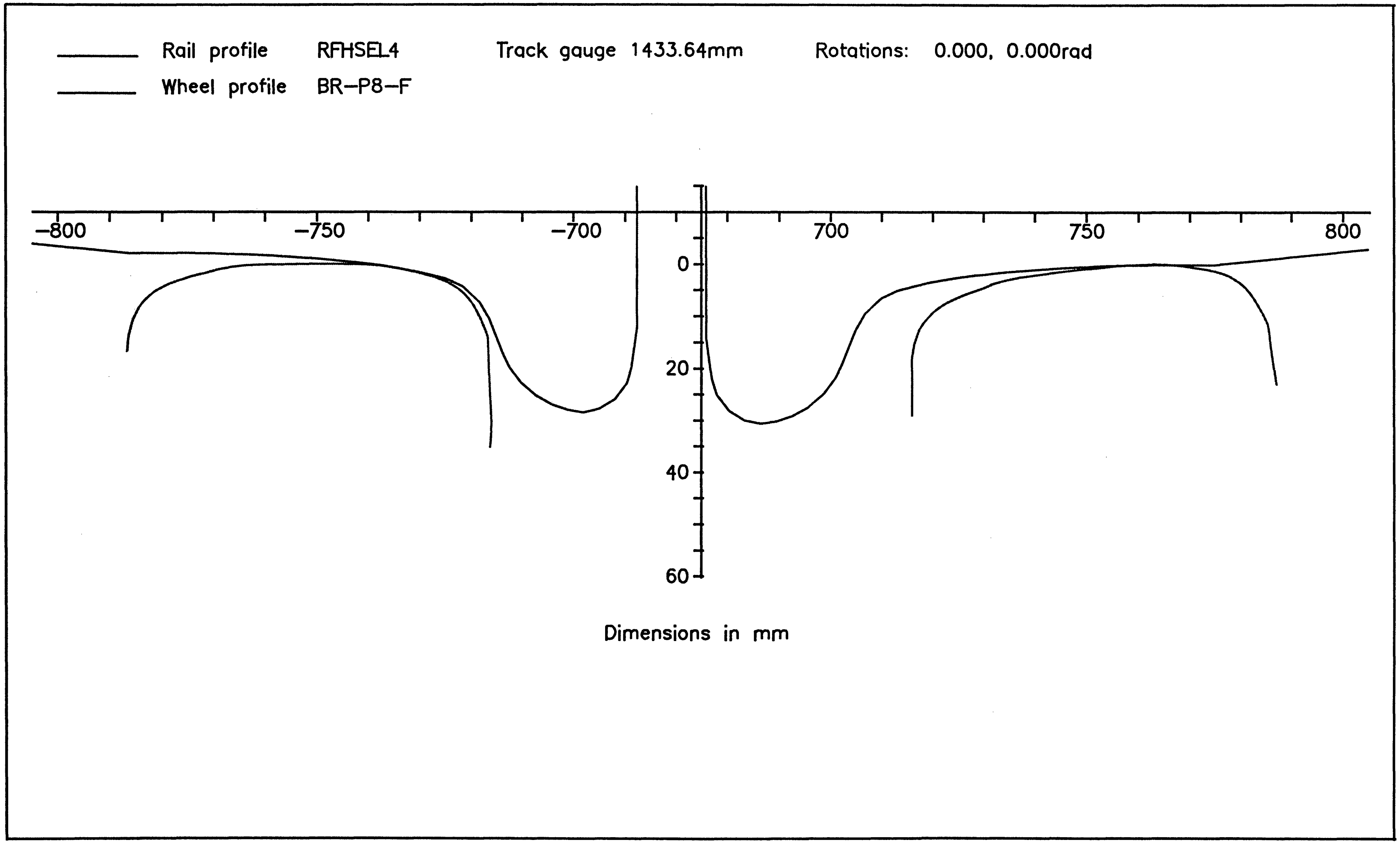
AEA TECHNOLOGY RAIL

Figure 11



AEA TECHNOLOGY RAIL

Figure 12

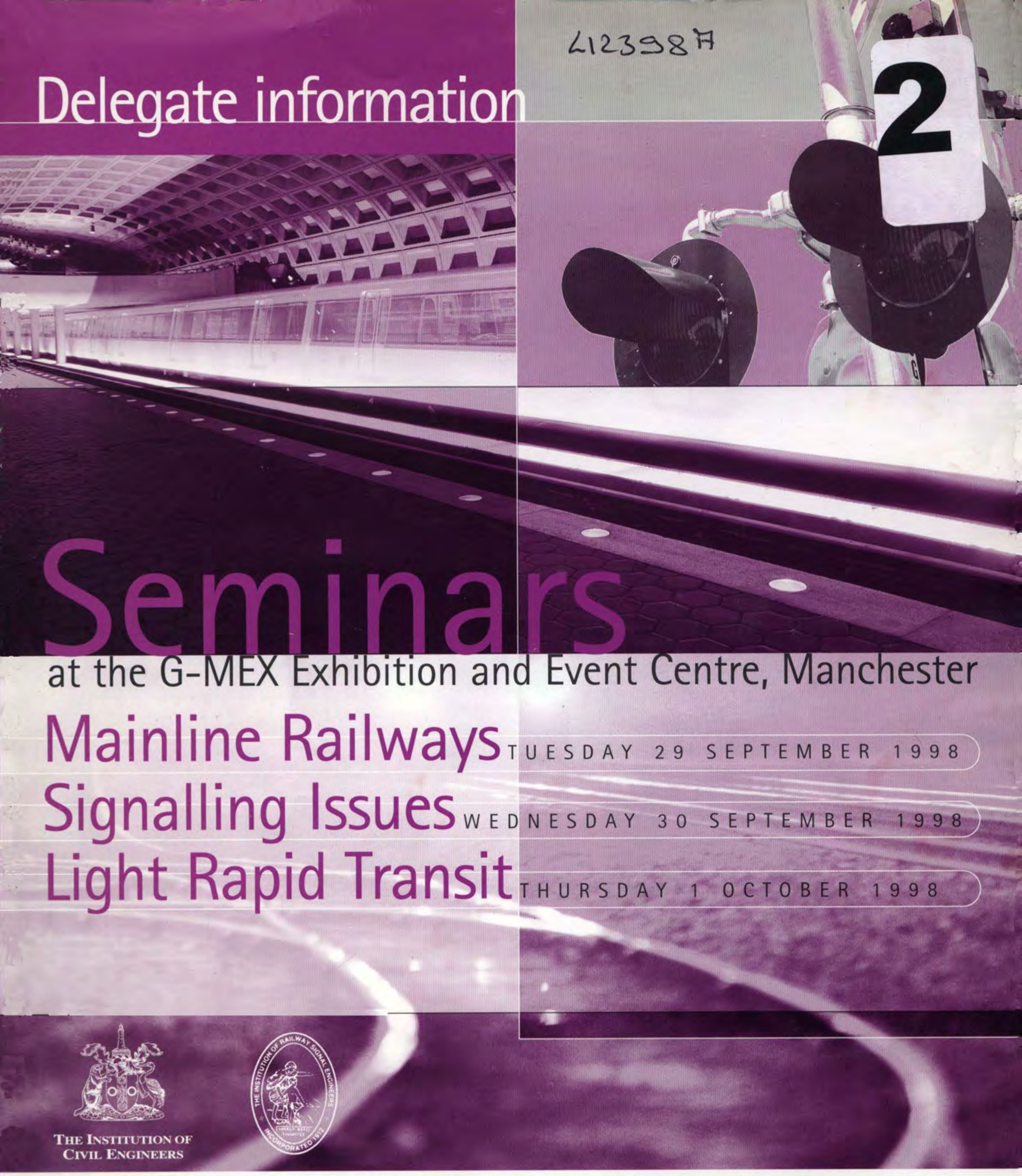


AEA TECHNOLOGY RAIL

Figure 13

Slide serial no 13

Notepaper



Delegate information

Seminars

at the G-MEX Exhibition and Event Centre, Manchester

Mainline Railways TUESDAY 29 SEPTEMBER 1998

Signalling Issues WEDNESDAY 30 SEPTEMBER 1998

Light Rapid Transit THURSDAY 1 OCTOBER 1998

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In conjunction with

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- Seminar Papers

- Notepaper

Seminar Programme

PROGRAMME (subject to amendment)
Seminar 2 - Signalling Issues
Wednesday 30 September 1998

0900 Registration and coffee
1000 Chairman's Welcome

SESSION 1

Chairman: *Neil Porter, Principal Engineer, Control & Systems Group, W S Atkins Rail*

1005 1. **Train detection - the Permanent Way forward?**
A Fisher, Technical Sales Manager, Adtranz Signal
1025 2. **Axle Counters**
G Wilms, Product Manager, Siemens AG, Germany
1045 3. **Interlocking**
M Howell, Design Manager, Westinghouse Signals Limited
1105 Discussion

1120 Coffee

1150 4. **Level Crossings**
L W Noble, Design Manager, P K Youle,Senior Engineer & C Fawcett, Senior Engineer, Mott MacDonald
1210 5. **Signalling Interfaces**
D Crabtree, Signalling & Train Control Group Manager, TCI Rail
1230 Discussion
1245 Close of session

SESSION 2

Chairman: *John Corrie, Mott MacDonald Ltd*

1415 6. **Control Systems**
A St Johnston, Managing Director, Vaughan Harmon Systems Ltd
1435 7. **Safety assurance in the UK rail transport industry**
D H Newing, Principal Consultant & D Mee, Principal Consultant, Michael Hamlyn Associates Ltd
1455 8. **Scheme Design**
G J Hill, Senior Engineer, Mott MacDonald
1515 Discussion

1535 Tea

1555 9. **Transmission-based signalling**
R E B Barnard, Principal Consultant, ALSTOM Signalling Ltd
1615 10. **Customer requirements**
F How, Principal Signalling & Telecomms Engineer, Safety and Standards Directorate, Railtrack
1635 Discussion
1700 Close of seminar

Introductory Notes

TRAIN DETECTION - THE PERMANENT WAY FORWARD ?

ALAN FISHER
Adtranz Signal
Plymouth
England

Introduction

This short paper charts the development of the form of train detection called track circuits. The principal function of the track circuit is to detect and confirm the absence of rolling stock in a defined length of track. This information is then used by the signalling system to safely control and regulate train movements.

Historical Developments

The history of train detection has closely followed developments in electrical technology and techniques. The invention and application of batteries and relays permitted, with the use of insulated rail joints, the development of the dc track circuit, this style of track circuit was used for many years and until electrification was introduced was sufficient for the needs of the railway industry.

With the introduction of dc electrification, the use of dc track circuits became unacceptable and the ac track circuit was developed. The impedance bond was also developed to allow the traction return current to flow in the running rails back to the electric sub-station whilst still allowing insulated rail joints to be used to separate the sections. The dc track was continued to be used for ac electrified territory. The traction return current in ac territory was carried by one rail, whilst the other rail was isolated into sections by single insulated rail joints.

Whilst the dc track equipment has remained substantially unchanged, with the battery power being replaced with a transformer rectifier feed set, the ac track developed various styles over many years. The original ac track was based on a 50 Hz fundamental frequency but over several years various other frequencies were used, 75 Hz, 83 1/3 Hz, 125 Hz together with frequencies generated by mechanical, electrically excited reeds. These frequencies ranged from 300 to 500 Hz. The reason for the development of many alternatives were twofold. Commercial opportunity created some variations, but the prime reason for such developments, was to attempt to develop equipment which would not be interfered with by either the fundamental or the harmonics of the traction supply or return current interference.

With the development of improved traction packages, changes to rolling stock design to meet changing customer needs and a desire to improve ride quality together with benefits in track maintenance, the jointless track circuit was developed. This style of train detection removed the need for physical separation by insulated rail joints and replaced them with electrical separation joints, achieved by resonating short sections of rail with tuning components. This tuned area could be configured as one of three combinations, either

a) Transmit / Transmit

b) Receive / Receive

c) Transmit / Receive.

This flexibility allowed for easy application when designing trackside equipment. The early designs of jointless track circuits were based on single frequency carrier signals and their use was restricted to non-electrified territory. In order to take advantage of the jointless application in electrified territories it was necessary to code the single frequency carriers to provide some protection to traction interference. Various techniques have been used including serial coding, FSK modulation and random signature analysis.

Recent Developments

With the changes in rolling stock and in particular the use of lightweight vehicles, the rail wheel interface has changed dramatically and alternative types of train detection have been adopted. The use of high frequency impulse track circuits have been adopted in areas where traffic movement is limited and the rail wheel interface rarely achieves the normal expected levels of shunt impedance due to rust corrosion or contaminants. Emergency crossovers and stabling tracks are typical applications for such forms of train detection.

High frequency train detection systems operating in the 80 to 100 KHz range are applied as overlay track circuits in points and crossings areas, the advantage of this style of application is that no insulated rail joints are required.

The emergence of new Mass Transit Railways has also created a changing need in train detection systems with the requirement to quickly release track sections to maintain tight timetable regulation and to provide track to train communication for Automatic Train Protection (ATP) data and in some applications Automatic Train Operation (ATO) data. This communication requires to be continuous, such that immediate notification of improved headway conditions can be transmitted to the driver.

Typically, train detection systems which use modulation frequencies for coding, provide fixed speed information and generate step changes in train performance by providing maximum speed limits regulated by driver action, systems which use serial coding tend to provide speed profile data which maximises the time a train is permitted to travel at higher speeds and regulates the driver to control the train to its best calculated performance profile..

As described earlier, the development of modern traction systems has caused the train detection design engineer to consider other methods of coding to ensure safe operation in the presence of unwanted traction interference harmonics. An alternative approach has been adopted for some rolling stock where the output of the traction package is monitored to confirm that no undesirable harmonics are being returned to the running rails or if some inband signal is being generated, that it is only permitted for a time duration less than that required to energise the train detection relay. This form of monitoring is called Interference Monitoring and the equipment fitted to the rolling stock is called an Interference Monitor Unit (IMU). The IMU comprises a transponder used to measure the return current of the traction unit and a processing unit used to measure the harmonic content and to trip the traction unit if or when it exceeds the specified limits.

The initial IMU's were developed to "police" rolling stock travelling over 50 Hz ac train detection areas. This unit was further developed to cover other frequency track circuits including reed frequency tracks and was identified as a Multi Frequency Monitor (MFM). This approach attempts to harmonise and integrate the user (trains) with the used (track) in a way which does not require major changes to either.

The Future

The style of future train detection systems is being determined by technology and application style. Transmission Based Signalling (TBS), is changing the emphasis of train detection from proving the absence of trains to accurate train positioning systems, where the exact location of a train is determined by the trains own controlling computers with the aid of satellite positioning systems, radar and other distance measurement techniques.

Other functionality, traditionally provided by track circuits, such as "train complete" and "broken rail detection" will now need to be considered as part of another system. Train detection using axle counters may well form part of the future control systems, but other complementary systems will also be needed to provide this additional functionality.

The approach to signalling is now becoming a systems approach, no longer will independent elements such as train detection be treated in isolation, but a comprehensive review of all elements that make up an operational railway needs to be undertaken so that each element can be functionally reviewed and if necessary, redefined. This systems approach has many benefits including the opportunity to integrate all elements into a single safety case and may lead to reduced costs, as some of the traditional functionality and disciplines change shape and scope.

Conclusion

The current boundaries of many engineering disciplines will change as elements of the control system change their location. What was once a train based function may become track based, what was once track based may become train based, what was once a centralised function may become a distributed function.

These boundaries are being challenged by the advances in technology and by professional engineers taking a greater interest in other areas of system design and performance.

TRAIN DETECTION BY AXLE COUNTERS

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SUMMARY
The best-known, and even today, the most widely-used method of track-clear indication is to apply track circuits in their various forms. However, track circuits are n[1]ot always suitable, which is the case when it is not possible to insulate the rails, or if the track section to be monitored is very long or difficult to reach. The system which has been developed as an alternative method is based on axle counting-in at one end of the track section and axle counting-out at the other end of this section. When both counts correspond, the track section concerned is indicated as clear. The basis module is the SIMIS®-C fail-safe microcomputer system checking all safety-relevant indications by 2-channel processing. Identical results of processing generate a track clear indication. Three versions are available, Az S 350 for track sections of up to 20 km, Az S 350T for track sections longer than 20 km, length defined by transmission equipment and Az S M for several track sections in one redundant 2-out-of-3 system.

1. PRINCIPLE OF THE Az S 350

The axle counting system Az S 350 is a fail-safe system for determining whether a track section is clear or occupied; the system is based on a microcomputer. One wheel detection equipment (DE) is installed at each end of the track section to be monitored. Each detection equipment is connected to the evaluation unit via a 2-wire telecommunication cable. This connection provides the power to both wheel detection equipment and, in the opposite direction, sends information on axles passing the wheel detection equipment.

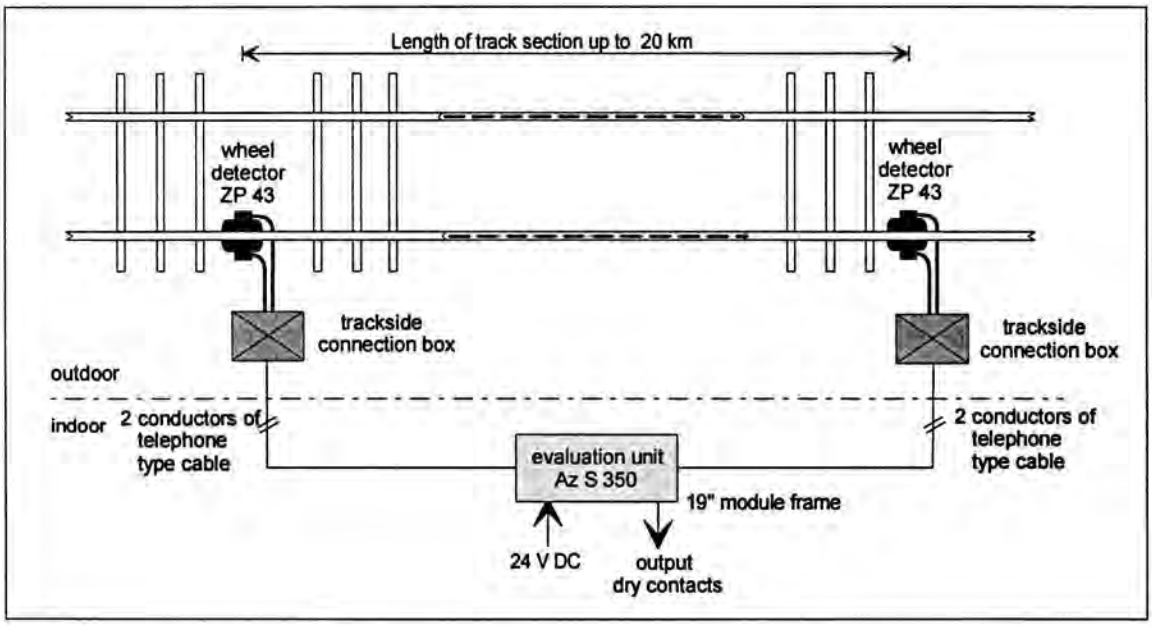

Fig. 1: Microcomputer Axle Counting System Az S 350

The evaluation unit is the central processing and monitoring device, compiling information received from the wheel detection equipment to a complete report and, with due consideration to operational status, provides a track-clear or track-occupied indication. Output of the track clear indication is handled by relay contacts.

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2. WHEEL DETECTION EQUIPMENT

Each wheel detection equipment (DE) comprises an electronic double wheel-detector, providing counting pulses, and a trackside connection box (CB) to house the equipment for the pre-processing of wheel signals.

The electronic double wheel-detector (ZP 43) consists of two electronic systems which are housed in one unit. Each of the systems has a transmit and a receive section via which signals are continuously transmitted. The transmitter is mounted on the outside of the rail and the receiver on the inside. Two systems are required for direction identification. To reduce interference from the rail, e.g. rail currents, both the receiver and the transmitter are provided with a reduction plate on the rail-facing side. This plate is matched to the rail profile and extends from rail base via the web to the underneath of rail head. There is a choice of plates to suit rail profiles.

The detector, fastened by two bolts in the neutral axis of rail web, is suitable for all normal-type rail profiles.

The wheel detector (transmitter and receiver) is connected to the trackside connection box by means of two approx. 4 m long cables. For mechanical reasons, these cables are permanently connected to transmitter and receiver.

The trackside connection box (CB) is made of die-cast aluminum and moisture-proof according to IP 68. It has a detachable and lockable lid. Pipe supports of different heights are available for mounting the connection box. Cable bushings of various diameters are also available.

The box contains the PC boards for controlling the wheel detector and for pre-processing the wheel-initiated signals. A terminal strip is fitted to the back of the subframe, connecting the two cables of the double wheel detectors and the cable to the evaluation unit.

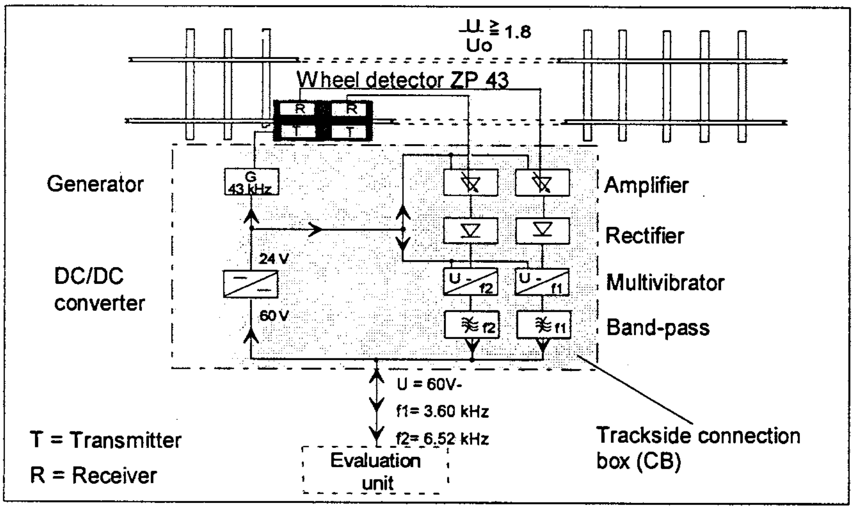

Fig. 3: Wheel Detection Equipment with ZP 43 (Functional Diagram)

For power supply and data transfer purposes, the wheel detection equipment is linked to the respective evaluation unit by means of a two-wire telecommunication cable. The voltage for wheel detection equipment is 60 V DC at evaluation unit. The voltage at wheel detection equipment decreases according to cable length. However, it must still be ≥30 V DC at the input of the connection box to achieve voltage stabilisation to 22 V DC.

The transmitter comprises a sine-wave generator. Its parallel switched resonant circuit coils – housed in one unit – are mounted at the rail. The transmission frequency is 43 kHz. When the wheel detector is not influenced by a wheel, the alternating field emitted by the transmitter coils induces, via the rail, a constant alternating voltage in each of the receive coils, also housed in one unit. These voltages control, independent of each other, the frequencies of two multivibrators using amplifier stages with subsequent rectification.

The incoming voltages and the multivibrator frequencies change as soon as the wheel detector is influenced by a wheel. If frequency deviations reach the band-pass width of the output filters the output voltages U_{f1} and U_{f2} start to drop. From this change of information, the evaluation units derive counting data.

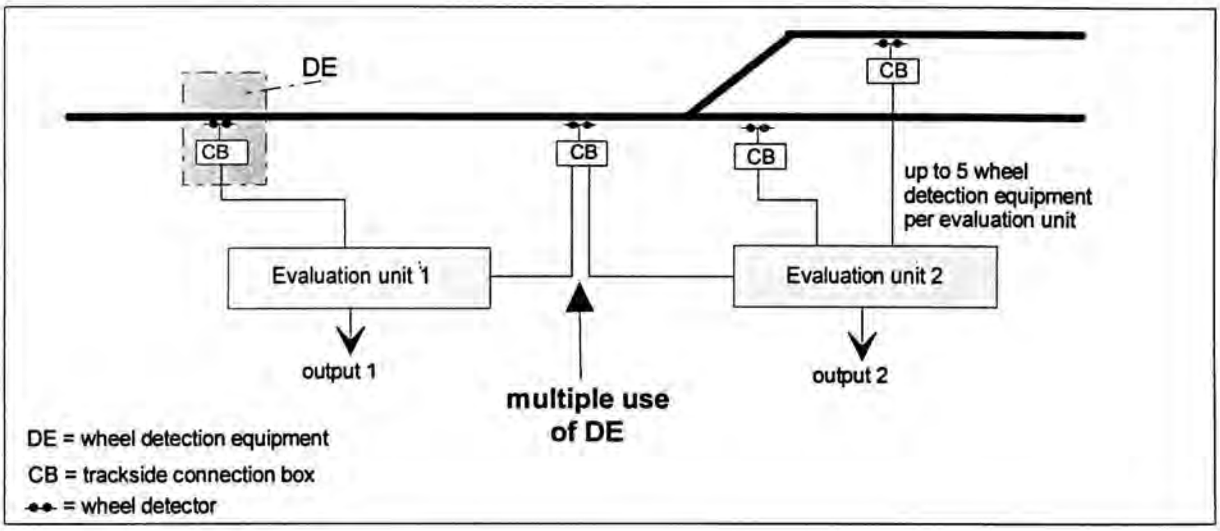

Fig. 4: Multiple use of DE for Az S 350

One wheel detection equipment can serve a double purpose when two axle counting sections border on one another, i. e., the counting-out of axles for one section and the axle counting-in for the neighbouring section take place simultaneously at the same counting location.

It is also considered to connect more than two wheel detection equipment to one axle count evaluation unit, e.g. in a switch area where several tracks branch off (maximum 5 wheel detection equipment per Az S 350).

3. EVALUATION UNIT

The evaluation unit is a fail-safe data processing device based on microcomputers. The fail-safe microcomputer system SIMIS-C forms the core of the counter unit, which has been tested and approved. It is based on two processing channels, with synchronous data flow in both channels.
An evaluation unit consists of a single-tier standard rack which holds the plug-in PC boards. The switching elements, combined into functional units, are mounted on the boards. All inputs and outputs as well as the power supply are plug-connected with the backplane of the PCB rack.
The evaluation unit requires an uninterruptable supply voltage of either 60 V DC or 24 V DC. DC/DC converters are available for both input voltages, which convert selected input voltage into the required internal voltage of 5 V DC and 12 V DC and, if necessary, into the 60 V DC supply voltage for wheel detection equipment.
The microcomputer system on the processing board functions on the basis of an 8085 microprocessor at a pulse frequency of 2 MHz. It has an 8k RAM main memory and a 8k EPROM program memory.

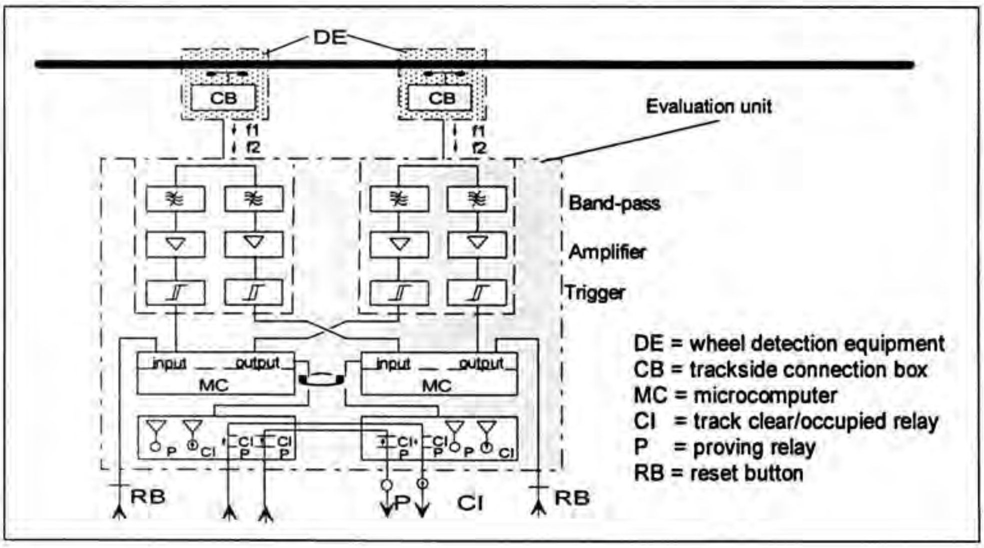

Fig. 5: Az S 350 functional diagram

Commissioning a system for the first time, the sequence of functions starts at the processing boards. To start both channels synchronously, it is necessary to briefly and simultaneously press both reset buttons on the front sides of boards.

The functional sequence of an EPROM program starts with the initialisation of a fixed program parameter, such as memory area allocation, interrupt mask setting, stack pointer defining, register resetting, etc.

After initialisation, the SIMIS test program routines begin. A complete run takes about 2 minutes. The test program runs as a background program of lowest priority and is only left after an interrupt request. The functions are concentrated on individual PC boards.

An interrupt request is transmitted in a fixed time-slot pattern for which a frequency divider is installed in the control and diagnostic board. Every 0.5 ms this divider issues a pulse which triggers an interrupt in the CPU. This time is based on a max. permitted train speed of 350 km/h for this axle counting system.

With standard layout the maximum cable length between wheel detection equipment and evaluation unit is approx. 10 km, depending on core cross section. With supplementary equipment the cable length can be increased up to 21 km. To take length of cable into account, the input amplifiers are provided with one setting possibility for each of the two frequencies f_1 and f_2. During commissioning of equipment, the input level must be set to a specified voltage value.

The corresponding potentiometers and measuring sockets are accessible from the front panel of the amplifier and trigger board.

The trigger output also controls an LED on the front panel of board which lights up, channel-specific, when wheel detector is being influenced.

The output of track clear indication to the peripherals comprises two contact arrangements connected in series, insulated from microcomputers and leading to the connector.

One contact arrangement functions according to the closed circuit principle and has one front contact for each of the four output relays. The other contact arrangement functions according to the open circuit principle.

Each channel has a pair of relays, one for track clear indication and the other for proving. These function inversely and, as for the system as a whole, synchronously.

If, after the passage of a train, the axle counter shows occupancy or, due to a fault, a track is indicated as being occupied when it is clear, the axle counter can be reset. Prior to taking this action, the interlocking operator must ensure that the track section concerned is indeed clear. This check is carried out according to a specified procedure. Reset restriction ensures that an inadvertently pressed reset button will not effect a resetting of axle counting system. This safety measure is based on the logic that the last axle counted must be a "counted-out" axle.

4. SAFETY CONCEPT

The SIMIS-C microcomputer system is responsible for the safe functioning of the entire Az S 350 system. It was developed for applications requiring fail-safe operation such as those of railway signalling.

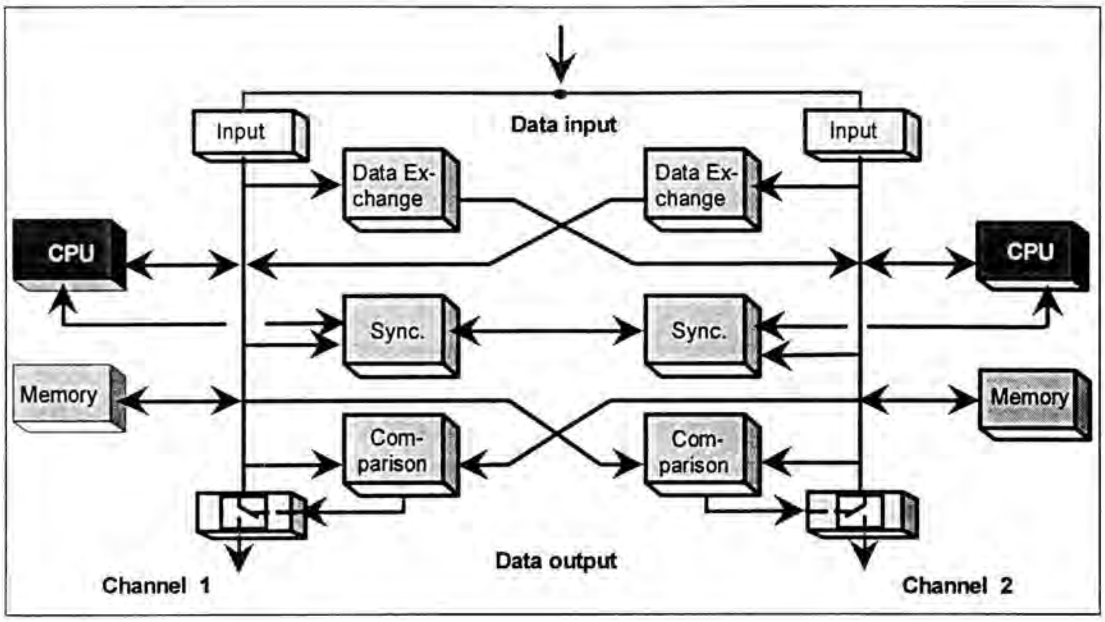

Fig. 6: Safety principle of SIMIS-C

Its two microcomputers, of identical design, function independently. Two-channel data output is achieved by supplying each computer, in parallel, with the same input data and carrying out identical processing (same programs). Two independently functioning comparators permit an output to the sequential circuit only if the processing results of both microcomputers are identical. If there is discrepancy between processing results, an interrupting device, switched to the comparators, de-energizes parts of the output circuit.

Test programs are part of the SIMIS operation. They ensure that any failure will promptly be detected. The SIMIS on-line test program runs as a background program with lowest priority. It is discontinued with each interrupt to permit process handling. The purpose of the test program is to perform a continuous and channel-specific check of all SIMIS functions.

The fail-safe functioning of the Az S 350 is based on the application of the two-channel SIMIS principle to all safety-relevant equipment of the system.

As the microcomputers and the comparators function independently, SIMIS-C cannot become unsafe as a result of one failure triggering one of the shutdown procedures. Safety shutdown is irreversible and cannot be annulled by the microcomputers.

5. DIAGNOSIS

The Az S 350 equipment is provided with several visual displays and measuring facilities. Most of these indicators are to aid fault diagnosis.

The measuring facilities, in combination with associated displays, aid preliminary setting and checking of data variable.

The diagnostic unit is used for setting and checking measurements of the wheel detection equipment. The diagnostic unit is plugged into the front side of the adapter PC board by means of a connecting cable. The adapter board must be plugged into the provided location in the PCB rack. The operating instruction assists the handling of the diagnostic unit.

6. PRINCIPLE OF THE Az S 350 T

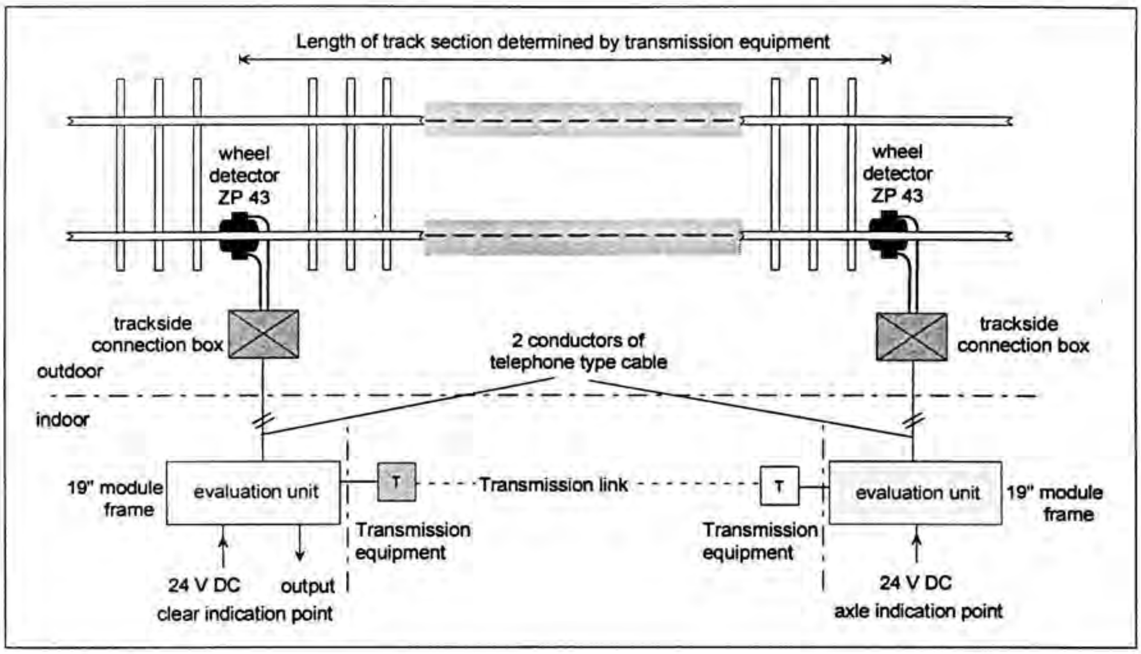

Fig. 7: Microcomputer Axle Counting System Az S 350T

The Az S 350 has been designed for track vacancy detection of sections longer than 10 km or 21 km respectively. The upper limit of length is determined by the transmission system used. In contrast to Az S 350 here an evaluation unit is installed in the vicinity of each wheel detection equipment. The evaluation units determine direction, calculate number of axles and store the result. One evaluation unit being master and having the track clear indication set-up. The other evaluation unit transmits its counting results in telegram form to the master. With this information it is then able to determine whether the section is clear or occupied. The evaluation units each have an international standard interface, the RS 232, which can be used with user-specific transmission equipment. It is also possible to transmit with the same transmission equipment additional information in both directions, e.g. block status indications. The basic axle count equipment as well as the safety concept correspond with Az S 350.

7. PRINCIPLE OF THE Az S M

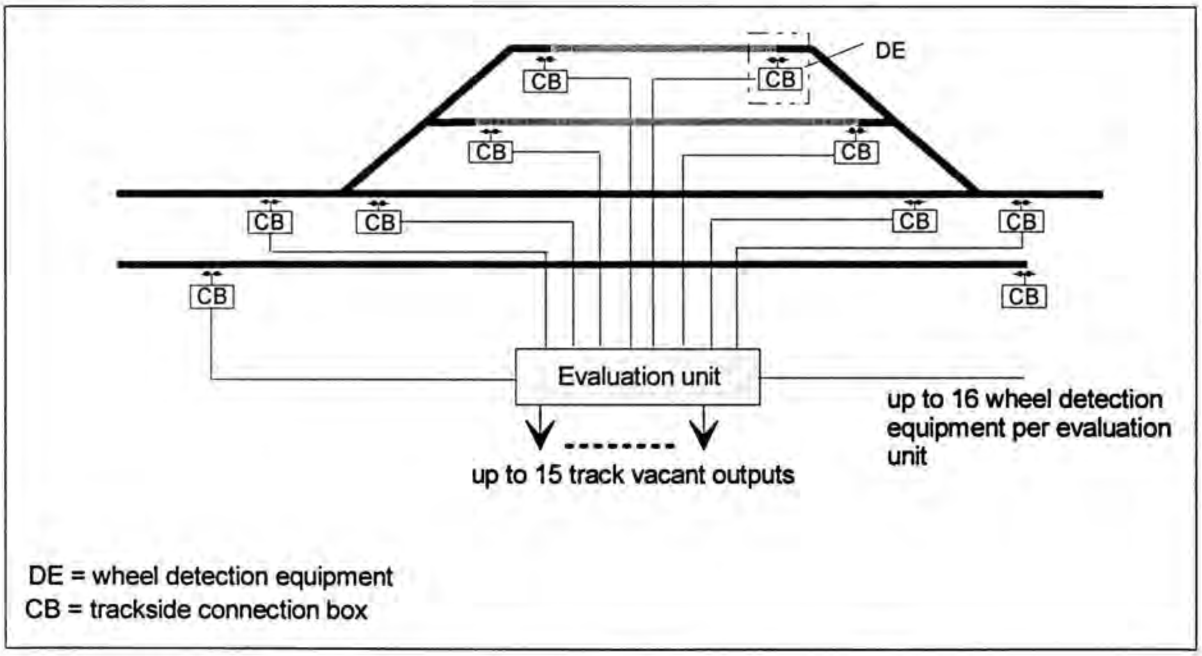

Fig. 8: Microcomputer Axle Counting System Az S M (Principle)

The Az S M has been designed for station/yard areas rendering possible the connection of up to 16 wheel detection equipment to one evaluation unit. Due to the large amount of data to be processed, a SIMIS 3216 is used. Provision has also been made to connect a microcomputer interlocking via a V.24 interface. Also here, the basic axle count equipment as well as the safety concept correspond with Az S 350.

The modernized line between Magdeburg and Berlin was used as a pilot project for the new microcomputer axle counting system Az S M. The axle counters are installed between the stations.

The technical data of this pilot project are:

- number of wheel detectors	350 ZP 43 E (with reference detectors, without reserve)
- number of evaluation units	29 Az S M (E)
- number of cabinets installed	19
- end of fail-safe analysis	December 1994
- interlocking function tests	May 1995
- safety qualification	September1995
- start of traffic operation	December 1995

Since then, approximately 300 Az S M systems have been installed in Finland and Germany. The countries South Africa and Netherlands are the next areas of approval and pilot project installation.
Az S M is the first train detection system with a redundancy solution (2-out-of-3).

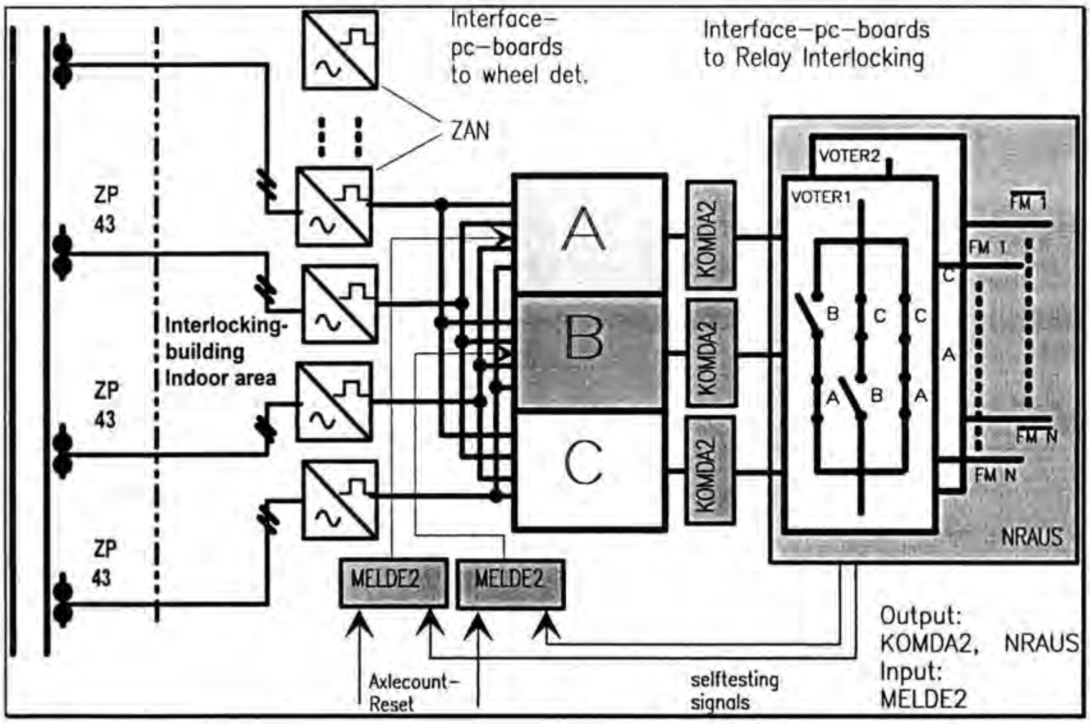

Fig. 9: Redundancy Concept of Az S M (Principle of the relay version)

Interlocking

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Within a railway signalling system the interlocking is responsible for control of the passage of trains whilst ensuring that a safe distance is maintained between trains on the same track, and safeguarding the movement of trains at junctions and when crossing a path which could be taken by another. The interlocking will receive input requests from an operational control system and will allocate areas of track to individual trains in a manner that ensures that there are no potential conflicts, issue corresponding movement commands to points and issue movement authorities to trains. The interlocking continually monitors the state of the railway (points locked, location of trains etc.) and will withdraw movement authority from trains should there be any unsafe change of status on the route ahead. It is also essential that in the event of an equipment failure the safety of the trains is assured, i.e. the interlocking is required to be of safety-critical nature (formerly known as fail-safe).

The processing function of an interlocking is fundamentally one of combinatorial and sequential logic evaluation and timing functions, that is functions that are ideally suited to electronic processor technology. Modern interlockings are thus vital electronic systems that are configurable for specific geographical applications. There are a number of different systems currently available but they each share common characteristics: architectural design techniques that address the problems introduced by failure modes of complex processors, failure modes of inputs/outputs and correctness of software; and the need for a configuration system to produce vital data. Whilst the requirement of safety-criticality remains inviolable, railway operators are more and more requiring high-availability and low mean time to repair.

The specific equipment that the interlocking needs to interface to (signals, points machines, track circuits, coded track, control centres etc.) will vary considerably with different railway authorities. Furthermore the principles, rules and practices governing the protection of train movements in different railway authorities have evolved independently. Thus the specification of interlocking requirements may vary significantly from one railway authority to another.

This presentation addresses the problem of developing a fail-safe electronic interlocking that has a flexibility of application that allows it to be used in any railway authority and provides high availability and low mean-time to repair. Westinghouse Signals Westrace interlocking is used as an example and particular issues addressed are: supporting a variety of equipment interfaces, being able to adopt different operational philosophies and signalling principles of different rail authorities, differing views on safety standards.

The development of Westrace was sponsored by the four railway signalling companies within the BTR rail group: Dimetronic S.A. (Spain), Safetran Systems Corporation (USA), Westinghouse Signals Ltd. (UK) and Westinghouse Signals Australia. The project thus had four different customers with, in many cases, quite disparate needs (e.g. differing system configuration options with any number of different signalling equipment interfaces). Similarly signalling philosophies vary across such a widely distributed marketplace, Westrace could not therefore be developed in such a way that users are constrained by hard-coded signalling principles. The user interfaces, and in particular the interface to the configuration system, were required to be easily used by the signalling design engineers and by the customers of the four companies. Above all else the Westrace system was required to have a safety case argument understandable by, and acceptable to, the markets of all four companies.

Westrace is a fail-safe processor, with extensive fail-safe discrete I/O and communications capabilities, and with comprehensive facilities to support maintenance and diagnostics. The Westrace system comprises a range of modules (Westrace Vital Logic Equipment (VLE)) which can be configured to suit many requirements for vital logic control, a configuration system and a set of application manuals.

A Westrace interlocking can be configured from the range of modules which includes: Vital Logic Module, Vital Input Modules, Vital Relay Output Modules, Vital Lamp Output Modules, Vital Communications Modules, Track Code Output Modules, General Purpose Output Modules, Non-Vital Communications Modules, Diagnostic Module.

Data preparation and simulation is performed using a Graphical Configuration System which is an off-line configuration and data preparation module, running on a standard IBM compatible personal computer with a windows interface. This system enforces rules for the selection and configuration of Westrace modules and allows direct ladder logic entry to the system by the design engineer. It enforces and eases the required verification and validation process and change control. A simulation facility is provided to facilitate full testing and checking within the design office, and a closed loop check from the configured Westrace installation back to the original design file is enforced.

Taking into account the disparate requirements, the considered approach was to adopt a modular design using discrete safety modules capable of being configured in a variety of ways and which would enable each of the group companies to provide economical systems to suit their particular markets.

The Westrace modules fall into three categories: Vital Logic Modules, Vital Slave Modules and Non-vital Slave Modules. There are a number of variants for each type of module. A Westrace installation is configured by selection of required modules and building them into Westrace housings whereby the modules will communicate via the Internal Module Bus (IMB) Each module has a single processor thus minimising costs and enabling low-cost system configuration for a variety of applications.

The heart of any Westrace installation is a Vital Logic Module (VLM), each installation has one VLM. The VLM is the central processing unit for the Westrace equipment, it contains the configuration data and the means to negate the system in the case of equipment failure (Output Power Control (OPC)). It receives inputs from vital and non-vital input modules and maps these input states onto its store of the system logic state (input states, output states, internal timers and latches), evaluates the logic in accordance with the application logic defined by the signalling designer and updates its store of the system logic state accordingly, then it drives the vital and non-vital output modules in accordance with the output states. The VLM controls the IMB in the installation. The slave modules are all I/O modules. Each slave module is either an vital module or a non-vital module, these functions are never mixed.

Diversity is implemented throughout the vital elements of the Westrace system. This is achieved by providing a diversely assured safe-processing environment and diversity in the applications.

The safe processing environment assures the integrity of each processor by self-checking, comprehensive defensive programming afforded by way of software diversity, and a process of inter-processor checking which is the Westrace concept of health monitoring. In the event that any of these mechanisms detect a failure then the system is negated via two diverse means (primary and secondary negation). A schematic of the Westrace safety architecture is shown in figure 1.

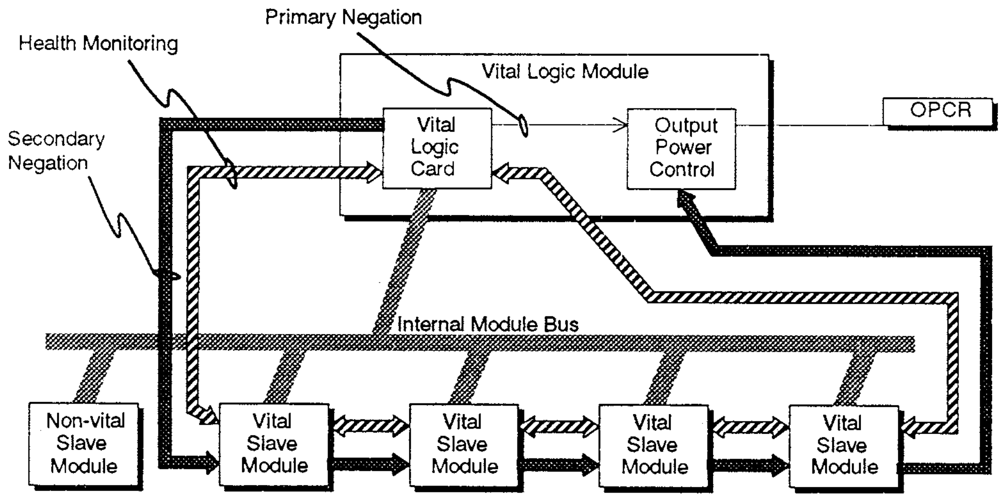

Figure 1. Westrace Safe Processing Environment

The VLM checks the health of all of the slave modules in the installation via the IMB communication process which must comply with the safety protocol including checks on the internal data diversity and response time. The primary negation signal is a waveform that is an indication of the successful execution of the software on the VLM processor (including all self and inter-processor checks). The secondary negation signal is daisy-chained through all of the vital slave modules on its route to the OPC, any of the vital modules have the ability to break this chain and prevent the signal from reaching the OPC. The receipt of the secondary negation signal by the OPC is thus the result of a high-integrity AND function of the health of all of the vital slave modules in the installation (including all self and inter-processor checks).

Westrace employs diversity for all vital functions, and the implementation of this diversity is systematic, leading to ease of design, simplicity and visibility. This approach uses different functional and control-flow operations and thus provides defences against failures of the processor or the validated compiler and also provides another mechanism for a safety-critical module to detect failure of the processing environment. The hardware is either of inherently fail-safe design or has its operation assured by two diverse means one of which must be fail-safe. In many cases the assurance of the integrity of the hardware (e.g. in the output-stage of a vital slave module) is provided by software. In these cases the provision of this assurance is a safety-critical function and the software is subject to the implementation rules above.

The design methods (standards, procedures and their observance) have been subject to a number of independent assessments by: Aurthur D. Little (on behalf of London Underground Ltd.), SRD (on behalf of Australian National), Admiral (on behalf of Queensland Railways), AEA Technology (on behalf of Queensland Railways), London Underground Ltd., Lloyds Register (on behalf of London Underground Ltd.), Railtrack. Notwithstanding the fact that the Westrace development precedes the publication of the Rail Industry Standards for safety-related software for railway signalling (RIA-23) and CENELEC standards, independent assessors have found the Westrace developments to be compliant or equivalent.

First line maintenance for a Westrace installation is the replacement of faulty modules, second-line maintenance is factory repair. In each case diagnostic information is required. This is provided by the diagnostic module which is a non-vital slave module. Each module in the Westrace equipment logs the results of any internal checks to a fault-diagnostics latch resident on that module, the diagnostics module polls the diagnostics latches on each of the other modules and logs all changes of state with a time stamp, as a fault record. The Diagnostics Module also receives all of the internal system logic states from the VLM via the IMB each complete logic processing cycle. The Diagnostic Module then identifies all changes of logic state and stores this information, with a time stamp, as an event record. The fault records and event records are accessible (either locally or remotely) through an external interface at all times, even after the remainder of the Westrace installation has been negated. The event log archives may be played back through an external playback system.

The facility for configuration of Westrace in a stand-by arrangement gives the designer further options for increased availability: in the case where temporary loss of any function is intolerable, and also in the presence of failures of functions required for assurance of the safe operation of the system, i.e. failures for which there is no possible graceful degradation.

Westrace has been applied in a number of countries and for a number of different types of application. It has been used in Australia, Germany, Indonesia, Norway, Portugal, Spain and the UK and it is currently being installed in the USA. There are currently 425 Westrace Installations world-wide. The applications include CTC and ATC/ATP (trackside and train-carried) for railway types as diverse as Heavy Haul, Metro, Light Rail and Mainline.

Technology for the minimal monitoring of level crossings

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Synopsis

This paper discusses technologies that are available to assist the signaller in decision making at level crossings remotely monitored via closed circuit television. A review of existing level crossings in the UK suggests a good level of safety is currently maintained but at relatively great expense. The introduction of network management centres may require significant expenditure, out of proportion to their cost and safety benefits, should it be necessary to replicate the existing closed circuit television set up in network management centres. Off-the-shelf technologies exist that are capable of detecting obstructions at level crossings and challenge the requirement for dedicated closed circuit television monitors. This paper reviews these technologies, some of the risks involved and possible methods of implementation.

Introduction

The background to this paper is the consideration of practical technology to replace the monitoring function provided by humans at manually controlled barrier (MCB) level crossings operated by Railtrack. This function could be defined as confirming that the crossing is clear:

a) prior to the lowering of the barriers or, if auto-lowering is permitted,

b) after the barriers have lowered.

A combination of technologies might provide the monitoring function, currently carried out by the signaller, to an acceptable level of integrity. The potential benefit is a reduction in man-power and closed circuit television (CCTV) hardware with major operational advantages once the Railtrack Network Management Centre (NMC) concept is introduced.

The following features are identified as reasons that might be considered for a MCB level crossing being installed as opposed to another type of level crossing:

- train/linespeed over 100 mile/hour
- risk of road traffic blocking back

- high pedestrian moment (e.g. children) or train traffic moment
- special trains
- economic reasons
- complex road junctions
- traffic moment exceeds automatic half barrier (AHB) limit
- herding cattle
- road profile
- multi-track crossing, e.g. a single road crossing operating over several tracks

Technologies

The following is a review of the main minimal monitoring technologies that are considered applicable to the detection of obstructions on level crossings. It is acknowledged that other technologies exist that are possible but not necessarily practical. For example, strain gauges might be used to detect heavy vehicles but it is likely that a multiple array of devices would be required to ensure that all areas of the crossing were safely monitored.

Road loops

An obvious disadvantage is that road loops are unlikely to detect animals, people, small non-metallic objects that nevertheless are capable of causing derailment or possibly smaller vehicles, e.g. motorbikes, bicycles, etc. Another disadvantage is that installation might be costly at reinforced level crossings. However, road loops could provide a very reliable method of detecting vehicles and large metallic objects and they are used successfully on the Swedish State Railway.

Figure 1. Under-concrete road loops.

Radar

This technology potentially has great advantages since it is not necessarily dependent on good weather, metallic objects or level crossing illumination. Depending on how the system is set up, it could detect both movement and static objects (if a stored radar image of the crossing when clear is used) of varying sizes. The only perceived disadvantages are poor detection very close to ground level and electromagnetic interference hazards.

Figure 2. Radar detector developed for level crossings © Honeywell.

CCTV image processing

Normal bandwidth video image processing (including colour) has the greater likelihood of off-the-shelf availability because of its diverse applications in security, highways, railways etc. However reliability under all weather conditions may be questionable (although this would probably depend on cost). CCTV cameras at level crossings are normally fixed high above the crossing looking down – this has the advantage of being relatively vandal/thief proof and less dependent on poor weather since the camera is focusing downwards. For minimal monitoring applications it may be more appropriate to locate the camera lower down for better detection of road vehicles close to the barriers. However, this has the disadvantage of being more vulnerable to vandals and thieves.

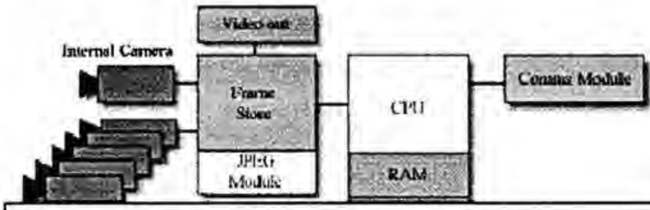

Figure 3. Image processing input stage.

Infra-red

This technology, which may be relatively expensive, could be split into two sub-categories:

b) Infra-red image processing – similar to standard CCTV image processing but with the advantage of better detection at low ambient light levels and possibly poor weather conditions (although not thought to be as effective as Thermal Imaging).

b) Infra-red detection – detection of objects radiating infra-red radiation as used in the security industry.

Figure 4. Cooled CCD camera.

Thermal imaging

Similar in application to infra-red CCTV, thermal imaging cameras detect emissions from the viewed area in an extremely narrow range of the electromagnetic spectrum. They are less affected by ambient temperature and lighting, and their operation should be extremely resistant to adverse weather conditions. Coupled with image processing, they would be very effective in detecting objects that radiate heat or absorb heat at different rates.

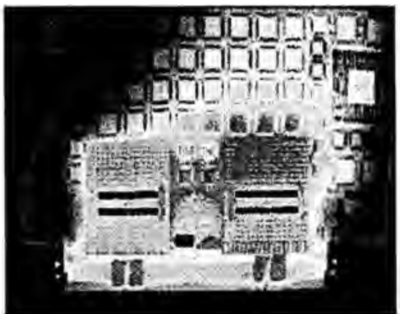

Figure 5. Thermal image.

Thermal imaging may be expensive to implement due to the high cost of top-of-the-range super-cooled cameras. For example liquid nitrogen cooled cameras, as might be used by the Fire Service, may cost up to £75,000 each; although normal temperature cameras, of slightly lower specification, are available for around £25,000 and may be acceptable for technology monitoring applications.

Figure 6. Thermal imaging software ©Compix.

Similar to infra-red detection, line of sight laser detection of obstructions and objects may be expensive and vulnerable to vandalism or theft. There may also be health and safety risks with the use of lasers in public. It is suggested that any technology that introduces new or increased risks to users is unlikely to be acceptable notwithstanding the HMRI's wish not to stifle innovation. Hence the use of lasers at level crossings may be difficult to support in the required safety case.

Ultra-sonic

Although security products and road traffic monitoring systems using ultra-sonic detection exist, this technology is considered to be inadequate in the detection of static obstructions and mitigation of key hazards. The system would need to discriminate between the constant noise and traffic during general traffic use and the noise generated by obstructions when under relatively high ambient noise conditions, e.g. when the barriers are lowering, audible alarms, vehicle engines etc.

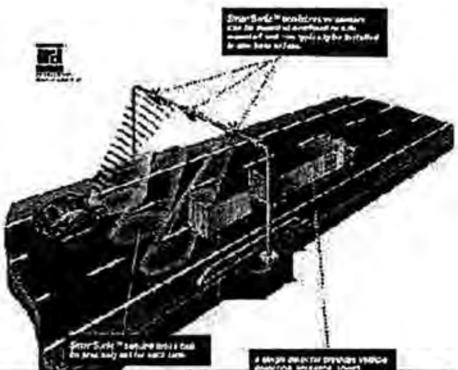

Figure 7. Ultra-sonic vehicle detection © Control Technologies.

Risks

Following a preliminary hazard identification and risk assessment, a risk matrix could be complied that assesses the ability of individual monitoring technologies to mitigate against typical level crossing hazards. The table below shows an example of how this might be achieved. It should be noted however that, in the absence of confirmed equipment for each category of technology, the mitigation would be subject to further review following further development.

		Technology/hazard mitigation							
No.	**Hazard**	**Human**	**Road-loop**	**Infra-red**	**Thermal Imaging**	**Radar**	**Image Processing**	**Ultrasonic**	**Laser**
1	Non-metallic object capable of derailment falls off vehicle onto crossing.	Maybe	No	Maybe	Yes	Yes	Yes	Maybe	Maybe
2	Pram trapped on the crossing.	Yes	No	Yes	Yes	Yes	Yes	Maybe	Maybe
3	Harmful electromagnetic radiation to pedestrians.	N/a	Maybe	Maybe	Maybe	Maybe	Maybe	Maybe	Maybe

Where hazard mitigation is denoted as "Maybe", this indicates either partial ability to mitigate by the signaller or unknown ability to mitigate until the exact technology is confirmed. Where hazard mitigation is denoted "N/a", this indicates that the hazard is not considered applicable because it is automatically monitored by the level crossing interlocking or it does not exist under current arrangements, e.g. a technology monitoring hazard.

The following are examples of functional requirements for level crossing technology monitoring that might be derived from a preliminary hazard identification and risk assessment:

Detection of large animals capable of causing derailment, e.g. cow, horse etc.

Detection of children on the crossing

Detection of vehicles on the crossing

Detection of inanimate objects capable of causing derailment

Detection in all weather and environments

Ability to discern between trivial obstructions and safety-threatening obstructions

High reliability

Built-in-testing to monitor deterioration of monitoring performance

Implementation

To achieve the necessary levels of reliability, integrity and availability it is suggested that a combination of technologies would be required to satisfy safety requirements and demonstrate that risks are no greater than that for the existing human monitoring system. It is envisaged that a combination of radar detection, thermal imaging or normal bandwidth CCTV image processing, coupled with road loop detection would meet the necessary performance requirements. It is acknowledged many permutations of operation are feasible, including voting, series detection and parallel detection, and that detailed system hazard analysis would be required to establish the best configuration for integrity and reliability.

To allow for minimal monitoring operation, it is suggested that the standard MCB-CCTV circuits (reference Railway Group Standard GK/RT0268) would need to be modified. Activation (buttons), indications, and system functions could all be achieved with relay logic. These relays could be integrated with the standard level crossing circuits to achieve the desired operational results.

Safety strategy

Accidents that might occur at level crossings could fall into the categories of *derailment*, *death of people or person on crossing*, *damage to train*, and *animal killed*. It is suggested that fault trees could be developed using these categories as top events and the faults that could lead to *derailment* might be laid out in a fault tree as shown overleaf.

Any safety case for the implementation of minimal monitoring technology would need to overcome (and not prejudice) the already low risk presented by existing CCTV MCB level crossings and robustly demonstrate that accidents, as illustrated in the fault tree overleaf, would effectively never occur through equipment failure alone.

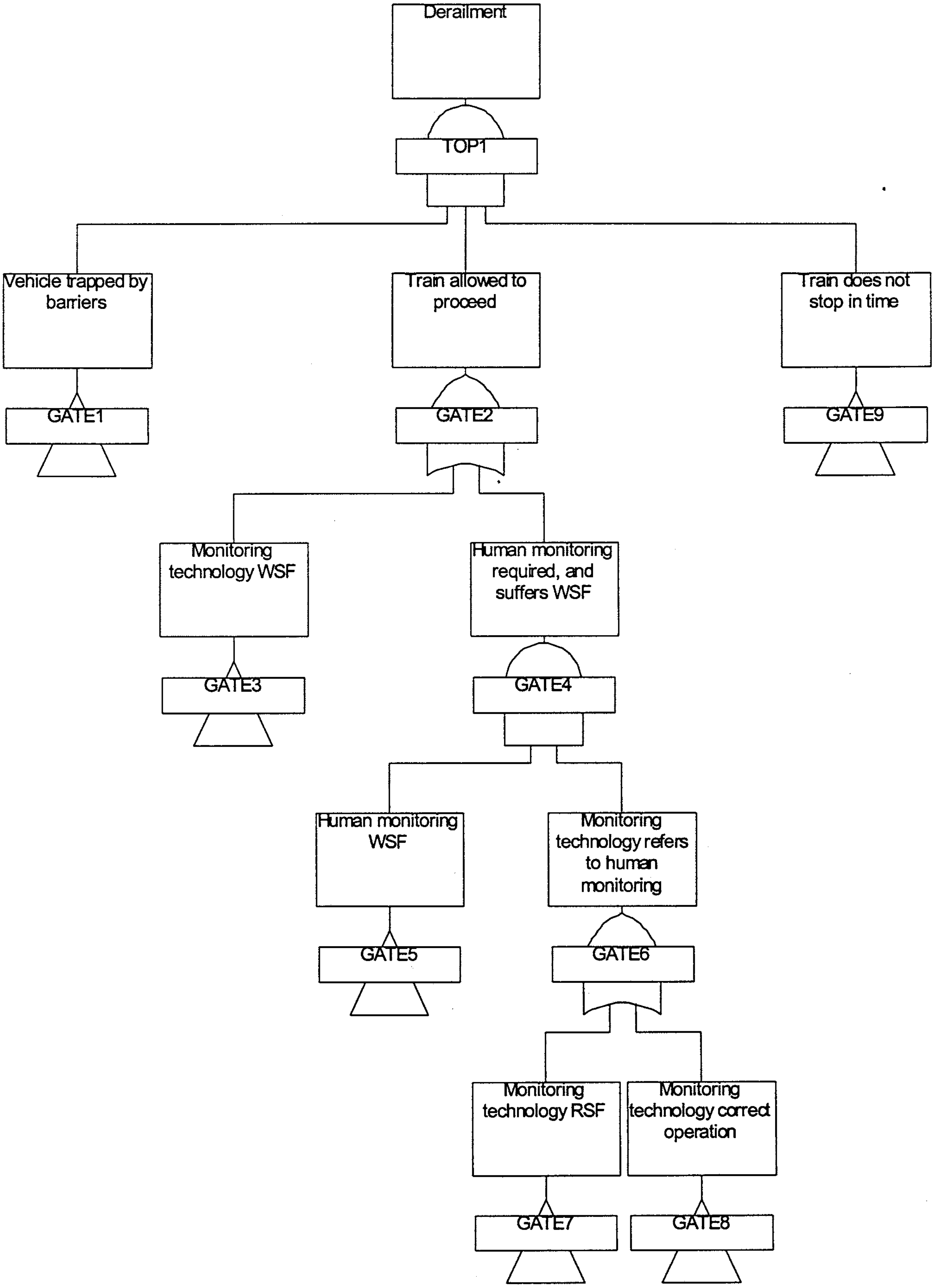

Figure 8. Fault tree for *derailment*.

Conclusions

The concept of risk reduction by the introduction of technology to monitor the level crossing area is considered feasible from a technology perspective and from a system perspective. Some of the hazards that need mitigation were identified with resultant safety and monitoring criteria being identified in outline form. All of these outline criteria could be met with technology monitoring, with further work being required on detailed specification of criteria. A system safety plan and a safety case are the documents into which it is envisaged such information would be placed.

The application of minimal monitoring technology to standard level crossings has been considered and, it is suggested, presents no particular technical problems. It is envisaged that a combination of radar detection, thermal imaging or normal bandwidth CCTV image processing, coupled with road loop detection might provide the necessary reliability and integrity to satisfy safety requirements. Activation (buttons), indication, and system functions could all be achieved with relay logic and these relays could be integrated with the standard level crossing circuits to achieve the desired operational results.

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CONTROL SYSTEMS

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Avoidance of collision in most types of transport is basically up to the driver of the vehicle. On the railway the driver can indeed stop the train but is not capable of avoiding another train because of the very constraints that make railways so efficient. The routing of a train is also not under his control. A train is a long heavy vehicle capable of carrying a large number of people at high speed and it is therefore essential that the driver is instructed what to do by external signalling in a safe manner.

The development of branches in the railway network required junctions controlled by points in order to route trains from one destination to several different destinations. The control of these alternative routes resulted in signal boxes which were, and many still are, in areas close to a junction or station where the points and signals were controlled by rods and wires. The Signalmen controlled where the train went by setting a route. This basically involved setting points to the required lie, and then taking the controlling red signal off to green. This was the second level of control which determined where a train goes. Signal control also allows a signaller to stop a train under disturbed situations in order to give priority to another train at a junction. The lever that controlled a points setting and that which clears the signal are denied setting in an unsafe manner mechanically. The first level of safety control is carried out by the lever frame itself by mechanical interlocking so that certain levers cannot be moved "out" of the frame when other levers are already out of the frame i.e. set.

Signal boxes of this nature are often close to stations and may also control a level crossing. Some boxes are at junctions not near a station. A sobering thought is that near the end of the 20^{th} century there are still a very large number of lever frame boxes still in service in the UK..

The next major step in control of rail traffic came with the use of electricity in power signal boxes (PSBs) where colour light signals and motorised points replace the rods and wires of the mechanical lever frame. The levers were replaced with push/pull buttons, or switches, and the state of the track indicated by lamps. Indications on a panel display show track route set and occupancy, the lie of points, signal states and so on. The safety of the lever frame was replaced by fail safe relay interlockings. Remote interlockings became possible by means of electronic equipment, that connect the outstation to the office end by telecommunication links. These PSBs with remote interlockings can cover a wide Control area. Obviously trains are outside the view of the signalmen in such a box and therefore it was essential for Train Describers (TDs) to be introduced to give the signalmen information on where the trains were over the whole area. TDs brought about the first introduction of computers into signal boxes in the late 60's.

Control Centres require a number of signalmen each with his own area of control. Controls for route setting and swinging points were either mounted directly with the indication lamps on mimic panels in smaller installations, or on control consoles on large installations such as London Bridge. Train describer displays were made in small "windows" in the panel and certain regions of BR started to use VDU maps (slide) in order to display TD information in mimic form to the signallers and to the regulators. This form of Control System has been widely installed. Computer based train describers (TDs) form an important part of this system, but do not directly control train movements.

The regulatory function is the third level of control, namely the management of the Control area by controlling the priority of trains under disturbed conditions, and reacting to changes such as cancellations. Signallers in smaller boxes and Regulators in larger ones, work from timetable information in order to route trains to the appropriate destination together with Carriage working notices for multiple station platform allocations. The BR CIF interface now provides this data by nightly updates for all users which include the ARS function of which more later.

A Relay interlocking, using the BR approved relays, took up a lot of space in a signal box or remote control room. BR Research in co-operation with the two major manufacturers at the time, GEC and Westinghouse, designed and implemented a standard interlocking based on computing techniques and other solid state components. The first of these Solid State Interlockings (SSI) was installed in Leamington Spa in 1985. Thus the first and safety level of control was taken over by computer based equipment. Three independent computers compared every action, if all three agreed the action is taken. If two agree the third is shut down; if none agree all signals are automatically set to red. The common software in these computers was rigorously scrutinised by a number of different teams because of its vital nature, now known as Safety Integrity Level 4 (SIL4). SSIs have a common hardware architecture and are customised to an application by use of a database. The SSI uses distributed lineside equipment on safe communication links. Connection to the conventional control panels is by use of a Panel Multiplexer (PMux) which turns the dual serial input/output of an SSI into individual digital circuits to drive indications, and to receive signalling control actions.

About this time BR Research developed a Junction Optimising Technique (JOT) which was subsequently extended into a full Automatic Route Setting system in conjunction with the Integrated Electronic Control Centre (IECC) that they were developing. This ARS system, effectively replaces the Signallers i.e. the second level of control became an automatic system driven from a combination of timetable and train movements that minimise a trains time to cross a complex station area. Signallers must be present for emergency working that is not catered for by the ARS, but the ARS can run the rest of the railway while the few signallers left concentrate on the emergency. It has clever algorithms that replicate how a signaller controls complex junctions. It has been a very successful system.

The IECC mentioned above was originally called a "Glass Panel", because it was a completely VDU screen based system doing away with the large Mimic Main Panels and facilitating the coupling of the ARS to signalling systems. This development was carried out in the early 80s; the first IECC was installed at Liverpool Street Station in 1989. Most of the IECC systems installed are in combination with SSI interlockings, however the coupling to relay interlockings has been used.

The Signaller uses the colour mimic map screens to monitor the railway, which include the full TD functions that show the location of all trains. There are two types of mimic screen namely Overview and Detail. HSE (the late HMRI) requires that a Signaller must have in view all the area of his control at all times. The Detail screens are used for carrying out control actions using a trackerball or keyboard, the appropriate Detail screen being called up for action. A route is set by targeting with the trackerball cursor firstly the entrance signal and then the exit. Other functions are carried out in the graphics in combination with menu keys.

The original IECC was developed in the pre PC era. A modern VDU based signalling control system uses PC technology for the workstation display system, thus providing great flexibility of the number of screens available for display. The control system for the Vaughan Modular Control System is essentially the company's standard ST1346 TD extended by signalling workstations to cater for the Railtrack required signalling control functions as now defined in the Line standard RT/E/S/1006 "Requirement Specification for a VDU based Signalling Control System".

Other factors than the signalling can affect the operation of trains. Much of the UK system is electrified but control of the electrical network is a normally relatively slow moving affair. However, total failures can occur at any time, and maintenance needs may require deliberate switching off of power. This latter is hopefully plannable.

A few railway authorities have coupled the state of the electrical supply into the signalling control system in order to avoid an electric train being routed into an electrically dead section of track. This has happened, particularly in systems with Automatic Route Setting.

How best to couple the state of the power system into the signalling system is a debatable topic. A signalling mimic becomes very cluttered if one attempts to display traction sections on the essentially signalling maps. An alternative that has been suggested by one authority is to block (collar) automatically on failure of a power section those signals that lead into routes that are fed by the failed section or sections. This would cut out one level of thinking by a signaller under emergency conditions. If this is done it would be wise not wise to remove the blocking immediately power is detected on again. A reinstatement may be of short duration, whether due to automatic reclosing or to maintenance actions. This authority would insist that it is a conscious management decision to advise the system of power reinstatement for service.

Perhaps the next step is that taken by one of the Australian railway authorities to provide integrated workstations any of which can be used for signalling, power control and other functions.

I would define Control as an action with an immediate response. However the Network Management Centres of the future will effect control at the highest level using factors which determine which train runs on which pathway, with what make up, and with which staff, and so on. Systems at the Centre will carry out extensive performance monitoring and calculation. Planning of possessions will be there, and probably more. Perhaps a member of the audience will advise us later.

1,671 words

Safety Assurance in the UK Rail Transportation Industry

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Keywords: railways, rolling stock, signalling

Introduction

The restructuring and privatisation of the rail network, commencing in 1993 and completed in 1997, brought about major organisational, commercial, and legislative change. British Rail was replaced by some 52 separate companies, encompassing infrastructure ownership, passenger and freight train operations, rolling stock leasing, and various engineering and support activities. These companies when considered together are officially known as the Railway Group.

A key feature of the legislation supporting this change were the Railways (Safety Case) Regulations 1994 (ref. 1). These imposed a duty on those members of the Railway Group that operate trains and infrastructure to produce a Safety Case to demonstrate that they have adequate measures in place to ensure the safe conduct of their operations. The infrastructure owner, Railtrack PLC, has a key role to play in the assurance of safety on its network, and its own Safety Case, with supporting policies, standards, and objectives are cascaded to all members of the Railway Group.

As well as its own Safety Case (ref. 2), Railtrack publishes, on behalf of the Railway Group, an annual Safety Plan (ref. 3), which monitors safety performance and sets objectives for the coming year with the aim of achieving a continuous improvement in safety performance. In support of this Safety Plan, Railtrack operates, and applies to all members of the Railway Group and their contractors, a rigorous Safety Management System which employs modern techniques to ensure the proactive control of all risks associated with their activities.

The safety of the railway network is overseen and the legislation enforced by Her Majesty's Railway Inspectorate (HMRI), which forms part of the Government's Health and Safety Executive (HSE).

Engineering Safety Management

The safety legislation applies not only to railway operations, but also to the engineering systems and processes which support them. In particular, any new system, or significant change to an existing system, needs to be supported by its own Safety Case which must be endorsed by Railtrack before it can be accepted into service. Major changes also need individual approval by HMRI.

To support this System Safety Case process, Railtrack has developed an Engineering Safety Management System (ESMS) (ref. 4), commonly referred to as the "Yellow Book" (actually now 4 volumes). This lays down the required principles of safety management and gives guidance on suitable safety engineering processes and techniques. This is the area in which the authors have been actively involved, and which forms the basis for the remainder of this paper.

The ESMS is based upon the requirements of IEC 1508 (ref. 5) and prEN50126 (ref. 6). The key activities required are as follows:

- The preparation and approval of a comprehensive Safety Plan, demonstrating that a robust and rigorous process will be used throughout the development of the system to ensure that specified safety criteria will be achieved.
- The development of Safety Requirements based on a risk analysis of the system, and the incorporation into the design of such measures as may be required to meet the safety requirements.
- The preparation and endorsement of a Safety Case. The Safety Case provides the evidence in written form to show that all risks associated with the system are controlled to an acceptably safe level, the Safety Requirements have been met, and the processes described in the Safety Plan have been adhered to during the development.
- Independent assessment of the safety management and engineering processes.
- Provision for ongoing risk management by the use of a Hazard Log or similar tools.

Table 1 - Risk Tolerability Criteria

Risk of fatality per annum to:	Upper Limit of Tolerability	Broadly Acceptable Level of Tolerability
Individual Employee Risk (all trackside staff)	10^{-3}	10^{-6}
Individual Passenger Risk (regular commuter)	10^{-4}	10^{-6}
Individual Public Risk (railway neighbour)	10^{-4}	10^{-6}

Acceptance by Railtrack of Safety Cases for major developments in signalling and related systems is undertaken by a System Review Panel (SRP), and for traction and rolling stock developments by a Rolling Stock Acceptance Board (RSAB).

Risk Management

The backbone of the ESMS is Risk Management. The process employed is based on the demonstration that the risk to all exposed parties, including employees, passengers, and members of the public is As Low As Reasonably Practicable (ALARP).

Based on guidelines produced by the HSE, the railway has defined upper and lower limits of risk tolerability, in terms of risk of fatality per annum, as applied to railway employees, passengers, and the public. The figures adopted are shown in table 1. Further development of these figures is made in the Railway Group Annual Safety Plan (ref. 3) in respect of specific groups, e.g. users of grade crossings.

When considering the safety acceptability of any given part of the railway system, for example an individual train, or a signalling control system for a particular area, the guidance figures need to apportioned to that equipment in relation to the whole system. A risk analysis may then be performed on the system concerned, and compared with the apportioned target. However, the ALARP principle dictates that further risk mitigation measures be applied wherever practicable, i.e. to a point at which the cost of further mitigation measures exceeds any further safety benefit.

In order to evaluate this practicability, a "Value of Preventing a Fatality" (VPF) may be used. Using the UK Department of the Environment, Transport & Regions criteria currently used for the purposes of road transportation, the current Railway Group Safety Plan quotes a basic VPF of £0.95 million for individual fatalities, while VPFs of up to £2.65 million may be used when addressing measures which are near the upper limit of tolerability, or which reduce the potential for accidents involving many fatalities.

Risk Management Methodology

The methodology adopted for Risk Management, as currently advocated by the ESMS, involves a 7 stage process, as described below:

Stage 1 - Hazard Identification and Ranking: All hazards associated with the change are identified using a suitable structured method, usually involving a team of experts. Methods used include brainstorming, checklists, and Hazard and Operability Studies (HAZOPs). On completion of identification, an initial ranking of hazards and the consequent risks is undertaken typically using a ranking table which estimates hazard rank on the basis of estimated hazard severity and frequency. It should be noted that this ranking is used to give an initial estimate of the relative severities only, and not to assess the tolerability of the hazard.

Stage 2: Causal Analysis: This stage involves the deduction of the various causes which may give rise to the identified hazards, and estimation the frequency of such events. From these, the frequency of the hazards can be identified, typically by the use of Fault Tree Analysis.

Stage 3: Consequence Analysis: This stage involves taking each hazard forward, typically by means of an Event Tree, through a range of intermediate conditions which may exist, to the final consequences which may result.

Stage 4: Loss Analysis: Having estimated the frequency of possible hazard consequences, a loss value, both in terms of death or personal injury to each of the exposed groups of people and in terms of potential commercial loss, can be calculated for each consequence.

Stage 5: Options Analysis: For each significant hazard, various potential mitigation measures are proposed, and the effectiveness and cost of each measure estimated.

Stage 6: Impact Analysis: The effectiveness of each mitigation measure proposed is subjected to a safety cost benefit analysis. It should be noted that while the scope of the benefits of this analysis are constrained to safety issues, any commercial benefits of the mitigation measures proposed may be set against the costs involved. The justifiability of the proposed mitigation measures in terms of ALARP can then be judged. If necessary, some of the processes above may need to be repeated until adequate risk mitigation is achieved.

Stage 7: Demonstration of ALARP and Compliance: By drawing on the evidence obtained above, an argument is presented that the risks associated with the development are both within the apportioned risk benchmarks and ALARP.

Example 1- A Signalling Control System

This example relates to the preparation of a safety case for a new VDU based Signalling Control System. The context of this system is illustrated in figure 1.

The control system provides a display for the signaller, based on information supplied by the interlocking, and accepts commands from the signaller to control the interlocking. All actions are subject to the over-riding control of the interlocking, which is itself a high integrity safety-critical system.

Traditional railway safety management methods would regard the control system as "non-vital", and therefore not subject to detailed safety analysis. However, the adoption of the Engineering Safety Management system has caused such systems to be included in the scope of safety management activities.

Hazard Analysis revealed the following principal hazards associated with the system:

- A signal not being set to red when required to do so (this applies to the signaller intentionally setting a signal to red, as opposed to the condition being applied by the interlocking).
- A train being sent down a route on which it is not permitted (the interlocking does not provide protection against this).
- A train being erroneously verbally authorised to pass a red signal by the signaller.
- A train being erroneously verbally authorised to proceed during manual working (manual working is used when some failure of part of the railway prevents normal operation; in these circumstances much greater reliance is placed on the ability of the signaller to interpret the display correctly).
- A train being erroneously authorised to enter a section of track where on-track staff are working (protection against such movements is provided within the control system rather than the interlocking).
- An electric train being erroneously authorised to enter a section to which an electrical isolation has been applied (the train may "bridge" the isolation, creating the possibility of electrocution of staff working in the isolated area).
- The imposition of manual working on account of failure of the control system (manual working is inherently less safe than normal working. This hazard relates to the general hazards related to manual working, and not those attributable specifically to the control system, which are dealt with separately above).

To evaluate the tolerability of the above risks, a spreadsheet was constructed to apportion the Railtrack risk targets to the area covered by a typical control system, and further subdivided by exposed groups as follows:

- Passengers
- Train Crew
- On-track Maintenance Staff

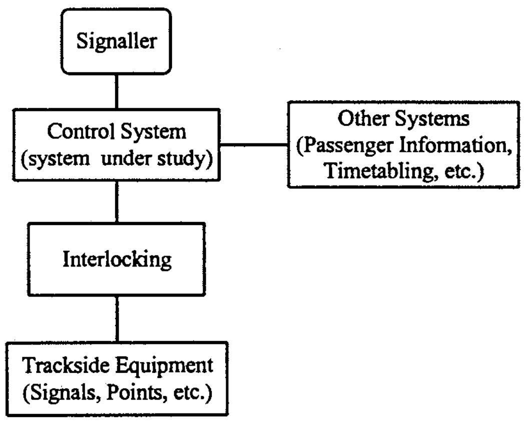

Figure 1- Context Diagram of Control System

- Public at Grade Crossings (this was recognised as a particular exposed group in consideration of the system under study)
- Other members of the public.

Causal and consequence analysis identified that all the identified risks were within the apportioned targets for all exposed groups, with the last mentioned risk (imposition of manual working) being negligible (this being attributable to the high reliability designed into the system). The remainder of the risks were shown to be in the tolerable region, and options and impact analyses were applied to demonstrate ALARP.

The most significant factor to emerge from the analyses was that the dominant risk factor was human error, i.e. the risk of the signaller misreading the display and/or making an incorrect judgement. The principal mitigation measure in achieving ALARP was therefore related to improving the training of signallers, rather than any further improvement of the system hardware or software design. A further justifiable mitigation measure was identified in respect of the testing of the controls protecting grade crossings. The risks associated with the remainder of the system design were demonstrated to be ALARP without further mitigation.

An interesting feature of this analysis is that the previous simplistic safety analysis method on the basis of "vital" and "non-vital" systems is to a large degree confirmed, in that, provided that it has adequate availability, the hardware and software of the Signalling Control System do not significantly impact on the safety of the railway when under manual control, relative to the safety-critical protection provided by the interlocking. (The addition of automatic route setting systems leads to different results from this analysis, but for the purposes of this paper is excluded from the above example.)

Example 2 - Traction & Rolling Stock

Since 1993 formal safety cases have had to be produced for the introduction of, or change to, locomotives and rolling stock. The safety cases have evolved over the past four years from using basic engineering judgement and now follow the ESMS. However, it should be noted that where possible engineering arguments are still the best route to closing out hazards.

A locomotive or rolling stock safety case is usually split into three parts:

- Civil Engineering, which investigates the train loading gauge and kinematic envelope, platform clearances, etc., to ensure that there is no possibility of the train hitting signalling equipment or lineside structures. Failures such as collapsed suspension are taken into consideration.
- Operations, which assesses effects of passenger crush loading, passenger ingress and egress, train evacuation in an emergency, fire precautions, brake performance, etc.
- Electrical Engineering and Control Systems (EE&CS), which covers all electrical systems on the train, including the traction system, and other critical control systems such as the wheel slip/slide controls and sliding door control.

Historically it has been relatively straightforward to produce robust safety arguments for both the Civil Engineering and Operational issues without resorting to Quantified Risk Analysis. All the hazards are well understood and many of the critical design elements of the train have previously been proven in service.

The area where most attention has been focused has been the EE&CS issues, in particular the traction and signalling interface. It has proven to be very difficult, in certain instances, to demonstrate conclusively that electric trains are compatible with the installed signalling system.

Signalling interlocking systems rely on train position information. This information is conventionally derived using track circuits. In its simplest form a track circuit comprises a voltage source at one end of an electrically isolated track section and a relay at the other end. The voltage source provides power to the relay via the rails. When a train enters the section, its axles short circuit the rails together, removing power from the relay. The relay contacts open informing the interlocking that a train has entered the track section; in signalling terms the track circuit is 'occupied'. It is fail safe because loss of the voltage source will indicate occupied, and the relays are specifically designed to fail with contacts open.

The traction interference current from electric trains can, under certain circumstances, appear to emulate the voltage source supplying the track circuit relay when the train is in the track section. This will cause the track section to register 'clear' (i.e. no train in section) and could cause the interlocking to allow another train into the same section.

This type of hazard was identified for operation of an Electrical Multiple Unit (EMU) on the a.c. electrified railway. Traction interference could cause wrong side failure of the d.c. driven track circuits (i.e. the track circuit indicates track clear when a train is in section) fitted to the route. This is an interesting example because it was shown by a process of theoretical analysis and mathematical modelling that a phenomenon known as transformer inrush would cause d.c. track circuits of a certain length to transiently register clear when the track section was occupied.

Transformer inrush is a large asymmetric current transient caused when an a.c. voltage is applied to a transformer, as illustrated in figure 2. Its magnitude is dependent on the transformer design and the point on the a.c. waveform at which switching occurs. This is a function of all electric trains and had never been seen to result in an unsafe condition before, but to close the hazard it was necessary to demonstrate formally why transformer inrush did not present an unacceptable risk.

The risk assessment process used a number of mathematical and statistical techniques to show that the probability of transformer inrush leading to a hazard was very low. The methodology was structured as follows:

- Determination of the length of track section susceptible to specific levels of transformer inrush transients (this had a number of dependencies, including current flows, number of tracks for current sharing, and position of electrification system components);
- Determination of a probabilistic algorithm for defining the level of transformer inrush (assuming that under fault conditions power could be randomly switched to the transformer at any point on the a.c. waveform);
- Use of Monte Carlo simulation to calculate the probability of a transformer inrush event causing the d.c. track circuit relay to register clear instead of occupied (wrong side failure);
- Causal analysis to calculate the probability of the track circuit wrong side failure leading to a train collision or derailment;
- Determination of the number of equivalent fatalities resulting from the train collision or derailment, i.e. loss analysis;
- Use of options analysis to identify what potential changes to the train or the signalling infrastructure could be undertaken to reduce the risk;
- Use of impact analysis to assess the costs of risk reduction (in terms of VPF) to assess whether any of the identified options were reasonably practicable to implement.

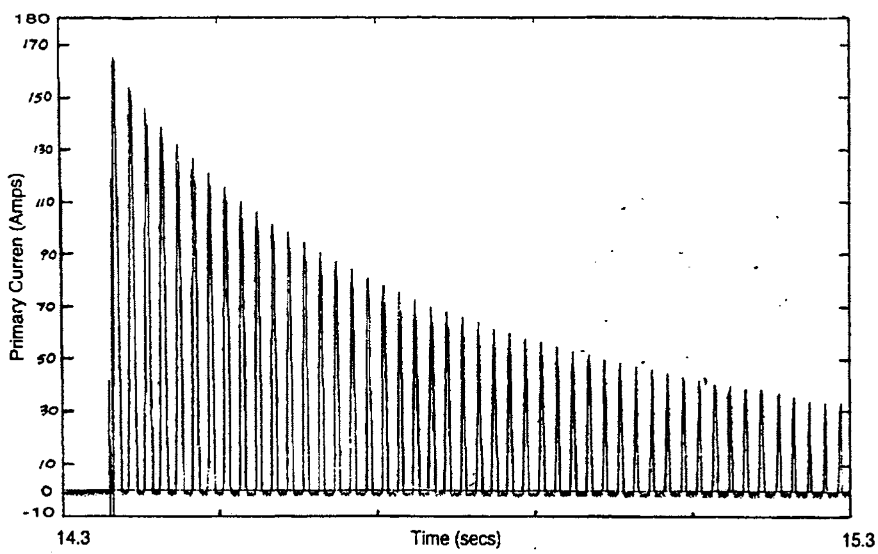

Figure 2. Typical Transformer Inrush Waveform

As well as demonstrating that the risk was very low, it was also shown that unless changes to reduce levels of transformer inrush or reduce track circuit susceptibility could be achieved for only tens of pounds, then the risk was ALARP. This was a very comforting conclusion considering that trains had been operating with this risk for nearly 50 years!

The Impact of Change

As can be imagined, such a fundamental restructuring of a national industry combined with an evolving safety philosophy has not been without its problems. In the wider context, perceived best practice has also been evolving rapidly. The production of product safety cases can be an expensive operation. In particular, careful judgement is needed to determine the level and depth of safety analysis required to achieve safety acceptance while keeping costs within reasonable bounds. Another challenge has been the reasonable apportionment of safety targets to individual parts of the railway system and to individual systems. It has certainly been a learning experience for both those involved in producing safety cases and those charged with accepting them. This has lead in many cases to the presentation and acceptance of interim safety cases with limited time span while further safety assurance work is done. However, the process is now working effectively, and safety cases are being produced with increasing degrees of confidence of acceptability.

Future Trends

As suppliers accumulate greater numbers of product safety acceptances, the process will become easier, partly from experience, but also from the accumulation of libraries of evidence that can be used in support of the justification of risk assessment, apportionment, and the demonstration of ALARP of similar products and systems. While the production of product safety cases is never likely to become a routine exercise, the uncertainties involved will certainly become less.

Conclusions

The changes in the safety management methods in the UK rail transportation industry have been brought about partly by changing safety legislation and by the general improvement of safety engineering techniques, but particularly by the need to clearly apportion and control risks in order to demonstrate safety in an industry which has undergone major organisational, legal, and commercial change. The changes have not been easy, but significant successes are now being achieved, and experience with application of the new methods will lead to even greater safety in future. Use of these methods has also served to confirm that in many cases the less formalised methods used previously have left us with an inherited system that is basically safe.

The future is perhaps best summarised by quoting Sir Robert Horton, the Chairman of Railtrack, in the Railway Group Safety plan for 1998/9:

> "Safety is, and will continue to be, the industry's highest priority and we must pursue the highest standards of safety to further improve the performance which makes rail the safest form of land transport in the UK."

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Disclaimer

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SCHEME DESIGN

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THE PURPOSE OF RAILWAY SIGNALLING

The purpose of any railway signalling system is:

a) To lock the position of the points and hold the routes that have been set;
b) To maintain a safe distance between two trains running in the same direction on the same track;
c) To protect trains at converging junctions and where there are conflicting movements;
d) To supervise the passage of trains according to the headway requirements and line speeds.

Many signalling systems around the world satisfy these criteria, including mixed traffic mainline systems, metro or rapid transit systems. The information that is transferred to the driver is usually by means of lineside signals displaying signal aspects or via cab signalling displays in the driver's cab. The information transferred to the driver can be in two forms; one which informs the driver of the route for which the train has been signalled and relies on the driver to control the speed of the train to complete this route safely, or secondly, by speed information that informs the driver what speed the train has permission for but not the route that the train is going to follow. These two fundamental types of system can be intermixed where both speed and route information is required by the driver.

The majority of the mainline signalling systems in Great Britain use signal aspects to convey route information to the driver.

The changes required to signalling systems over the years have resulted in advancement of technology for the controlling systems, the introduction of new more efficient motive power, increased customer requirements, and experience gained from the occasional incident.

The personnel that design, install, test, commission and maintain the signalling systems are assessed for competency to perform the functions that they are request to undertake. The changes required to the signalling are controlled with version control and traceability measures and take place within a management system compliant with BS EN ISO9001, or similar. These measures control the signalling design from scheme conception through to final commissioning and final records.

CAPACITY OF THE SIGNALLING SYSTEM

A signalling system has to be designed around the operational requirements of the client. This information usually is included in an Outline Project Specification and as a bare minimum should include:

- Types of rolling stock and braking characteristics
- Headway requirements in time
- Station dwell times
- Lengths of trains

An example would be for an operator to ask for a service of trains to be run at 3-minute intervals non-stop at speeds of 60 mile/h or a stopping service of trains at 5-minute intervals. The signalling system must be designed so that it can provide a theoretical headway, which is an improvement than the required operating headway. A margin must be included to cover variations including driving techniques, tractive power differences and train loading. If the signalling system has to be designed for mixed traffic with differing performance and braking distances, then the worst case scenario would be the constraining factor.

It is therefore essential to know the required capacity of the signalling system. This can be expressed in terms of the headway.

Headway

The headway of the system is the minimum spacing between two trains so that the following train can safely maintain identical speeds to the first train. Headways can be expressed in terms of time or distance, but the headway time is the significant term as it can be related to a system capacity.

Figs. 1 and 2 show the elements that make up the headways of a three and four aspect signalling system respectively. These figures show the headways of the two trains running at a constant speed on an isolated section of plain line. If train A is going to maintain its constant speed and hence its headway behind train B it must sight all signals at green otherwise the driver will have to reduce the train speed and the headway will not be maintained. In considering a three aspect signalling system as depicted in Fig 1 the tail of train B clearing the overlap point of signal 3, will cause signal 2 to change from red to yellow and signal 3 to change from yellow to green. If at that point in time train A sights signal 1, it will then be running at minimum headway behind train B.

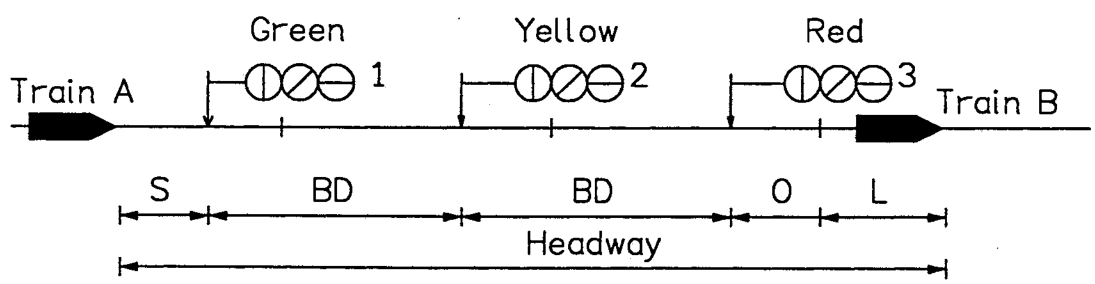


FIGURE 1. Headway of a Three Aspect Signalling System

Similarly in the case of a four aspect signalling system, as depicted in Fig 2, if as train A sights signal 1, it changes aspect from double yellow to green (as a result of train B clearing the overlap of signal 4), then it will be running at minimum headway. The minimum headway with a four aspect system is thus shown to be less than with a three aspect system.

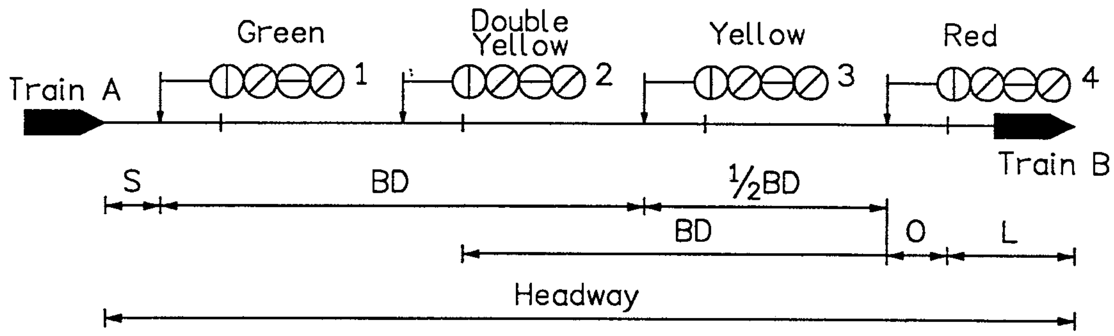


FIGURE 2. Headway of a Four Aspect Signalling System

In practice signal spacing can vary from section to section and when related to train speeds it is possible to identify critical sections.

The headway around station areas is critical in the smooth operation of the railway. Station dwell times combined with the time required to enter and depart the station are very important. If the protecting signal for station platform is too far away from the station, the station re-occupancy time would be to excessive and constrain the headway.

<u>Elements of Headway</u>

Before considering headways as a whole, the elements that make up headways should be considered. These are: -

<u>Sighting Distance (S)</u>

Although adequate braking distance is allowed from the first cautionary signal to a stop signal it is generally recognised that a driver will take some action to reduce his speed at a point before a cautionary signal rather than at the signal itself.

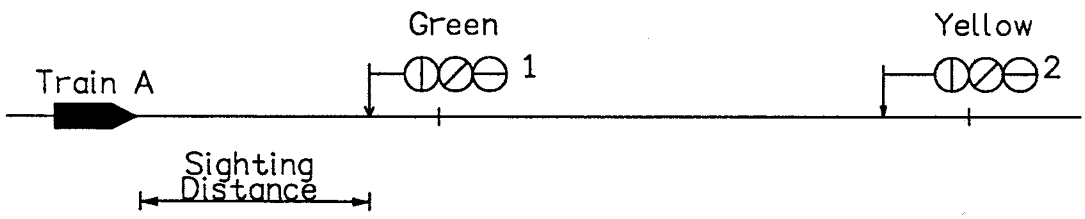


FIGURE 3. Sighting Distance From The Signal

This point is known as the sighting point and it is at sighting distance from the warning signal. Where signals can be seen for a considerable distance the sighting point is not necessarily the point at which a driver first sees the signal. The point at which the driver takes first action varies from driver to driver and from railway line to railway line. On those lines where drivers are used to running trains on proceed aspects other than green, this sighting point is often close to the signal. For theoretical headway purposes a sighting distance related to time is the best figure to use. A time of 10 seconds is commonly used although a distance in the order of 300 yards, is sometimes used for trains in the speed range 60-90 mile/h particularly when the Advanced Warning System (AWS) which transfers information to the driver of the approaching signal aspect is positioned at 200 yards from the signal. The two figures are comparable.

Braking Distance (BD)

The purpose of any cautionary signal is to give adequate warning for a train to stop at a stop signal. For any stop signal this means that its warning signal(s) has to be placed far enough back for any train travelling at its maximum allowable speed to be able to stop at that stop signal with the use of a normal braking application (see Fig 4). This distance is referred to as the Service Braking Distance and can vary with factors such as gradient, speed and braking characteristics of a train eg. Vacuum brake, air brake, and any partially braked trains.

A full brake application in case of an emergency will bring a train to a stand in a much shorter distance but such a brake application is not desirable in normal service conditions.

It is found that the braking distance varies approximately with the square of the speed. There are other factors that are allowed for. These are: -

(a) Variations in weather conditions;

(b) Driver's reaction times to a warning;

(c) A driver's slight misjudgement of brake application;

(d) System reaction time to a brake application, i.e., how long it takes for the brakes to come on fully after a brake application;

(e) Variations in a standard braking system from train to train, e.g., as a result of normal wear in the equipment.

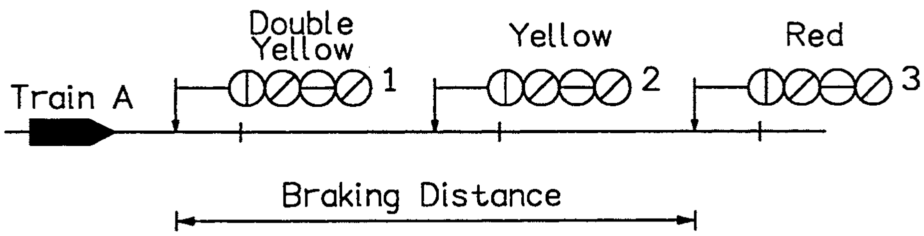


FIGURE 4. Braking Distance To The Stop Signal

Overlaps (O)

Overlaps are used to provide a small safety margin against the possible overrun of a signal. They are also used to guarantee a space interval between two trains. This means that it is not possible to clear the signal in rear until the tail of a train has cleared a point some distance beyond the next signal. The standard overlaps used on many mainline railways are 200 yards, but these can be reduced in very exceptional circumstances and demonstrate the safety with the use of risk assessment.

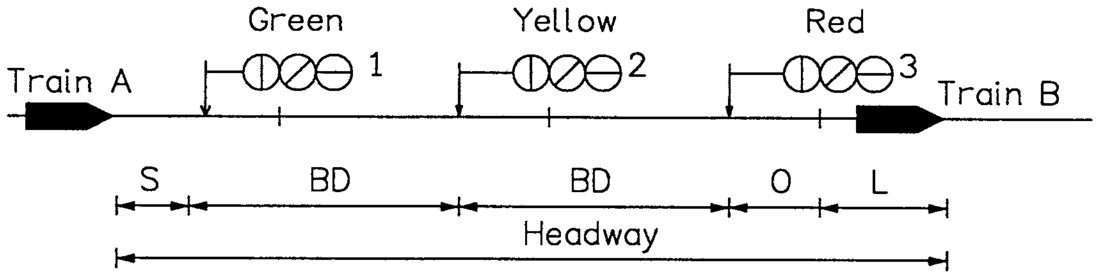
Train Length (L)

The last factor in the headway of a given line is the maximum length of trains using this line. Train lengths do not normally have a very significant effect on headways unless long trains are in use, but nevertheless it must be taken into consideration.

Headways of three and four aspect Signalling Systems

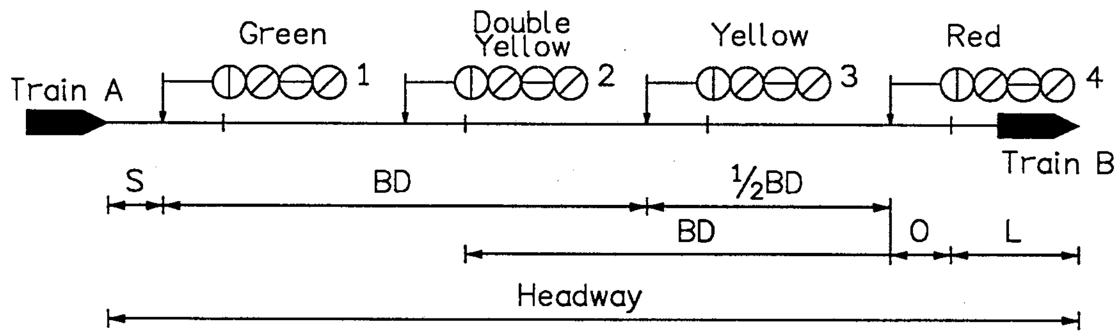
Minimum Headway Distance for a three aspect signalling system H_3

$$H_3 = S + 2BD + O + L$$



and Minimum Headway Distance for a four aspect signalling system H_4 are

$$H_4 = S + 1.5BD + O + L$$



Where:

S is the Sighting Distance
BD is the service Braking Distance for the maximum line speed
O is the overlap
L is the train length

A distance, as such, is of little value to an operator who wishes to know how frequently he may run trains.

Thus at a train speed of V the headway times of t_3 and t_4 for three aspect and four aspect signalling systems respectively are as follows: -

$$t_3 = \frac{1}{V}(S + 2BD + O + L)$$

$$t_4 = \frac{1}{V}\left(S + \frac{3}{2}BD + O + L\right)$$

Where V is the speed of the train in feet per second.

i.e. $10mph = \frac{10x1760x3}{60x60} = \frac{52800}{3600} = 14.666 feetper \sec$

The headway of a two aspect signalling system is dependent upon the spacing of the stop signal aspects, which is usually constrained by the headway requirements, and the areas of conflictions including junctions and stations.

On a 3 aspect signalling system with a maximum line speed of 40 mile/h the operating department require a 120 sec minimum headway. With the following additional information:

Sighting Distance 300 yards
Maximum Train Length 200 yards

Using the formula for the 3 aspect Headway calculation the Signal spacing requirement can be determined.

$$120 \sec = \frac{900 + 2BD + 300 + 600}{58.666}$$

$$(120x58.666) - 900 - 300 - 600 = 2BD$$

$$2BD = 5240$$

$$\therefore BD = \frac{5240}{2} = 2620 feet = 873 yards$$

This measurement will be the maximum distance that the signals can be spaced along the stretch of line concerned. The braking distance required by the particular rolling stock can then be checked against the relevant braking curve and the average gradient between the first cautionary signal and the stop signal.

If the average gradient between two signals was in excess of 1: 45 falling then a 4 Aspect signal sequence may be required to give the required Headway time, because the steep gradient would place the signals further apart and therefore the Headway times would be increased.

Excessive signal spacing distances may contribute to a signal passed at danger (SPAD) and should be avoided. A general rule is that the maximum signal spacing should be 1.25BD on lines where the speed is less than 60 mile/h and 1.5BD on lines where the speed is greater than or equal to 60 mile/h. The signalling engineer will need to examine the signal spacing and determine if this rule can be relaxed depending on the linespeeds and understanding how the driver will control the train in normal and abnormal weather conditions. The conclusions may have to be supported by a risk assessment.

This base information is used to determine the signal positions on the scheme plan, but need to be re-calculated due to the gradients profile of the line so that braking distance is still maintained and that overbraking does not occur. The positioning of the signals will also need to consider the requirements for station working and junction strategies.

THE ART OF SIGNALLING

The signalling engineer needs to focus on the whole system and not only the signalling during development.

Placing signals on viaducts or in electrified neutral sections has serious implications on the operation of the railway.

The transition from different types of signalling needs to be seamless, to provide adequate information to the driver while maintaining the safety.

The signalling system needs to be flexible to the operator so that the trains can be efficiently and safely controlled during normal conditions or when the system is experiencing perturbations.

The information that is conveyed to the driver when approaching a junction or station needs to be functional so that the train can continue through the junction safely due to turnout speeds. Advanced warning of a diverging route may need to be conveyed to the driver so that the train can be controlled to stop at the junction signal. This is particularly important when a wrongly routed train would have serious implications on the operating service, e.g. sending an electrified train on to a non-electrified line.

The train crew may require additional indicators so that the train service can be operated efficiently and safely. The addition of banner signals due to poor sighting conditions at stations and overbridges is common. Indications at station platforms including Close Door (CD), Right Away (RA) and signal 'OFF' indicators assist the train crew in providing this service.

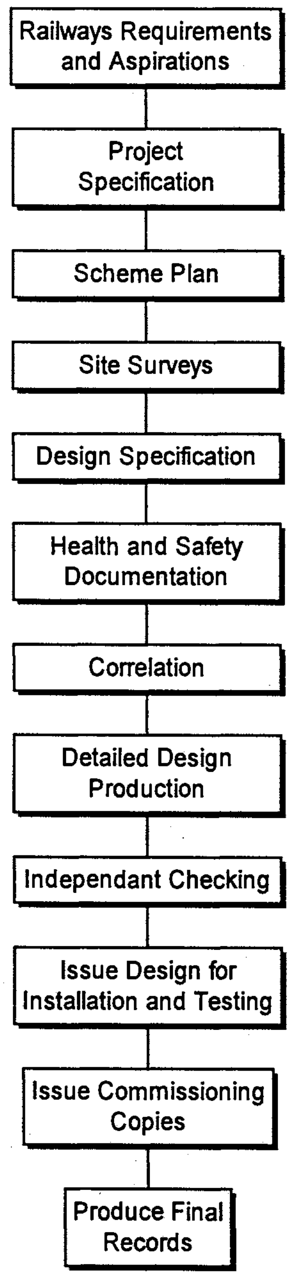
The signal engineer needs to remember how the system is going to be operated and maintained throughout the whole life of the system.

SIGNALLING DESIGN PROCESS

The process for signalling design needs to be included in a company quality system that can manage and develop the process. This quality system needs to manage more than just the detailed signalling design process but other functions including design standards, training and competency requirements, monitoring of the design and checking process, controlling the documentation, data storage and process issues.

The signalling design process has not changed drastically over the past years apart from the addition of more powerful computers allowing for modelling techniques to be developed and the addition of CAD. The systems that are being developed require the design process to be flexible enough to be able to manage, design and commission the variety of systems that are evolving.

A typical signalling design process can be explained using the following flow chart:



Railway Requirements and Aspirations

The project sponsor's requirements and aspirations need to be stated so that a Project Specification can be developed. The information that is required as a minimum is usually:

- A brief outline to the project;
- What type of operation service pattern that is required as a minimum;
- What type of signalling can be used (speed, route, cab signalling etc.);
- What type of electrification is to be employed.

It is an important part of any project to fully understand the railways requirements completely, so that a quality signalling system can be designed.

Signalling systems have to be designed to different operating practices, different standards which the signal engineer is required to use.

Project Specification

The project specification needs to take the railways requirements as the overall requirements, but expand them to provide a more definitive set of requirements including the operating practices and the required railway and statutory standards. The requirements within this specification need to be the true functional requirements and constraints that the designed system needs to implement.

Signalling Scheme Plan

The signalling scheme plan is developed from the client remit and the OPS and represents a graphical description of what is required to implement the client requirements. Generally it will show the changes required to the present signalling infrastructure, and provide a reference guide for the project team to implement the changes. The information that could be included in the finished signalling scheme plan is:

- Changes to existing signalling control areas;
- Where the new signals are required and what type;
- Which existing signals need to be altered or removed;
- Where and what type of train protection is required;
- Where changes to the track work are required or can be avoided;
- What type of train detection is to be used;
- What alterations are required to the present train detection system;
- What the line speeds are;
- What speed restrictions are imposed;
- The locality and type of operational communications that are required;
- Additional operational equipment that is required (TRTS, CD, RA, OFF plungers or indicators);
- The position and type of electrification equipment;
- The position and identity of fixed structures (Stations, Bridges, Tunnels);
- The position and details of the physical line gradients.

This list is only a guide and is not exhaustive.

The existing track layout and fixed structures are plotted accurately to a plan from a variety of sources including track plans, signal box diagrams and civil engineering diagrams. The diagram will show a scaled representation of the line with the main route running straight with point work drawn using curves. The addition of mileposts, gradient details and existing speed restrictions are included on the plan.

The existing signalling at the fringes of the signalling scheme will be required to be altered and should be shown on the plan. This can be shown in many ways, but the usual signalling colour convention is to shown equipment that is to be recovered in green and new equipment in red. It is not always required to show the signalling arrangements within the re-signalling boundaries when a complete renewal is required.

Once this initial plan has been finished, the new signalling can be plotted on to the signalling plan with reference to the relevant signalling principles and operation requirements kept in mind. The new signal positions will be one of the first additions to the plan but need to be placed intelligently to maintain the operational flexibility required by the signalling system and maintain the safety integrity using the appropriate signalling principles.

Once the scheme plan has been designed and checked, it is issued to the client and may require approval.

Site Surveys

Following the scheme plan production, site surveys are carried out to confirm what the project aspirations are and if they can actually be fulfilled on site. The major tasks of the site surveys will include:

- Signal Sighting Committee; to determine the most suitable and safe position and form of each signal and associated equipment including all types of signals and associated indicators and notice boards;
- Positioning of new equipment; including determining the space of new equipment in existing equipment housings, space for completely new equipment, providing additional information not contained in the OPS that will be required by the Design Specification.

Design Specification

The design specification is produced specifying the signalling works to a sufficient level to comply with the railways requirements and is usually generated from the project specification, information from the scheme plan and any site information from the site surveys.
The information that is contained in the design specification varies depending on the type, size and complexity of the project, but should consider the following:

- Project description and limits of work;
- Project timescales including all design deliverables;
- Risk assessments that may be required including any mitigation measures
- For new systems or major change in application of existing equipment, safety case or type approval need to be defined;
- Any specific information required on the existing system;
- Staff competency arrangements and resource planning;

- Interactions between different design functions, other disciplines and sub-contractors;
- The scope of correlation and remedial action required;
- Stagework and testing philosophies;
- Methodology of design production;
- Methodology of design checking and recording;
- Configuration control to all design and checking functions for all types of systems including software;
- Processes for design documentation submission for the various approval authorities;
- Other information and assumptions required including environmental considerations, train service operations, system interfaces, permissible speeds, headway, type of electrification, etc;
- Change control measures for all design functions including the client aspirations, the scheme plan and the design specification.

Health and Safety Documentation

If the project was in the United Kingdom and falls within the scope of the Construction (Design and Management) Regulations, then the design function will contribute to the production of the Health and Safety Plan and documentation submitted into the Health and Safety File.

Correlation

Correlation is carried out on copies of the current master drawings to determine that they correspond to the existing infrastructure. Any deficiencies are rectified before design work is allowed to proceed. The investigation will be carried out on the existing signalling equipment including the physical wiring, track circuit equipment including bonding, level crossings and associated equipment, control panels and mechanical locking.

Detailed Design Production

The detailed design can progress when the scheme plan and design specification have both been produced, checked, approved where required and the correlation investigation has been completed with all remedial action closed. The actual design work can be carried out on various mediums including CAD, but always by competent personnel in the particular design that is being carried out. The detailed design needs to fulfil the requirements from the design specification and all the relevant client and statutory standards, which could run into hundreds of standards.
The detailed design production needs to have in place procedures and configuration control measures to complete the design in a controlled manner. Copies of the master records are stored during the period of the design work including any stagework until the commissioning has been completed for security reasons.

Independent Checking

Once the designer is satisfied that the design is complete, it is then passed on to an independent person that is competent to check the design that has been carried out. The detailed design can be issued to the client for approval if required once the independent checker is satisfied that the design is:

- complete, clear, accurate and compliant with the clients requirements;
- all the relevant standards have been applied in their correct manner;
- that assumptions that have been made are justified;
- hazards that have been identified are properly controlled.

Issue Design for Construction

The detailed design can be issued for installation and testing once the design has been checked and approved by the client where required. Any alterations to the design after it has been issued are also completed in a controlled manner, throughout the installation and pre-testing and commissioning period.

Issue Commissioning Records

The records of the existing signalling system are updated to reflect the changes that have been commissioned.

Production of Final Records

The final process in the signalling design process is to update the source documentation to include any testing comments that have been identified during the testing procedures. This process confirms that the records that are returned correctly reflect the installed signalling that has been commissioned. Copies of the completed records are then distributed to the relevant disciplines including the maintenance contractor. The as built drawings are returned to the clients records custodian to update or replace the pervious records that were held for security reasons.

THE FUTURE OF THE SIGNALLING ENGINEER

Signalling systems are fast becoming integrated systems including signalling, electrification and telecommunications. The design process needs to move with the developing systems and not constrain the development.

The railways now require schemes to be developed with a wider application for delivering an operational railway for a more demanding service. The issues that now need to be addressed during the scheme design include:

- Electrification:- a more efficient distribution with re-generation;
- Rolling stock:- the introduction of various new traction packages, loading gauges, tilting trains, and varying train acceleration and braking performances;
- Information systems:- more integrated communications systems to all users of the system
- Operation:- maximum train paths through the system with the variable train types. Quick responses to system disruption to allow the train service to be maintained or run in a degraded mode and restored as soon as possible;
- Maintenance:- reduce the whole life costs, change to maintenance routines to suit the system requirements, introduce preventative maintenance techniques including early fault analysis.

The use of modelling techniques on the operation of the system under all conditions is a powerful design and verification tool and should be developed to provide real time signalling modelling.

The use of risk assessment techniques and junction modelling can provide a means of identifying areas of the design or of the system requirements that need to be amended.

The use of real time train path planning can greatly decrease the need for conflicting signalling moves, which increases the system safety and could be implemented more easily with the new integrated signalling or control systems that are now readily available.

The mainline signalling industry in Great Britain is moving in to a new era with the proposed introduction of Transmission Based Signalling (TBS) on the West Coast Mainline using digital GSM-R technology for the communications between the control centre and the train. This new signalling system will provide the capability of running the train service with in cab signalling without the need of lineside signals. The added advantage of Automatic Train Protection (ATP) will be introduced with the new system, which will intervene by safely controlling the train if the driver allows the train to exceed the maximum permissible speed of the line, or is exceeding the service braking curve for that particular rolling stock. How will the signalling design techniques including the scheme plan adapt to show the implementation of TBS?

The changing requirements from the Health and Safety Executive need to be implemented in to the systems to continue the safe operation of the control systems. A small change in a requirement can have a large impact on the signalling system.

The most important item to remember is the operating personnel that will use the system including the train drivers, control staff, maintenance staff and occasionally faulting staff. The system needs to be clear for all of these personnel to understand to perform their duties or the system will become a liability and not deliver the service that it has been commissioned for.

The last thought. Is the Signalling Engineer slowly becoming a Systems Engineer?

Transmission Based Signalling

by

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European railways are at a turning point. From their historical position of national isolation, the growth of international high speed traffic and the political demands for separation of infrastructure from train operation to permit open access to the network, with encouragement from the EU, is forcing serious comparison and review of the entire culture and practices of the various railway authorities.

Most national railways have invested heavily in ATP systems, many networks possessing at least two systems for different purposes. To cater for non-stop international high speed trains, complex arrays of on-board ATP equipment are installed, occupying significant volume, and contributing to train failures. Designers of later generations of high speed trains have been able, in some instances, to integrate different on-board equipment and drivers displays into common systems, with consequent size and reliability benefits. The ETCS/ERTMS initiative was the next logical step in this process of integration; specifying common track-train communications links, and a common language in which to express system functionality, whilst retaining the ability to interface to existing national systems. Progress with ERTMS specifications has been slow and difficult, and it is likely that there will be many pressures to adopt divergent variants of the common technology to satisfy the remnants of national practices.

But technical interoperability is only part of the solution. The rules and regulations used by drivers and other staff are widely divergent in different countries. Another European initiative - Project HEROE - aims to harmonise the rules applicable to ERTMS operations. This project team face a difficult task.

The notion that focusing on the needs of the European high speed network would solve the problems of national railway administrations was flawed. International traffic will always be a small proportion of total rail traffic, and unless future train control systems meet the real needs of the emerging national railway businesses, they will fail.

Railways, in a time of business-led growth, are forced to scrutinise all calls for investment against their top-level goals, which will ultimately be financial. Increased profitability will only come from reducing costs and from offering an improved service. Service means not only dependable delivery of what has been sold, but responsiveness to the changing needs of users, in order to generate the new business which will allow the enhancement of the rail network. We will be seeing the frequent appearance of new entrepreneurial train operators, demand-responsive services, changed timetables, new trains and even additional routes, in the coming railway age.

Whilst Level 1 and Level 2 ERTMS offer some interesting prospects for increased competition in the market for replacement national ATP systems, it is the Level 3 option, with radio-based cab signalling and moving block operation, that offers the prospect of really exciting possibilities for train control to help operators to respond positively to business pressures in the future.

Such radically different concepts for train control must include an easy migration path from existing systems for operators, whilst reducing costs and permitting increases in income to be achieved by responsiveness in the rail travel marketplace. Easy migration will mean very rapid roll-out across the network, which is possible because of the ability to install Level 3 ERTMS non-intrusively, test it in "shadow" mode, and commission it in very large stages.

There will be difficult issues of interoperability to resolve, particularly since ERTMS standards will doubtless be controlled at a European level, and system responsibility, even nationally, will be spread across a mixture of infrastructure authorities, train owner/operators, suppliers, and other stakeholders. Much greater clarity and definition of roles and responsibilities will be needed than was the case for simpler ATP systems within a monolithic national railway organisation in the past.

Reduced costs will come from lower equipment cost, particularly at the trackside, leading in turn to lower maintenance costs. The use of commercial service providers to provide services, such as communications, that historically were provided within the railway organisation, will alter costs and will introduce interesting commercial issues about performance guarantees.

Other savings will accrue from the recognition that planned and unplanned work will always be needed to maintain the extensive railway infrastructure, and facilities built into the train control system to maximise the effectiveness and safety of such work, and to allow traffic to flow when such work is under way, will form an important part of the next generation of train control system. Increasingly, savings will also be made by the avoidance of train delays which will cost the originator significant money in penalties to those affected.

Level 3 ERTMS avoids the need for track circuits and lineside signals throughout much of the network, reducing costs and improving reliability as a result. Also, the architecture of Level 3 ERTMS is such that fault-tolerance is possible through most of the system elements and transmission links, allowing operation to continue almost unaffected in the presence of faults. It can provide warnings of trains to staff working on the track, and permits engineering possessions to be managed effectively, whilst bi-directional operation takes place past the work site.

Moving block, in which trains report their position by radio, and can be given movement authority up to the latest reported position of the preceding train, offers several advantages. It enables track circuits to be eliminated, and it allows traffic to maintain close headways as line speeds reduce (e.g. due to congestion in rush hours). It also allows the effect of a disturbance to be contained in the smallest possible area of the network. By minimising headways between trains, it gives the maximum potential for additional train paths to be provided, to allow timetabling flexibility, particularly when other ERTMS features allow paths to be delivered in a dependable manner.

Level 3 ERTMS will provide a radically improved approach to signalling and train control on mixed traffic main lines. Its features are well-matched to the needs of the railway networks of the future. There will be challenges to be overcome in successfully implementing such systems.

CUSTOMER REQUIREMENTS

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In writing about customer requirements, I am taking it for granted that the supplier is meeting the customer's specification, and completing within budget and to time. So you may well question whether there anything else to say on the subject!

Today's customer (and railway administrations are not unique in this respect) is looking for a great deal more from suppliers than just the system, equipment or product for which the contract was let. He, or she, is looking for additional support and services as an integral part of a contract. These can be broadly categorised into four key areas:-

- Assurance
- Information
- Expertise
- Creativity

The signalling supplier who can meet these needs is, I suggest, highly valued by any railway administration.

Assurance

First of all, the customer wants to know that supplier has the capability to provide a system or product that meets his needs. He or she is seeking evidence and answers to questions such as:-

- Will the product or system meet requirements in respect of functionality? Will it do what the customer wants? Will it perform properly from day one onwards, and will it be workable, in the real railway environment?
- Does the product or system implement, or comply with, an acceptable set of railway operating rules (of which signalling principles are a part)?
- Is the product or system, and the manner in which it will be designed, constructed and commissioned, compliant with relevant legislation?
- Is the reliability, availability, maintainability and safety of the product or system adequate? If RAMS targets are specified, can the supplier demonstrate that they will be met throughout the in-service life?

- Are the development, design, manufacturing and construction processes adequate to ensure that the customer's requirements are met? This includes factors such as the use of competent people in the processes, the provision of safety management systems to underpin the processes, and the application of appropriate tools, techniques and methodologies.
- Does the supplier have the means and commitment to provide support for the product or system when in service?
- In the case of manufactured products (signal heads, point machines, SSI modules, etc.), does the manufacturer have the commitment and capability to ensure configuration control?

Information

Next, the customer needs information about the product or system during its development and design. This includes such things as:-

- The system or product architecture. Customers do not generally want to buy black boxes without any knowledge of how the system functions and how its component parts behave. Such an understanding is particularly important at the interfaces with other systems, infrastructure or indeed with people. It is also important in order that the behaviour of the system under fault conditions is understood and hence appropriate rules applied for operating the railway during failures. Misunderstandings or lack of knowledge about the architecture may also lead to subsequent errors during maintenance, modifications or changes of application.
- The application requirements. These are rules, conditions and constraints relevant to the system or product in its proposed application. They may include requirements for the site-specific configuration and interconnection of component parts; precautions and methods for installation, testing and commissioning; methods for maintenance and fault-finding; instructions for operation/use; information regarding modification and de-commissioning. The supplier who fails to provide these has only supplied half a product!
- The extent to which the product or system is compliant with customer requirements. Non-compliances inevitably arise, but in the long term it is far better to be open about them than to hide them. The earlier they are acknowledged, the easier and cheaper it will generally be to provide a solution. Unless caused by negligence or incompetence, a non-compliance should not be regarded as a failing. The solution may lie in changing the product or system, but it could equally well lie in changing the customer's requirements to align with what is achievable or with a better practice.
- Additional features and benefits offered or provided by the supplier, even though they were not called for in the customer's requirements. If they demonstrably provide a tangible benefit (which usually means expressing the benefit in financial terms), the customer - if he or she is sensible - will be interested. Do not assume that the customer wants only what was specified and no more.

Expertise

Over and above the expertise necessary for the design, construction and commissioning of a signalling system or a product, the signal engineer is today expected to be knowledgeable in a range of other disciplines. Perhaps even more significantly he or she needs to understand the limits of their expertise, and therefore when to call in specialist help. Some of the areas in which expertise is necessary are:

- Relevant legislation (HASAW, EAW Regs, Level Crossings Regs...)
- The European dimension (The Interoperability Directive, ERTMS, Cenelec standards...)
- Risk management and safety assessment (HAZOP, FTA, FMECA, cost benefit analysis...)
- Human factors (ergonomics, human factors in safety...)
- Systems engineering, with particular reference to complex systems and those which interact/interface extensively with other systems
- Reliability engineering (fail-safe signalling systems that are unreliable, and consequently have to revert to a safe state on a frequent basis, can lead to significant diminution of overall safety when trains have to be moved without the protection of the system)
- Operational rules which the railway applies in conjunction with the signalling system, particularly under failure conditions
- Value management (optimisation of the solution to the customer's requirements).
- Engineering change management (control of change to the operational signalling system)
- Whole life asset management (operation, maintenance, modification and decommissioning)
- Knowledge of other railway engineering disciplines which inter-relate with signal engineering
- Experience of other railway administrations, and of best practice in other industries.

The application of this expertise is important for a number of reasons. One in particular deserves mention, namely the supplier's use of his expertise to advise the customer about options, obligations, risks... the list is long. If the day ever did exist within the signal engineering profession where the customer was the expert and the supplier simply produced what was required, it is certainly no longer true. The supplier has a crucial role in providing expert advice as an integral part of a supply contract.

Creativity

Finally, today's signal engineer needs to be creative and innovative. Customers do not necessarily want more of what they already have, when new technology and new ways of using technology can offer them more. The supplier of today needs to:

- Find workable solutions, not just identify problems
- Offer new ways of meeting the customers needs which exploit technology to offer lower whole life costs and greater operational benefits
- Avoid the "not invented here" syndrome.
- Challenge traditional thinking, principles and practices.
- Apply engineering creativity in fields such as diagnostic and monitoring aids; degraded modes of operation; system flexibility; lower cost maintenance requirements; system obsolescence; integration of train control systems with other railway management systems.

Creativity does not just happen within a company or organisation. It flourishes where there is an appropriate blend of culture, organisation, people and processes. Signal engineering, perhaps to a greater degree than other railway engineering disciplines, is heavily laden with principles and practices that can unnecessarily constrain the efficiency with which a railway runs. Signalling systems are also expensive to provide, and the cost-benefit justification for resignalling is often marginal. Creative thinking by engineers has a significant role in helping to develop the cost-effective train control systems that the railways need.

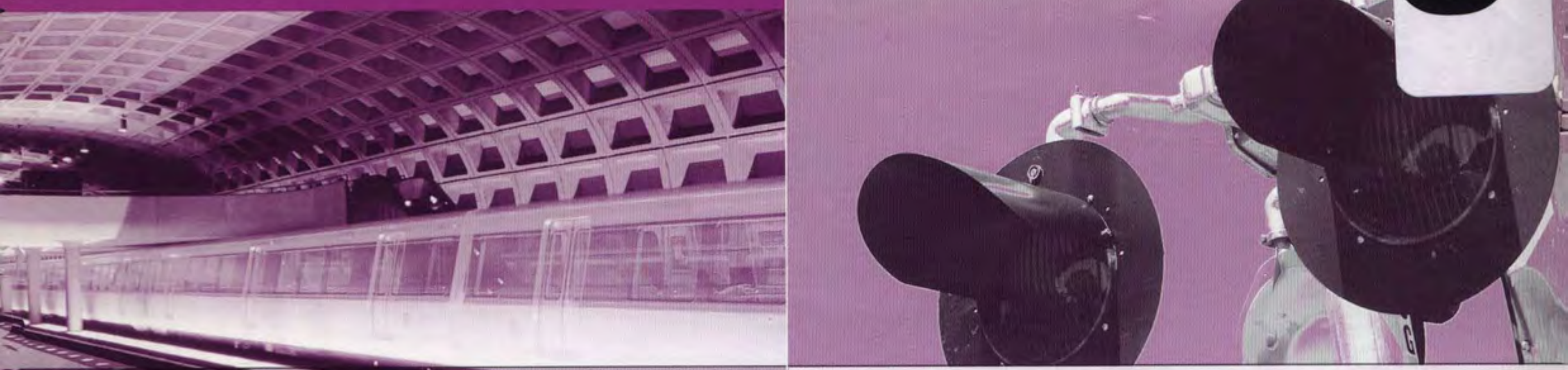
The role of the customer

This has deliberately been a one-sided presentation, namely what the railway administration expects of suppliers. It is worth observing, however, that almost everyone who is a supplier is also a customer of someone else. Thus the need for assurance, information, expertise and creativity extends through the chain of suppliers almost endlessly.

The customer's attitude is crucial in creating the environment in which the supplier can provide assurance, information, expertise and creativity. Wrongly handled, the supplier will find that the provision of these things causes more problems than it solves, and he will soon stop making the effort. Conversely, if managed properly, both parties will benefit from this approach. The customer gains through systems and products that more closely meet his real needs, and the supplier gains through the progressive development of his products and his capabilities, which in turn leads to more business.

Notepaper

Delegate information



Seminars

at the G-MEX Exhibition and Event Centre, Manchester

Mainline Railways TUESDAY 29 SEPTEMBER 1998

Signalling Issues WEDNESDAY 30 SEPTEMBER 1998

Light Rapid Transit THURSDAY 1 OCTOBER 1998

THE INSTITUTION OF CIVIL ENGINEERS

Organised by Thomas Telford Conferences on behalf of the Transport Board of the Institution of Civil Engineers and the Institution of Railway Signal Engineers

In conjunction with

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Paper 12.	**Track design, construction and maintenance** • **polymer embedded rail** • **shallow track** David Bateman, Hyder Consulting

- Notepaper

Seminar Programme

PROGRAMME (subject to amendment)
Seminar 3 - Light Rapid Transit
Thursday 1 October 1998

0845 Registration and coffee
0930 Chairman's Welcome

SESSION 1

Chairman: *Tony Young, Tony Young Consultancy*

0935 1. **Metrolink Phase 2 - Eccles Phase 2: an overview**
J R Hall, Director of Projects & Infrastructure, Greater Manchester Passenger Transport Executive

0955 2. **Metrolink Phase 2 - Eccles via Salford Quays: the alignment**
T Beamon, Consents Manager, Mott MacDonald

1015 3. **Metrolink Phase 2 - Eccles via Salford Quays: the structures**
C King, Senior Project Manager, Halcrow Group

1035 Discussion
1045 Coffee

1110 4. **The Lewisham DLR Extension**
- **bridge structures**
- **stations and tunnels**

N Gray, Lewisham Concession Manager, Docklands Light Railway Ltd & W Shepherd, Project Manager, John Mowlem & Co plc

1140 5. **LRT under Portsmouth Harbour - Britain's first immersed tube rail tunnel**
K Willcox, Project Manager, South Hampshire Rapid Transit & P Meeuwissen, Deputy Managing Director, Delta Marine Consultants bv, Netherlands

1200 6. **Practical application and operation of light rail signalling**
H Saffer, Principal Engineer, Traffic Signal Design, Sheffield Design & Property & P Gross, Associate Director, Symonds Travers Morgan

1220 Discussion
1230 Close of session

SESSION 2

Chairman: *John Bygate, Consultant*

1400 7. **17 years experience of Tyne and Wear operation on Metro tracks**
P Johnson, Technical Services Engineer & I Clayton, Head of Operations, Tyne and Wear Metro

1420 8. **Sunderland metro - challenge and opportunity**
K Mackay, Project Director, Tyne and Wear PTA

1440 9. **Environmental track design - paved and grass tracks for Dublin**
J Bourreau, Project Director, Semaly Ireland Ltd, Eire

1500 Discussion
1510 Tea

1535 10. **Design of track for kerb-guided and electronically-guided buses**
D Mack, Associate, Maunsell Ltd

1555 11. **Design issues for guided bus as a rapid transit syste - experience from developing systems in the UK**
G Dunnett, Director of Transport, Ove Arup

1615 12. **Track design, construction and maintenance**
- **polymer embedded rail**
- **shallow track**

D Bateman, Deputy Director, Hyder Rail, Hyder Consulting

1645 Discussion
1655 Closing Remarks
1700 Close of seminar

Introductory Notes

METROLINK PHASE 2 - ECCLES via SALFORD QUAYS - 'AN OVERVIEW'

J R HALL
CEng FICE FIStructE MIMC, Manchester, England

1. INTRODUCTION

The existing Metrolink route from Bury through the city centre to Altrincham was developed by the Passenger Transport Authority and the Passenger Transport Executive (PTA/PTE) in September 1989. It was the first Design Build Operate Maintain (DBOM) contract of its kind in public transport involving the PTA/PTE in a public sector/private sector partnership with GEC/Alsthom, Mowlem, AMEC and Greater Manchester Buses Limited (now Greater Manchester Road Car Company).

Metrolink has enjoyed wide acknowledgement of its success, showing how investment in a transport system which is modern, efficient and reliable, can increase patronage and contribute to the conurbation's public transport needs. In addition Metrolink has secured employment, brought environmental benefits and given Greater Manchester a modern transport image.

However it has always been acknowledged that Metrolink to Bury and Altrincham was only the first phase of a planned network, and consequently since 1989 the PTA/PTE have been progressing their plans to extend the system.

In conjunction with the district councils of Greater Manchester, the Metrolink extension to Eccles via Salford Quays was selected to be the first extension of Metrolink and was included in the Greater Manchester Package Bid for 1996/97. In 1995 the PTA/PTE approved work on the tender process to secure the Eccles via Salford Quays extension.

Prior to commencement of the tender process, review was undertaken to consider the best way forward to secure the proposed extension, at the same time maximising the private sector's contribution to the project.

A number of factors including the terms of the existing contract and compliance with European Procurement Regulations very much influence the decision to procure the extension by a repeat of the Design, Build, Operate and Maintain (DBOM) form of tender.

The Operate and Maintain element of the concession embraces the operation and maintenance of the existing system (Phase I) Altrincham/Bury until the commissioning of Phase 2 (Eccles via Salford Quays) is completed. Then subsequently it embraces the whole of the expanded system under the terms of the new Concession Agreement.

The Design and Build element of the tender covers the design and construction of the proposed 6.5km extension to Eccles via Salford Quays.

The Contract Structure for the Eccles via Salford Quays extension is included as Appendix I.

Currently the Executive are also preparing tender documentation for the Oldham/Rochdale extension.

At an early date an order of priority will be given to the remaining extensions to Manchester Airport, Ashton and East Didsbury. The Dumplington extension priority is subject to the availability of 100% private sector funding.

2. AWARD OF CONTRACT

The contract for the Eccles/Salford Quays extension was awarded by Greater Manchester Passenger Transport Executive to the Altram consortium in April 1997.

Altram is a consortium formed of John Laing, Ansaldo Trasporti, Serco and 3i. A Joint Venture of Laing Civil Engineering and Ansaldo has been awarded the design and construct sub-contract from Altram.

Serco Metrolink have been awarded the sub-contract to operate and maintain the system.

The award of the contract to Altram followed European Procurement Procedures. An advertisement in the official Journal of the European Communities sought interest from consortia to pre-qualify for the proposed Metrolink extension.

To pre-qualify organisations were required to demonstrate their contracting and design strengths, operating experience and availability of resources to carry out the project. As a result, twenty consortia were issued with Contract Information Packs and formally registered their intent to tender.

Four consortia were as a result selected to tender. During the tendering period however one consortium withdrew with three consortia finally submitting bids.

All bids were evaluated in accordance with public procurement rules with tender evaluation criteria determined at the outset of the tendering process.

The outcome of the selection process concluded in the selection of Altram as the 'Preferred Bidder'.

Following the 'preferred bidder' selection in November 1996, the tortuous path of financial close was embarked upon and finally concluded in April 1997 with the signing of the contract with the Altram consortium.

3. OUTLINE OF THE PROJECT

The Eccles via Salford Quays extension is a 6.5km route which starts at a new junction at Cornbrook which enables the extension to branch off the existing Metrolink Bury/Altrincham line.

From the Cornbrook Junction a new viaduct links the line between two new bridges over the Bridgewater and Manchester Ship Canal. From the new high level crossing of the Ship Canal the new line drops down to ground level at Exchange Quays.

The extension now at grade then crosses Trafford Road into the Salford Quays area. From the Quays the new line continues through Broadway, South Langworthy Road and into Eccles New Road. Before terminating at Eccles Town Centre the line goes via a new underpass at Ladywell Hospital to pass under the existing road roundabout at Gilda Brook Road.

The existing and the proposed Metrolink route to Eccles via Salford Quays is included as Appendix II.

The extent of the works contract includes

- Refurbishment of three bridges and construction of three new bridges
- Construction of two new viaducts
- Construction of an underpass at Ladywell Roundabout
- Construction of eleven tram stops with various methods of access, including lifts, steps and ramps
- Five new power supply sub-stations and upgrading the capacity of six existing ones on Phase 1
- Upgrading the existing Queens Road control room
- Provision of six new vehicles
- Installation of a new scissors crossover outside Piccadilly Undercroft.

The contract was signed on the 24th April 1997 with the first phase of the extension from Cornbrook to Broadway having a duration of 28 months. Phase 2 of the works from Broadway to Eccles having an overall duration of 35 months.

The contract commencement date was fixed at 4 clear week after contract signing.

The construction programme will enable a service operation to Broadway (Salford Quays) by the Autumn of 1999 and a full service operation to Eccles by the Spring of the year 2000.

4. FEASIBILITY AND FUNDING

Transport and Works Act

Powers to construct and operate Phase I - Altrincham to Bury were obtained under the Greater Manchester (Light Rapid Transit System) Act 1988 and the Greater Manchester (Light Rapid Transit System) No.2 Act 1988.

The Powers to construct the Eccles via Salford Quays extension are in two parts.

- The Salford Quays Act 1990
- Transport and Works Act Order 1996

The stages in obtaining a Transport and Works Act order can be simplified as follows:-

Public Consultation Period

Process Results of Public Consultation

Authority (PTA/E) considers the result of Consultation

Determine the contents of Draft Order

Serve Formal Notice on those affected by the Scheme
(6 week objection period)

Draft Order Application

Consideration of Objections by the Secretary of State
possibly leading to Public Inquiry

(Public Inquiry)

Inspector's Report

Granting/Rejection of Order by the Secretary of State

Funding

The financing of a project of this scale is complex and as with most major public sector schemes now involves a joint partnership arrangement between the public and private sector.

The total cost (excluding interest during the contribution period) of the extension is anticipated to be £160m. This includes not only the main contract works to be carried out under the Construction Joint Venture but also the PTE's costs of land acquisition, utilities diversion costs, and preliminary enabling contracts entered into separately by the PTE. The estimated public sector cost is £53m thus leaving £95m to be financed by Altram. This in turn is being financed through equity and subordinated debt from John Laing, Ansaldo, Serco and 3i's with the primary lending by Bank of America. The balance of funding is a combination of 'land gifts' and Developer Contributions. In return to meet their financing and equity returns Altram have the benefit of the net revenues from the extension for the next 17 years.

5. PUBLIC RELATIONS

During the construction of a project of this nature and particularly with the interference caused to businesses, households and the travelling public, it is essential that an extensive public relations programme is established.

In addition to both PTE and contractor's staff, meeting with premises owners' in advance of the works an information office has also been established in the centre of Eccles and regular meetings take place with both businesses and domestic representatives.

Monthly information sheets are distributed giving information on the progress of works and the programme of the coming month's work. A quarterly newsletter is also circulated.

The requirements of good public relations cannot be over emphasised and the need to keep the public informed is an essential element of any project of this nature.

6. METROLINK 2000

The Altrincham/Bury and Eccles via Salford Quays lines are the first two phases of an overall light rail network for Greater Manchester.

The total proposed Metrolink network is as outlined in Appendix III.

The overall timing of future phases will greatly depend upon funding availability and receiving appropriate Transport and Works Act powers where required.

Currently the Executive are programming tender documentation for the Oldham/Rochdale extension and a review is ongoing to time schedule the remaining routes.

7. CONCLUDING REMARKS

By the very nature of the title of this presentation it can only be a very general introduction to a complex but interesting project.

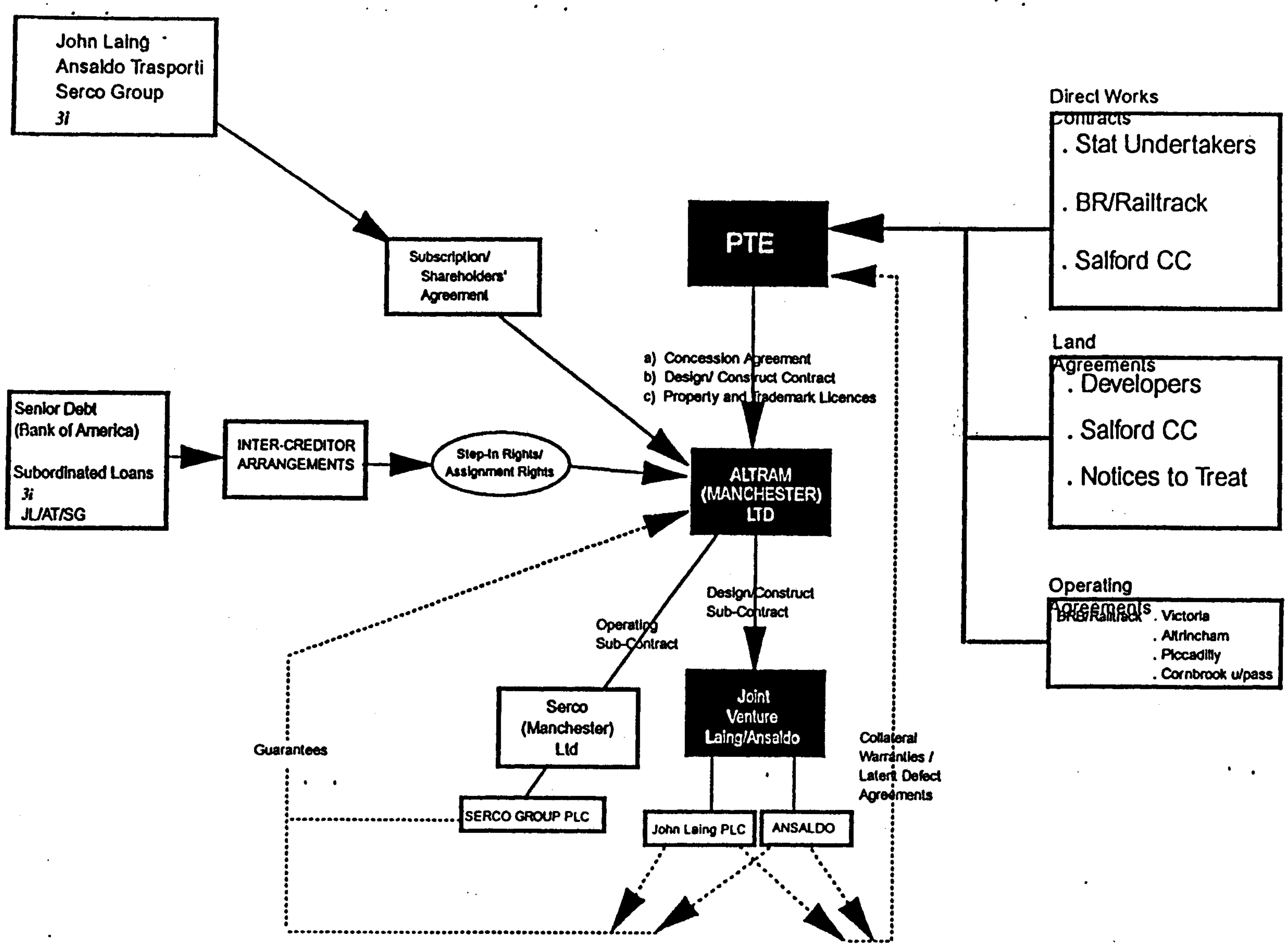
Many cities like Manchester wish to see light rail systems as a way to solving their transport needs. They will only come to fruition if they are part of an overall transport strategy and the funding is justified by a stringent cost benefit analysis.

Certainly the success of Manchester's Phase I Metrolink system from Altrincham to Bury and hopefully to be followed by even greater success of the Eccles via Salford Quays line has proved that light rail has a place in our cities.

There is also no doubt, that albeit with a likely number of variations, the Design, Build, Operate and Maintain form of contract is here to stay.

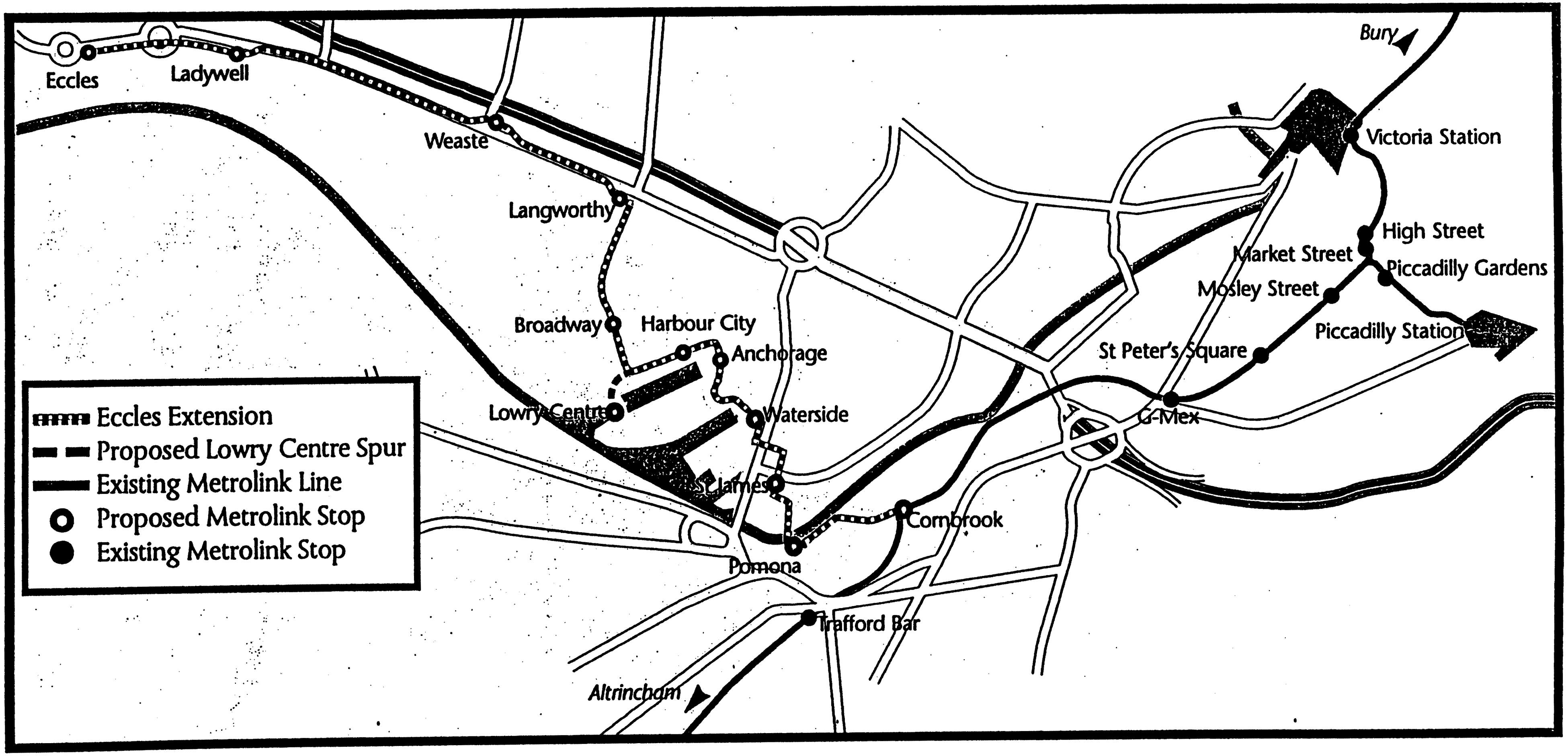
APPENDIX I

CONTRACT STRUCTURE



APP4SMI.SAM

The Extension of Metrolink to Eccles via Salford Quays

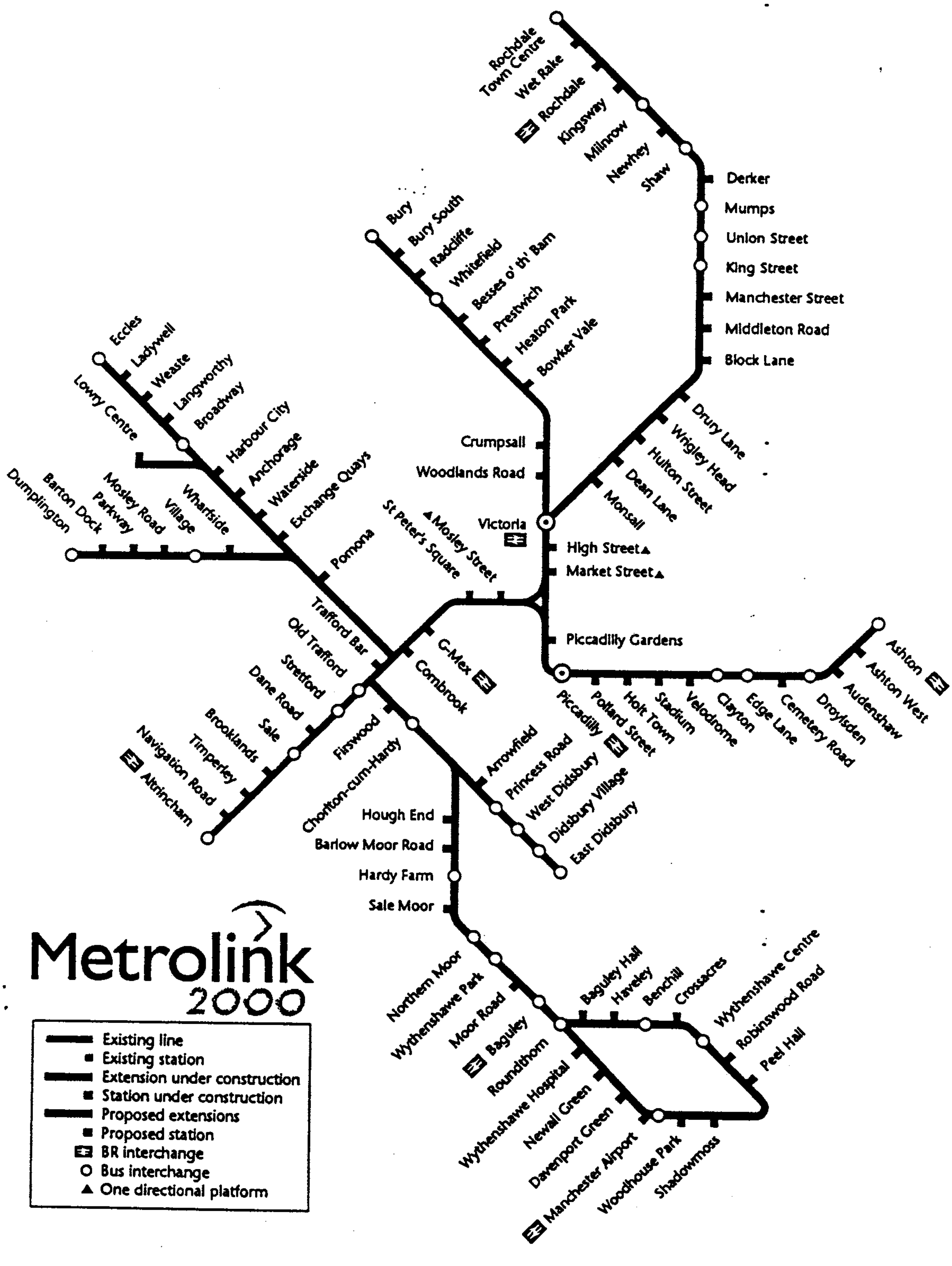


APPENDIX 11

GMPTE

Metrolink 2000

PROJECTED NETWORK FOR METROLINK IN GREATER MANCHESTER



METROLINK PHASE 2 - ECCLES via SALFORD QUAYS 'THE ALIGNMENT'

TP BEAMON
C Eng MICE, Manchester, England

1. INTRODUCTION

This paper sets out a brief history of the alignment, its principal design influences and continuing development through to the present day construction.

The applications for powers for this design and construct project are described including the Transport and Works Act order.

A brief description of the alignment (a plan is attached as Appendix 1) is given which includes appreciation of the design constraints which have been accommodated.

Comment is made on the working relationships that assure the alignment complies with the powers and consents, and the DBOM contract.

2. BRIEF HISTORY

2.1 History

A Bill deposited in 1987 sought powers for an extension to Salford Quays. Deposit of the Bill followed a feasibility study of potential routes for a light rail extension to serve Salford Quays, Pendleton and possibly Eccles. Parliamentary powers[i] were subsequently obtained for the Salford Quays extension as far as Broadway.

At the time of GMPTA's Strategic Development Plan, an immediate progression from Salford Quays to Eccles was not envisaged, and the Salford Quays extension was proposed to be built from private funds. However following further discussions with the private sector it was determined that Salford Quays alone would not be sufficiently attractive from an operational point of view as demand would be highly peaked and tidal. It was suggested that proposals to extend beyond Salford Quays should be re-examined and, as a result, Eccles was chosen as the most logical destination for the line.

In 1994 Mott MacDonald was appointed to review the findings of the 1987 study and advised that it would still be practical to construct an LRT extension to Eccles albeit with a number of significant changes to the earlier proposals.

Following public consultations an application for an order under the Transport & Works Act was submitted in April 1995 for an extension beyond Salford Quays to Eccles. This led to a public local inquiry at the end of October 1995. When the order came into force[ii] in November 1996 GMPTE had acquired all the powers necessary to construct and operate an LRT alignment from Cornbrook through Salford Quays to Eccles.

2.2 Private Bill Process

The areas which the two parts of the route traverse are very different and this was reinforced by the different procedures for obtaining the powers. In the case of Pomona and Salford Quays the alignment was determined by means of protracted negotiations with third parties and the authorities. Where there was uncertainty regarding the ultimate extent or form of a proposed development, the limits of deviation for the alignment were set wide to accommodate all practical routes across the site. In many cases these 'wide' limits were subsequently circumscribed by negotiation/agreement to allow developers sufficient confidence to invest in their sites and not to petition Parliament with objections.

2.3 Transport & Works Act

GMPTE's order application for an extension to Manchester Airport formed the subject of the first major LRT proposal under the Transport and Works Act procedure. The Eccles Extension formed the subject of the second major application by GMPTE. Whilst only 3.5km long, with the exceptions of rural landscape and ecological impacts this extension encountered many of the issues associated with much larger LRT and highway schemes. In particular GMPTE's case at inquiry included evidence in respect of;

- Highway conditions and traffic impacts
- Noise and vibration
- Urban design
- Construction programme and impacts

The alignment was developed and modified in consideration of the above. For example between Langworthy and Weaste stops the alignment is located in the centre of the carriageway to minimise the potential for noise and vibration impacts to residential property. In South Langworthy Road consideration of construction methods led to the wide landscape strips being included in the limits of deviation. This enabled GMPTE to confidently enter into agreements with local businesses regarding maintaining two way traffic in working hours during construction. An example of typical consultation material is attached as Appendix 2.

2.4 Comparison of Approaches

A major difference between the Bills and the order application for the Eccles Extension was the extent to which GMPTE had to circumscribe the powers it was seeking. This was achieved by a number of means including;

- Limits of deviation were set only so wide as could reasonably be justified by the proposals illustrated
- Supporting information was submitted in the form of technical development plans and urban design proposals

- The draft planning direction included suggested conditions and a list of elements of the development which would require the approval of the planning authority
- A Code of Construction Practice reinforced statutory protection including working hours and gave additional powers to the local authorities

In drafting the above it had to be borne in mind that the ultimate form of contract was likely to be design and construct. This meant that the limits of deviation had to leave sufficient flexibility for development of the detailed alignment and construction operations. At inquiry the inspector accepted the point that supporting information was only indicative of the final development. However GMPTE and Altram have had to ensure that the scheme as finally constructed is essentially that which was determined by the inspector.

3. THE ALIGNMENT

The design influences on the alignment included principally

- To serve employment and recreational facilities in Salford Quays
- To link Eccles town centre with Manchester City centre
- To find an economic route which minimises impacts on property and amenity
- To be compatible with other proposed Metrolink extensions and the existing Phase 1 Metrolink infrastructure/vehicles
- To serve residential areas along the corridor to Eccles and a possible park and ride site at Weaste Quarry

Schematic plans of the Salford Quays and Eccles Sections are attached as Appendix 3 & 4 respectively, whilst Appendix 5 lists the geometrical parameters used in alignment design.

The Phase 2 alignment commences at Cornbrook where the track of the original Phase 1 outbound line has been slewed to accommodate a new stop between the main running lines and also a north facing bay platform. South of the stop the outbound Salford Quays alignment passes over the existing Phase 1 alignment at bridge A34A before running alongside the inbound line from Salford Quays to cross the Bridgewater Canal. The layout at Cornbrook is designed to maintain maximum capacity of this junction so that services originating from GMPTE's other proposed extensions to the Airport and Trafford Centre can be accommodated as required.

The alignment is elevated alongside the Bridgewater Canal at high level all the way to the Pomona Stop which comprises an island platform between the tracks. On leaving the stop the alignment turns sharply right to cross Manchester Ship Canal. No cant is applied to the tracks at this point as provision has been made both in the alignment and the structure for a junction to form the start of the proposed Trafford Park Extension. Pomona also marks the end of the block signalled section, at this point the trams convert to line of sight operation for the remainder of the route to Eccles.

After crossing the ship canal the alignment quickly descends to ground level. It remains at grade for the remainder of the route with two exceptions, Furness Withy viaduct and Ladywell Underpass. Throughout the area of Salford Quays the alignment runs on a segregated right of way. At times this is remote from the highway such as at Exchange Quay, Salford College and Broadway, and elsewhere the alignment will give the appearance of an extension to the street such as at Furness Quay and alongside The Quays road. Again apart from the structures, pedestrians will not be segregated from trams, and as a consequence of the curving alignment and spacing of stops operational speeds will be low in the order 20-40kph. There is no ballasted track in Salford Quays, track is to be one of three types;

- street running slab track with asphalt surfacing (road crossings)
- street running slab track with block paviors (stops and pedestrian areas)
- grass track (verges and segregated areas)

Crossovers are provided at Salford Quays (formerly Waterside) and Broadway Stops to permit services to be turned back at these points, or to permit additional short services to be introduced as demand increases.

Full street running operation with general traffic commences beyond Broadway as the alignment heads northwards in the carriageway of South Langworthy Road.The two tracks are set apart leaving a series of right turning pockets in the centre of the carriageway. Right turning vehicles can wait in these pockets without impeding trams or other road traffic.

From South Langworthy Road to Ladywell the alignment runs in the carriageway of Eccles New Road except at the stops where it negotiates 50m radius curves to enter the platforms which are located off street in every case. As referred to earlier between Langworthy and Weaste the alignment is located on the crown of the road. Beyond Weaste the tracks follow separate alignments as they are once again set apart to accommodate storage for right turning vehicles in the centre of the carriageway. A further crossover is located at Weaste.

The layout of the carriageway in Eccles New Road has been the subject of much discussion between the highway authority, Altram, GMPTE and the Railway Inspectorate. It incorporates cyclelanes on-street and also a small offset between the centrelines of the road vehicle lanes and the LRT alignments.

The alignment passes beneath the Ladywell Roundabout to reach the long single platform of the Eccles terminus. This stop can accommodate an out of service tram at the end of the line. Regent Street is to be remodelled to give passengers cross platform interchange with buses. The Metrolink stop is designed to be complimentary to the larger town centre redevelopment scheme sponsored by City of Salford and a developer.

4. WORKING RELATIONSHIPS

The Contract states that it is the responsibility of Altram to obtain all the required approvals to the scheme (be they technical, planning, etc). Similarly Altram's proposals have to comply with all the provisions of the Acts and orders.

Thus Altram's design team meets with City of Salford's project team weekly to progress design approvals. In practice no distinction is made between the two sections of the route for the purposes of design approvals, although formally SCC enjoys far more extensive control of the detail of the proposals in respect of the Eccles order.

GMPTE has appointed Mott MacDonald to review Altram's highway proposals to ensure that;

- they continue to comply with the Contract
- design developments are acceptable to GMPTE

and in respect of construction;

- systems operate to ensure public health and safety issues are addressed
- Altram's Quality Assurance System delivers adequate control of the street works and that the works are being constructed in accordance with the agreed proposals.

5. COMMENTS

As with the alignment of any transport system the alignment of the Eccles via Salford Quays Extension represents a compromise between conflicting influences and constraints. It is neither the shortest or (except at peak times) the quickest route between Eccles town centre and Manchester City Centre. However it will connect an area which is currently poorly provided with public transport to a growing number of destinations as further Metrolink extensions are completed.

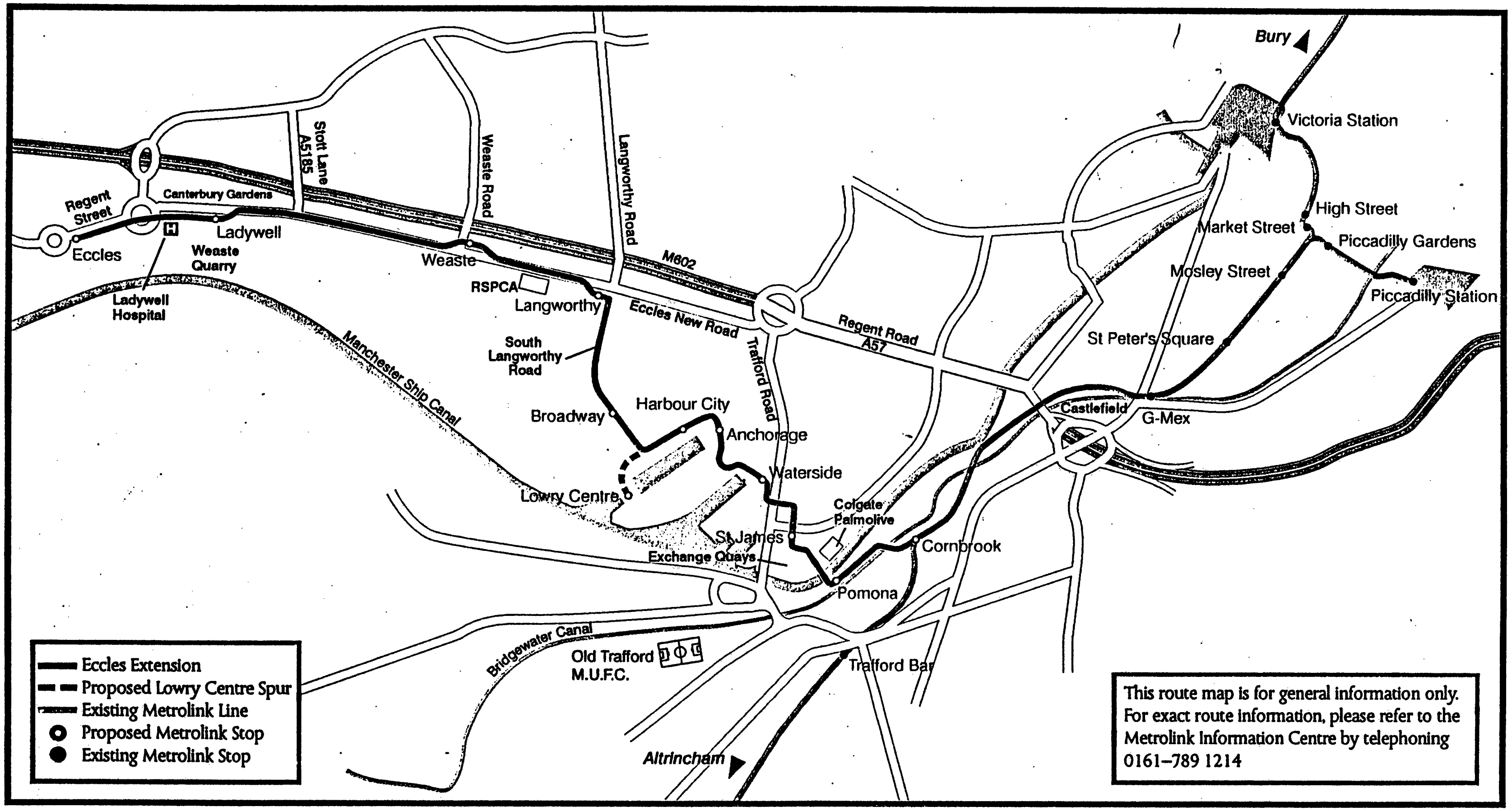
The alignment has developed in detail through the design and construct process, and yet in principle there is little change from that which was proposed at the time of the initial feasibility studies or applications for powers. The conclusion must be that the early planning stages of a scheme such as this are crucial to its eventual success.

References

(i) Greater Manchester (Light Rapid Transit System) Act 1990, and Greater Manchester (Light Rapid Transit System) (No.2) Act 1990

(ii) Greater Manchester (Light Rapid Transit System) (Eccles Extension) Order 1996.

The Extension of Metrolink to Eccles via Salford Quays



GMPTE

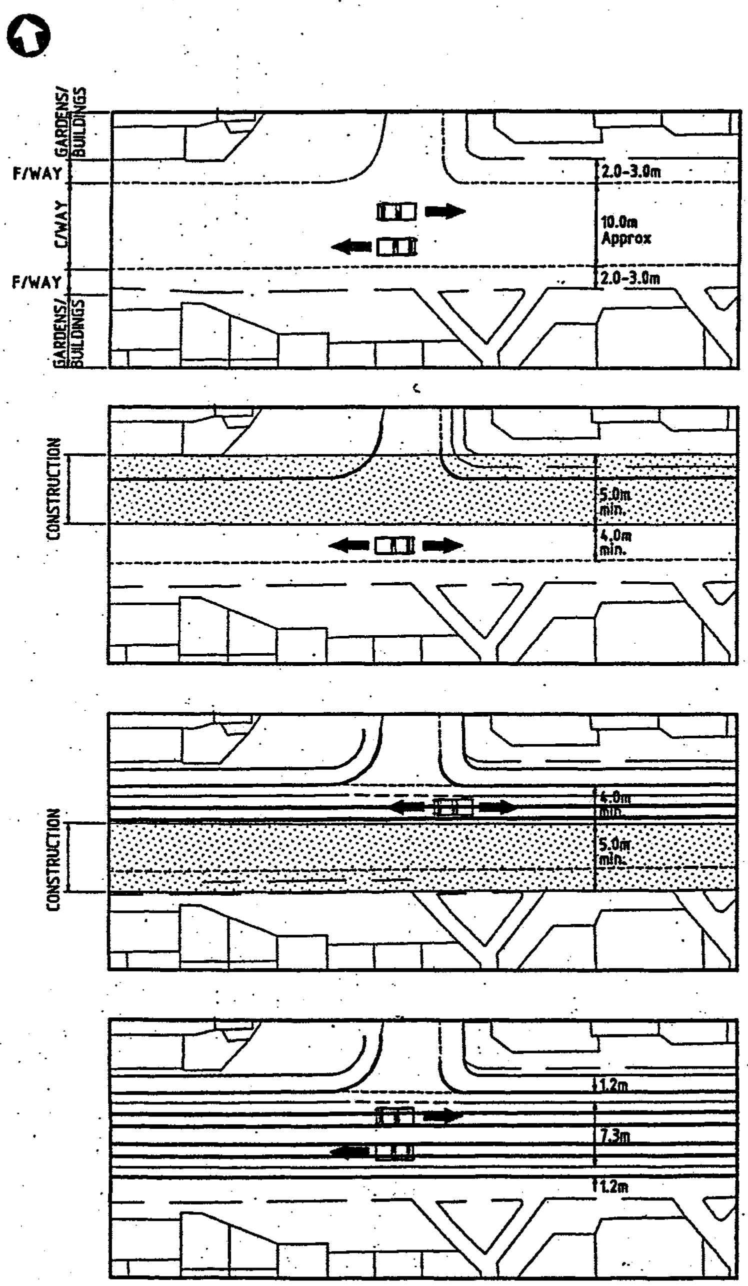
Metrolink 2000

Appendix 1

TP Beamon

Appendix 2

Typical Consultation Material



STAGE 1

EXISTING TWO LANE CARRIAGEWAY CONSTRUCTION MUST TAKE PLACE IN EXISTING HIGHWAY AS NO VERGES ARE PRESENT. FOOTWAYS RUN ADJACENT TO PROPERTIES AND GARDENS.

STAGE 2

TEMPORARY TRAFFIC LIGHTS CONTROL SINGLE LANE OF TRAFFIC. LRT TRACKS CONSTRUCTED. FOOTWAY MAINTAINED ON ONE SIDE THROUGHOUT CONSTRUCTION. ACCESS TO PREMISES TO BE MAINTAINED.

STAGE 3

TEMPORARY TRAFFIC LIGHTS CONTROL SINGLE LANE OF TRAFFIC. LRT TRACKS CONSTRUCTED. FOOTWAY MAINTAINED ON ONE SIDE THROUGHOUT CONSTRUCTION. TRAFFIC LANE RUNS ON LRT TRACKS CONSTRUCTED IN PREVIOUS PHASE.

STAGE 4

COMPLETED SECTION.
1.2m CYCLE LANES PROVIDED IN EACH DIRECTION.

LEGEND

AREA UNDER CONSTRUCTION

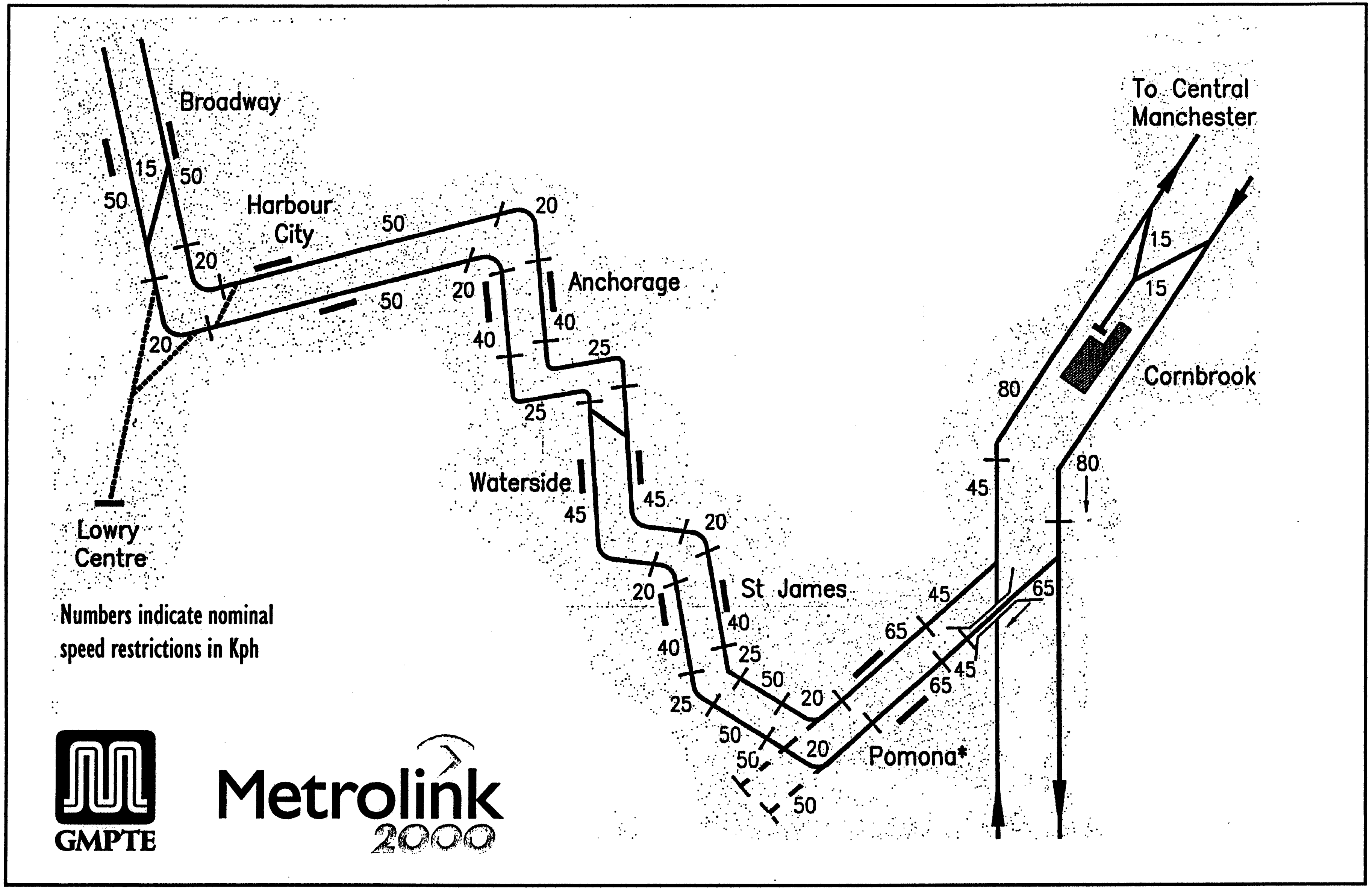
LRT TRACKS

Mott MacDonald | GMPTE

PROPOSED CONSTRUCTION SEQUENCE FOR SECTION 3, ECCLES NEW ROAD - WEASTE ROAD TO LANGWORTHY STOP.

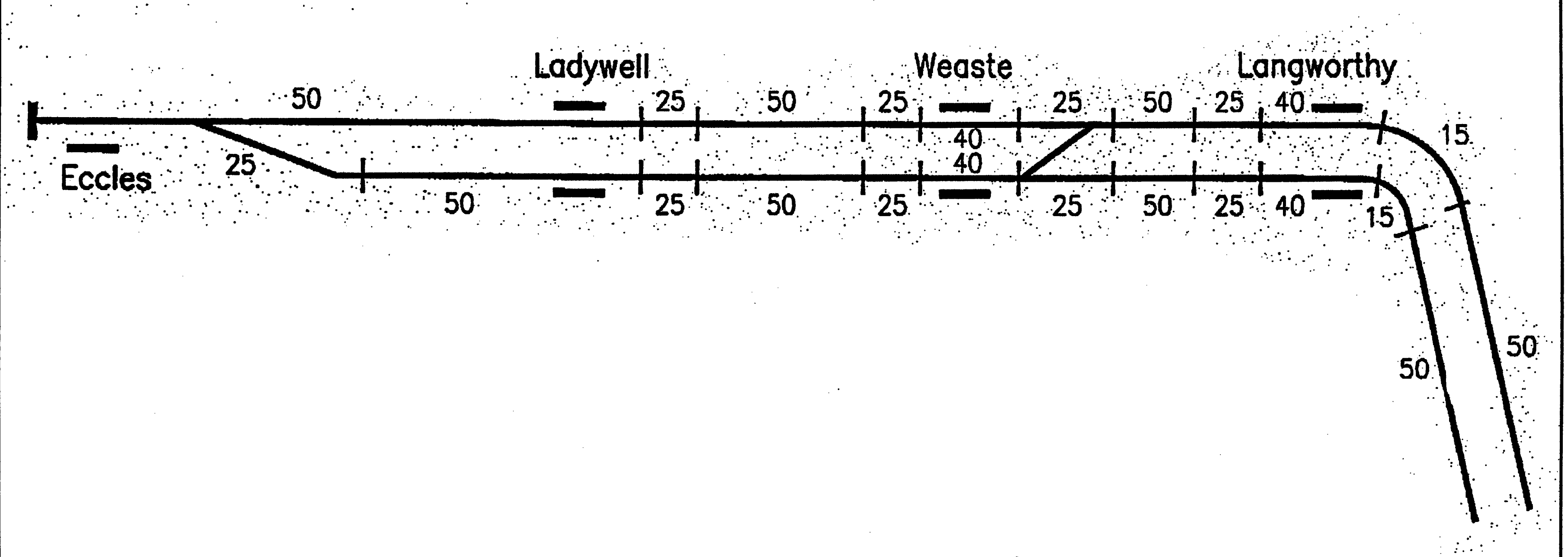
Figure 12

Schematic plan of Salford Quays section



Appendix 3

Schematic plan of Eccles section



GMPTE

Metrolink 2000

Numbers indicate nominal speed restrictions in Kph

Appendix 5

Geometrical Parameters used in Outline Design

Geometric standards

Recommended minimum horizontal curve radius	50m
Desirable minimum horizontal curve radius	30m
Absolute minimum horizontal curve radius	25m
Desirable minimum vertical curve radius	1000m
Absolute minimum vertical curve radius	400m
Desirable maximum gradient	6.5%

Stops

Platform height	915mm
Platform length	56m
Platform width	3m
Ramps	20%
Desirable minimum length of straight track	80m

METROLINK PHASE 2 - ECCLES via SALFORD QUAYS - 'THE STRUCTURES'

CH KING
C Eng MICE , Manchester, England

1. INTRODUCTION

The contract to design, build, operate and maintain (DBOM) Phase 1 of the Metrolink system between Bury and Altrincham was awarded to the GMA Group in 1989.

In 1996 as part of the planned expansion of the Metrolink system Greater Manchester Passenger Transport Executive (GMPTE) issued tender documentation for construction of Metrolink Phase 2 the extension of the existing system to Eccles via Salford Quays and operation of the existing plus extended systems. This Contract was awarded to Altram a consortium formed of John Laing, Ansaldo Transporti, Serco and 3i in May 1997.

This paper will focus on the construction of Metrolink Phase 2 and in particular on the major civil engineering structures which form a significant part of the works.

It will outline the Statutory, legal and contractual framework within which the detailed design of the structures has been developed and will outline the principal factors which have influenced the design of the works.

To conclude it will describe the 'enabling' role of GMPTE in this DBOM Contract.

2. LEGAL AND CONTRACTUAL FRAMEWORK

The overall form of the structures has been dictated by the legal and contractual constraints placed on Altram by the various Contracts between Altram and GMPTE.

The contractual arrangements are highly complex and therefore the following is a summary of the main features which influence design.

2.1 DESIGN & CONSTRUCTION CONTRACT

The key elements of the Contract which have influenced the design of the structures are detailed in the following sections :-

2.1.1 STATUTE

In addition to complying with the legislation which would normally apply to design and construction eg the Construction, Design and Management Regulations, Altram are also required to comply with the enabling legislation 'the powers' necessary to construct and operate a tramway eg both Greater Manchester (Light Rapid Transit System) Acts, 1990 and the Greater Manchester (Light Rapid Transit System) (Eccles Extension) Order, 1996.

These influence the design and construction of the works in a number of ways :-

- The limits of deviation constrain the horizontal and vertical alignment and specify minimum headrooms for various structures.
- These include protective provisions for various affected third parties which not only support the rights of these parties but also contain specific requirements relating to the design, construction and operation of Metrolink.
- By virtue of the General Development Order requires that the local planning authorities are consulted on certain aesthetic aspects of the structures.

2.1.2 LEGAL

In order to secure 'the powers' it was necessary for GMPTE give certain undertakings and enter into various legal agreements with the owners of land affected by or required for construction of Metrolink.

Many of these owners intend to develop their sites once Metrolink is operational and therefore these legal agreements and undertakings often describe the form of structures and specify in some detail the various enabling works required prior to construction of the main works.

2.1.3 DESIGN & CONSTRUCTION PROPOSALS

As part of their tender submission Altram were required to provide detailed technical proposals. These describe how Altram propose to carry out the detailed design and construction of the works. These include the form of the structures as well as the standards to be adopted in the design process.

These proposals are bound into the Contract and cannot be varied by Altram without the consent of GMPTE.

2.2 CONCESSION AGREEMENT

The Concession Agreement defines Altram's operational and maintenance obligations for the existing system and Metrolink Phase 2. These influence many aspects of the design including :-

- operational regime eg the service requirements have dictated the fatigue loading adopted in the design.
- all aspects of maintenance from bridge maintenance requirements to the frequency of removal of graffiti. In order to facilitate compliance with this latter requirement Altram have specified the use of an anti graffiti coating on accessible parts of the bridge structures.
- passenger / staff safety and security has influenced the form of structures and the design has sought to create a safe and secure environment.
- the requirement to comply with the Disability Discrimination Act and maximise accessibility to passengers has resulted in the incorporation of lifts to elevated stations, extensive use of tactile paving and emergency access ramps on platforms etc..

Finally a key feature of this contract is that Altram derive revenue from operation of the system and therefore in addition to their contractual obligations to GMPTE their commercial success depends on them creating a passenger friendly environment which encourages patronage to the system.

3.0 DESIGN OF THE MAIN STRUCTURES

The route of Metrolink Phase 2 is illustrated in Figure 1. Major structures are located at Cornbrook, Pomona, Furness Withy and Ladywell Roundabout.

This section of the paper will describe how the designs of some of these significant structures has developed and illustrate how the constraints defined in section 2.0 have influenced the design of the works.

3.1 CORNBROOK STATION

Cornbrook Station is located at the interface between Metrolink Phases 1 and 2. Currently the area surrounding the station is derelict, however it is intended that in addition to serving as an interchange for passengers it will provide access to proposed major developments once these are completed. In keeping with the wider plans for redevelopment of the area the station has been designed as a high profile 'landmark' structure.

The existing track runs on Victorian masonry arch viaducts and in order to provide both stairs and lift access to ground level a reinforced concrete core structure will be constructed within one of the arches. Typical details of the station are illustrated in Figure 2.

The design was further complicated because of the need to construct the station, including demolition of the arch, whilst maintaining Metrolink Phase1 services and ensuring the safety of adjacent Railtrack infrastructure which relies on the arches for support.

In order to ensure that construction of such a structure was viable within the confines of an operational viaduct and ensure that the structure met all GMPTE's requirements the Halcrow Group and architects EGS Design were commissioned to carry out a detailed design of the station. This was offered to prospective tenderers in the Tender Documentation and the design was adopted by Altram.

3.2 BRIDGE A34A

This steel, box girder bridge spans the Cornbrook Diveunder on the Phase 1 system and carries the Phase 2 outbound line to Pomona. Typical details and a site plan are provided in Figure 3. These illustrate the considerable access difficulties to the site which is bounded by the Bridgewater Canal, Metrolink Phase 1 and Railtrack's infrastructure.

As a result of close liaison with Trafford Metropolitan Borough Council GMPTE was able to procure the bridge under a separate Contract with the White City Link Road contractor Alfred McAlpine Civil Engineering Ltd. The detailed design and site supervision was carried out by the Halcrow Group.

The bridge was erected using an 800T crane located on the White City Link Road Site during two 27 hour weekend possessions of Railtrack and Metrolink infrastructure. Careful planning and good weather conditions meant that this operation was successfully completed within overall project timescales.

3.3 MAJOR STRUCTURES AT POMONA

On leaving the Altrincham Line at Cornbrook the tramway continues on a series of major viaduct and bridge structures through the derelict Pomona Dock site and across the Manchester Ship Canal. The Pomona site is virtually an island lying between the Bridgewater Canal on the one side and the Manchester Ship Canal on the other.

A new station at Pomona will improve access to the 'island' and improve the development potential for the area.

Design and construction in this area is influenced by the headroom constraints contained in 'the powers' and various legal agreements with the landowner the Manchester Ship Canal Company (MSCCo). In order to protect their development interests in the area the MSCCo required that a detailed 'Concept Design' be developed by GMPTE for the works and this was bound into the legal agreements. Variation from this design requires the agreement of the MSCCo. The Halcrow Group developed this design on behalf of GMPTE.

With the agreement of the MSCCo, Altram have further developed the design to suit their construction methods and have produced a solution which is both elegant and durable. An artist's impression of Pomona Station and the Manchester Ship Canal Bridge is included in Figure 4.

3.4 LADYWELL UNDERPASS

In order to maintain traffic flows across Ladywell roundabout and allow acceptable transit times between stops the tramway descends underground in a tunnel structure beneath the Ladywell roundabout at Gilda Brook Rd.

Altram have adopted this principle and have developed a detailed design which uses contiguous bored piles and allows an efficient 'top down' method of construction. Details are provided in Figures 5 and 6.

4.0 AUDIT OF ALTRAM'S DESIGN & CONSTRUCTION PROCESS

Although Altram are fully responsible for the design and construction of the works, GMPTE consider it is prudent to monitor this process.

GMPTE have therefore commissioned the Halcrow Group to carry out a number of checks including :-

- review of Altram's designs to ensure compliance with the Contract
- review and assessment of Altram's design developments to ensure these are acceptable to GMPTE
- audit Altram's Quality Assurance System to verify this adequately controls and monitors the design and construction process
- audit of the construction of the structures to verify that the Quality Assurance procedures are being correctly applied and confirm that the works are being constructed in accordance with the agreed designs

5.0 CONCLUDING REMARKS

By their very nature schemes such as this which pass through densely populated urban areas and follow the legislative route required to obtain 'the powers' have certain features of their designs fixed long before documentation has been issued to prospective tenderers.

Although tenderers are able to prepare alternatives which would have to be agreed with appropriate third parties Altram have chosen to develop the designs described in the agreements and therefore minimise the 'design approval' risk.

This has provided elegant new and refurbished structures which maximise the development potential of the sites, whilst allowing Altram the freedom to develop buildable designs and therefore construct durable, high quality structures.

The audit and checking process carried out by GMPTE to date has confirmed that Altram are using this freedom as intended and all involved should be congratulated on this.

It can be seen from the Manchester experience that much of the groundwork necessary to obtain the rights to construct on third party land, to reduce uncertainty associated with the design process and 'enable' such a scheme to be carried out successfully is carried out well in advance of letting the main Contract.

REFERENCES

1. Information Pack for Prospective Tenderers, GMPTE, 1995.

2. 'Invitation to Tender', Extract from GMPTE Tender Documentation, GMPTE, 1996.

3. Design and Construction Contract Between GMPTE and Altram (Manchester) Ltd, 1997.

4. Concession Agreement Between GMPTE and Altram (Manchester) Ltd, 1997.

5. Greater Manchester (Light Rapid Transit System) Act 1990.

6. Greater Manchester (Light Rapid Transit System) No. 2 Act 1990.

7. Greater Manchester (Light Rapid Transit System) (Eccles Extension) Order 1996.

8. Manchester Ship Canal Company Bridgewater Canal Bridging Agreement, 1996

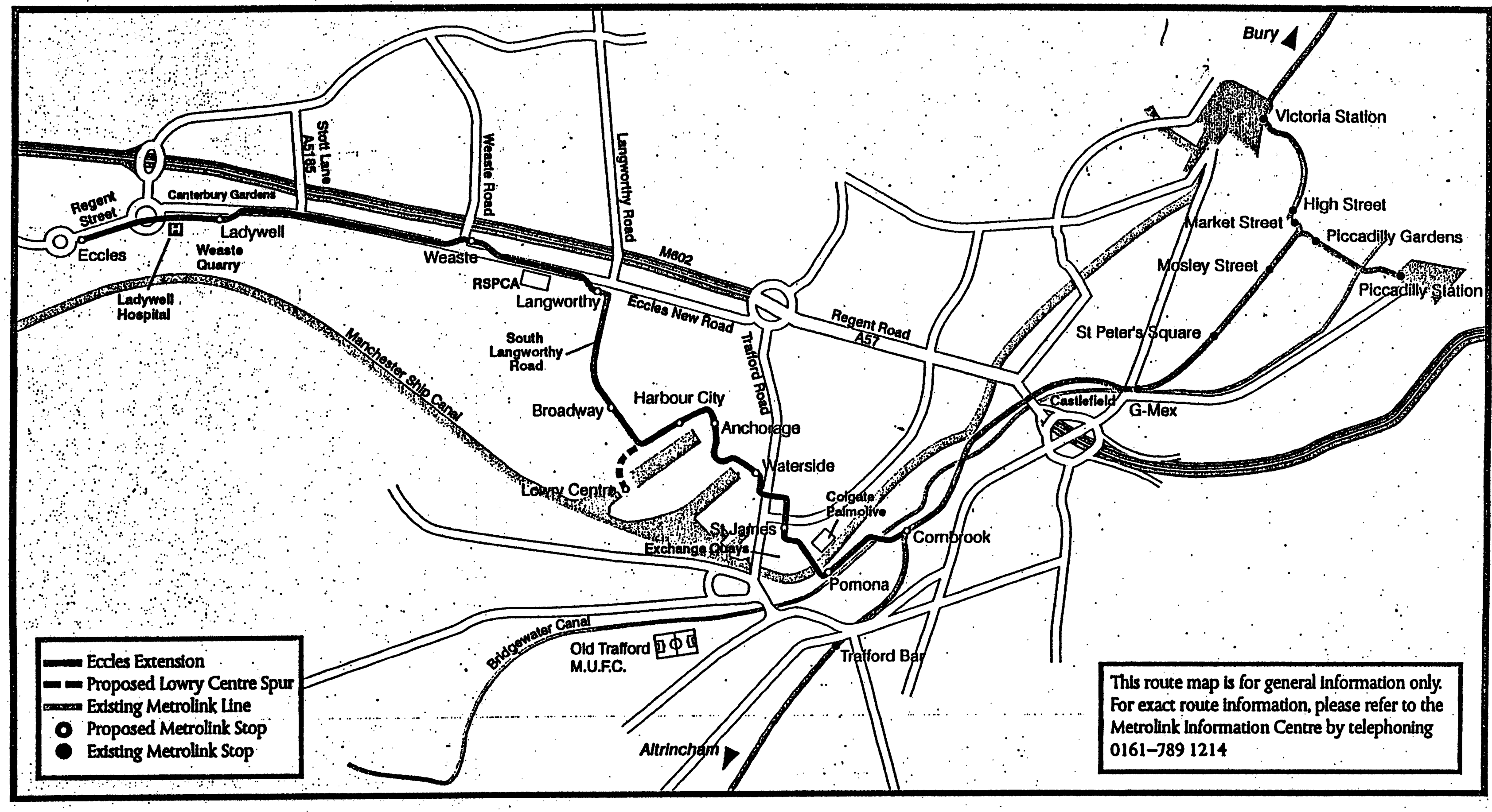
9. Manchester Ship Canal Company Manchester Ship Canal Bridging Agreement, 1996

10. Manchester Ship Canal Company Pomona Land Transfer Agreement, 1996

FIGURES

Drawings are reproduced with the kind permission of GMPTE and Altram (Manchester) Ltd.

The Extension of Metrolink to Eccles via Salford Quays



GMPTE

Metrolink 2000

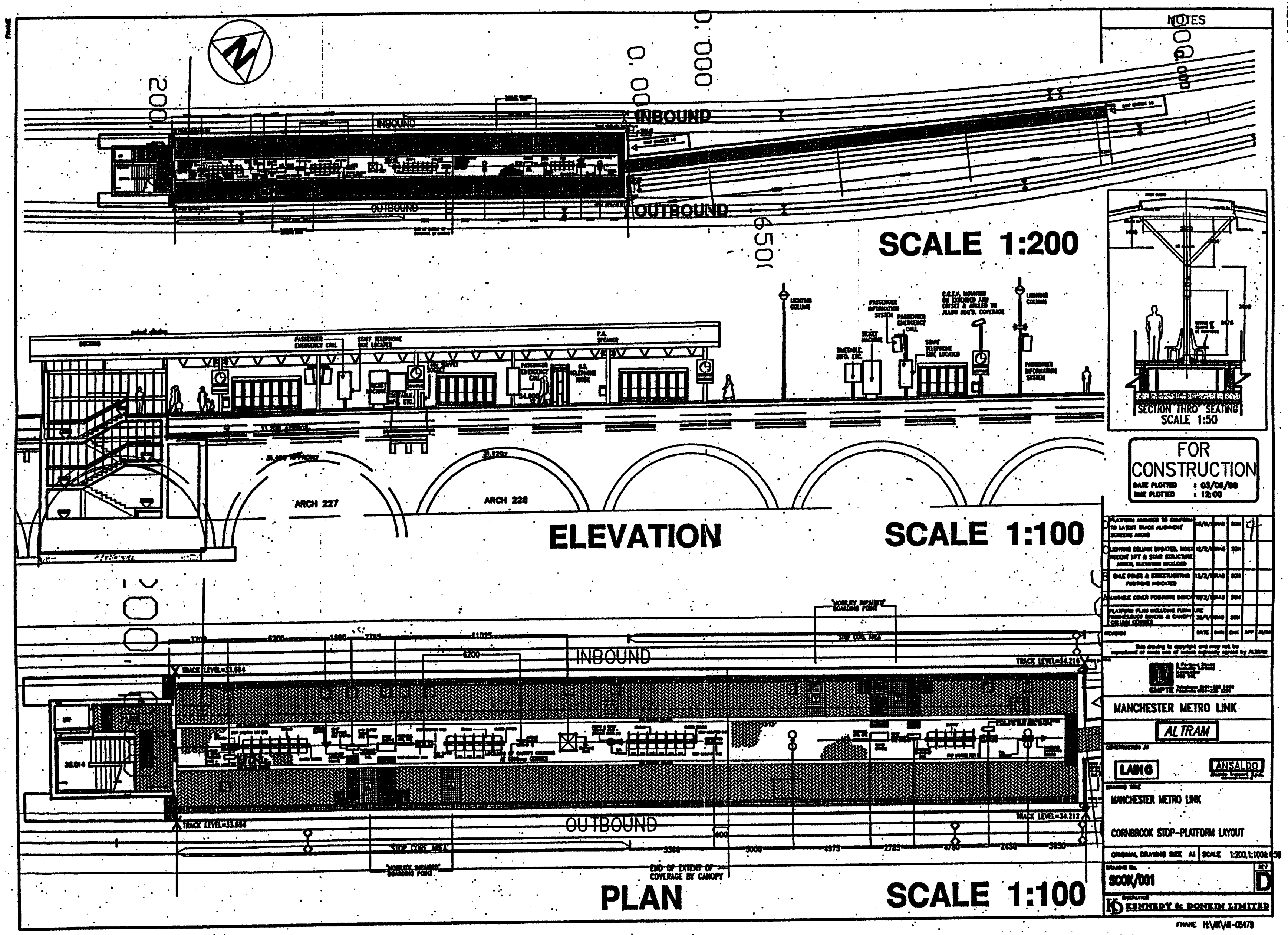

NOTES
INBOUND
OUTBOUND
SCALE 1:200
SECTION THRO' SEATING
SCALE 1:50
FOR
CONSTRUCTION
ARCH 227
ARCH 228
ELEVATION
SCALE 1:100
INBOUND
OUTBOUND
PLAN
SCALE 1:100
MANCHESTER METRO LINK
ALTRAM
LAING
ANSALDO
MANCHESTER METRO LINK
CORNBROOK STOP-PLATFORM LAYOUT
SCOK/001
D
KENNEDY & DONKIN LIMITED

Figure 2

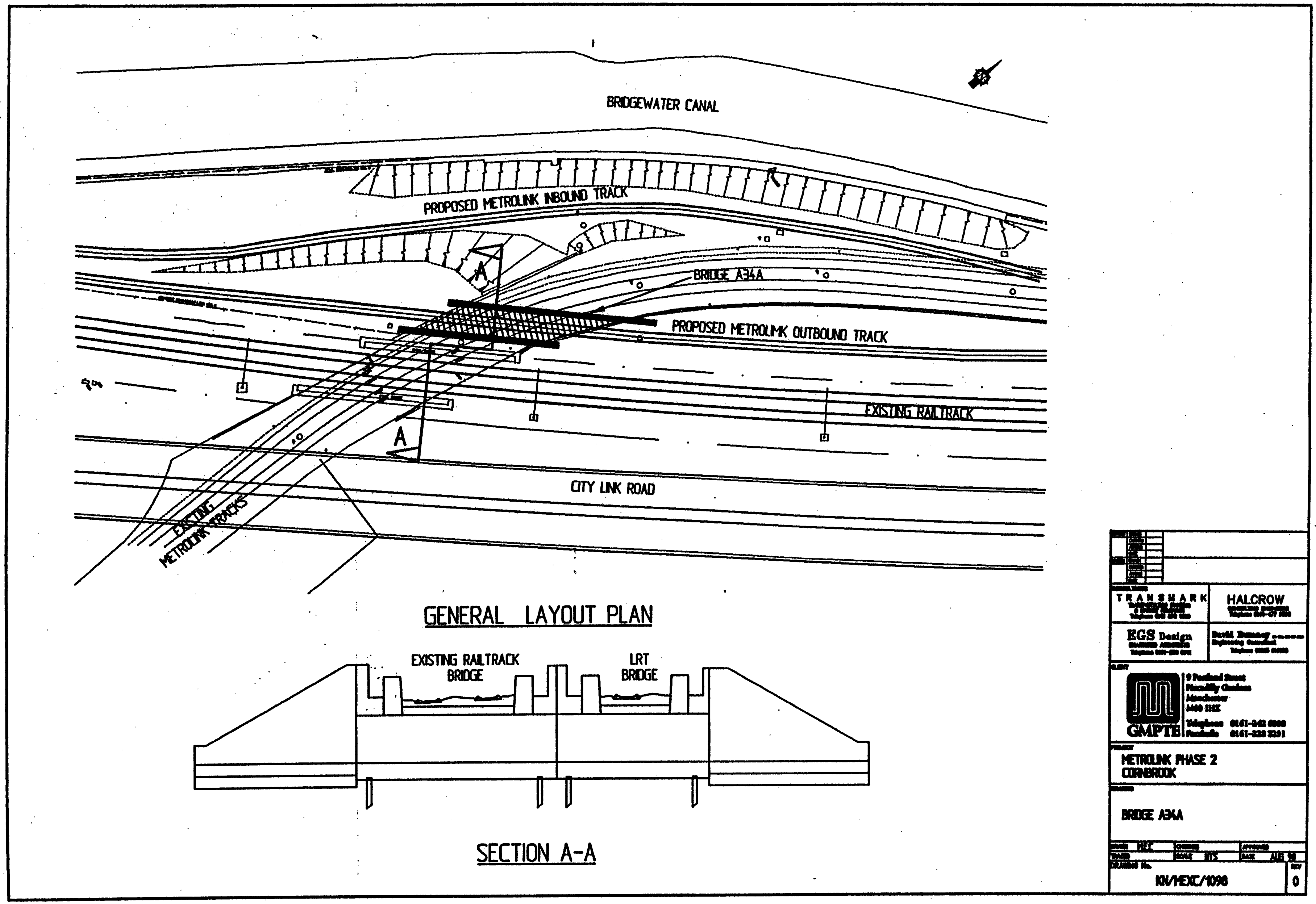
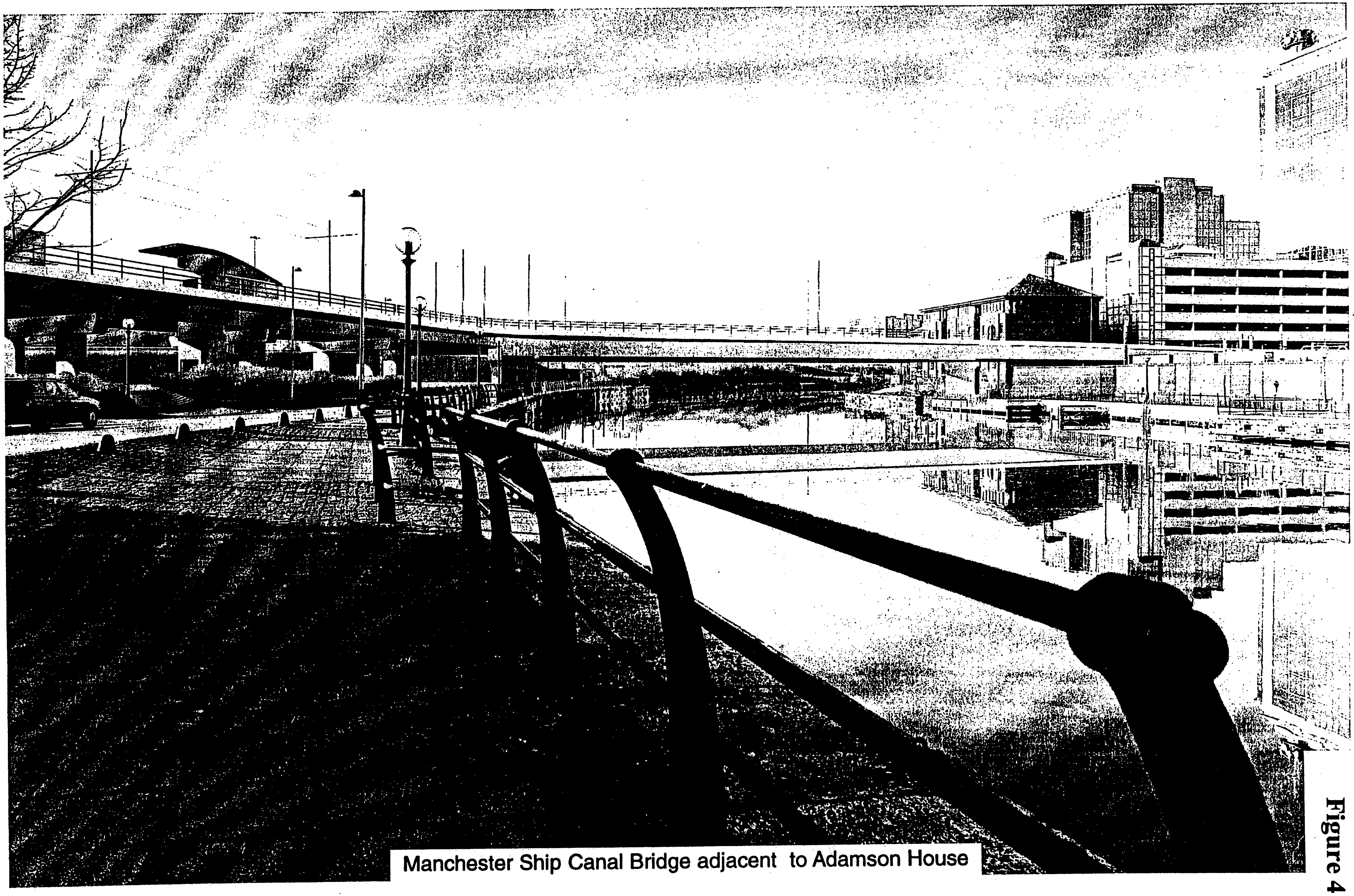

BRIDGEWATER CANAL
PROPOSED METROLINK INBOUND TRACK
BRIDGE A34A
PROPOSED METROLINK OUTBOUND TRACK
EXISTING RAILTRACK
A
A
CITY LINK ROAD
EXISTING METROLINK TRACKS
GENERAL LAYOUT PLAN
EXISTING RAILTRACK BRIDGE
LRT BRIDGE
SECTION A-A
TRANSMARK
HALCROW
EGS Design
GMPTE
METROLINK PHASE 2
CORNBROOK
BRIDGE A34A
NTS
KN/MEXC/1098
0

Figure 3



Manchester Ship Canal Bridge adjacent to Adamson House

Figure 4

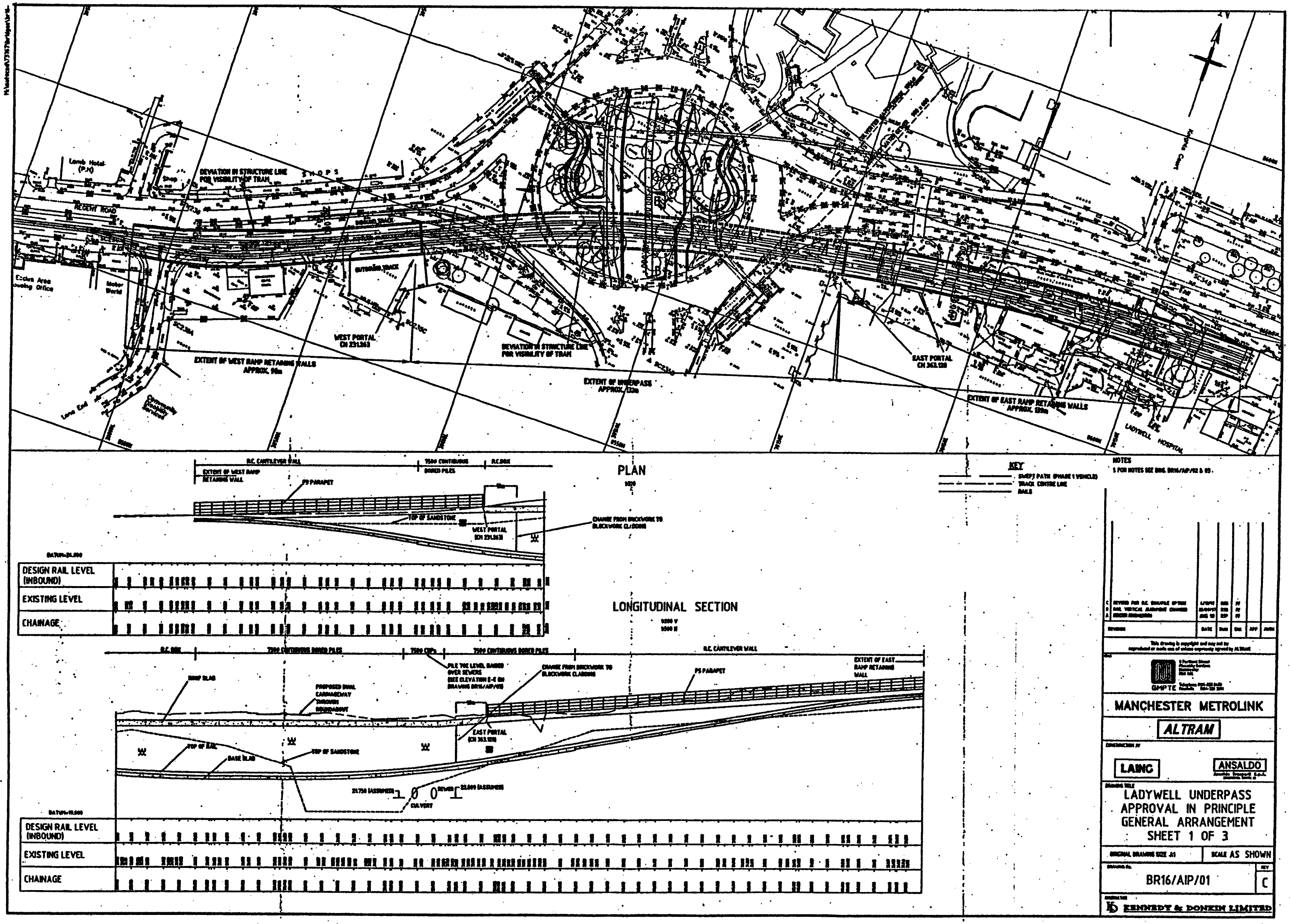

PLAN
LONGITUDINAL SECTION
DESIGN RAIL LEVEL (INBOUND)
EXISTING LEVEL
CHAINAGE
DEVIATION IN STRUCTURE LINE FOR VISIBILITY OF TRAM
WEST PORTAL
EAST PORTAL
EXTENT OF WEST RAMP RETAINING WALLS APPROX. 90m
EXTENT OF UNDERPASS
EXTENT OF EAST RAMP RETAINING WALLS
LADYWELL HOSPITAL
KEY
NOTES
MANCHESTER METROLINK
ALTRAM
LAING
ANSALDO
LADYWELL UNDERPASS
APPROVAL IN PRINCIPLE
GENERAL ARRANGEMENT
SHEET 1 OF 3
SCALE AS SHOWN
BR16/AIP/01
C
KENNEDY & DONKIN LIMITED

Figure 5

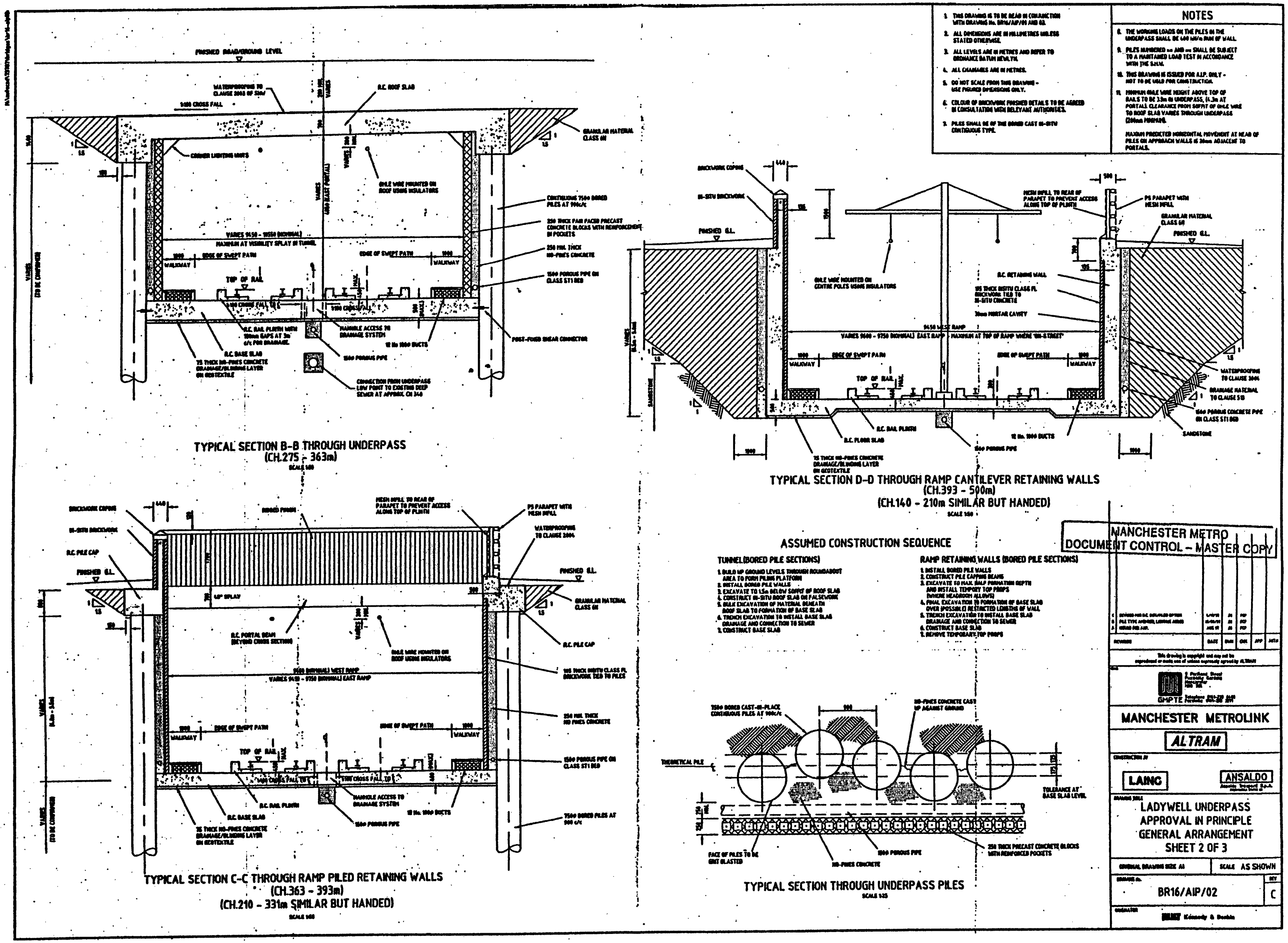


Figure 6

CH King Page 14

Seminars in association with Infrarail 98

Light Rapid Transit, 1 October 1998, Manchester

LRT under Portsmouth Harbour

Britain's first immersed tube rail tunnel

1. Introduction

The South Hampshire Rapid Transit (SHRT) Project, Phase 1: Fareham - Gosport - Portsmouth, is a proposal by Hampshire County Council and Portsmouth City Council to introduce a Light Rapid Transit system into South East Hampshire. At an estimated capital cost of £150M, it represents the development of a major new piece of public transport infrastructure and breaks new ground for the promoters from an engineering perspective and in obtaining the necessary enabling legislation. Perhaps the key to the success of the scheme is the connection of the Gosport peninsula to the City of Portsmouth by using an immersed tube tunnel to cross Portsmouth Harbour. This also distinguishes the project from other LRT schemes, planned or built, in the UK.

2. Project description

The route is between Fareham's town centre in the north, and Portsmouth's city centre in the south. From Fareham it utilises a disused railway alignment to travel down the densely populated spine of the Gosport peninsula, before emerging on-street to travel through the town centre of Gosport. Gosport is situated on Portsmouth Harbour, the home of the Royal Navy and a thriving commercial port. The link across the harbour is currently made by a passenger ferry which carries approximately 10,000 passengers a day. The immersed tube tunnel would enable a seamless journey, in just under half an hour, along the 14km route. With an anticipated peak hour service frequency of 7 1/2 minutes, the sixteen stops will provide access for an estimated 18,000 passengers, daily. In the absence of SHRT, a considerable number of these journeys may be undertaken by car, with consequent adverse effects on the environment. The location and outline of the scheme is shown in Figure 1, which clearly illustrates the advantages of an estuarial crossing. Indeed a trip from the middle of the route to the Portsmouth terminus would cut the journey time, travelling round the harbour by car, in half.

3. Programme

On the 6 March 1998 a draft Order, under the Transport and Works Act 1992, for powers to construct and operate the scheme was submitted to the Secretary of State for the Department of the Environment Transport and the Regions (DETR). An extensive publicity programme accompanied the application and to date 447 objections, 10 representations and 14 letters of support have been received by DETR. They are primarily concerned with scheme details and not the overall principle. Work is now being undertaken by the project team, based at Gosport, to overcome the objections through negotiation, prior to Public Inquiry which is likely to be held in February 1999.

In tandem with the legislative process, funding is being actively pursued from both the public and private sectors. An initial submission under Section 56 of the 1968 Transport Act, has been made to DETR. The forecast operating ratio for the scheme is 1.8:1. An Outline Business Case (OBC) was assembled in early 1998. It is intended to submit the OBC in early 1999 following further work. The aim is to ensure that funding mechanisms are in place when the Powers are granted.

4. The choice of tunnelling method for SHRT across Portsmouth Harbour

Pre-feasibility studies into the engineering costs and economic viability of the scheme, carried out between 1989 and 1990, quickly identified design criteria which would strongly influence the tunnel design. Particular to the operation of a public transport scheme was the importance of integration with the Gosport bus station and the Hard public transport interchange at Portsmouth; both are situated immediately on the harbour front. Stops would provide considerable patronage for the scheme as well as fulfilling transport policy aspirations.

A bored tunnel through the surrounding complex ground conditions would require deep workings, 9m of cover is needed above the tunnel crown. Expensive underground stops at the interchange points could not be avoided without exceeding the operating gradient of LRV's. When compared to the cost of immersed tube construction a bored tunnel is 33% more expensive.

An immersed tube tunnel would require only shallow workings with the crown positioned about 2m below the over dredging limit for the harbour bed. This will enable an LRT stop to be located adjacent to the Gosport bus station, and a further stop providing access to the Hard interchange in Portsmouth.

5. The immersed tube method of tunnel construction

The concept of providing a sub-aqueous crossing using the technique of sinking pre-fabricated units within a dredged trench across the bed of a river or estuary is well established. Since the 1960s the popularity of the technique has blossomed in Europe. In 1991 and 1996, road tunnels were opened under the River Conwy and Medway, the first and so far only immersed tube tunnels in the UK.

The large reinforced concrete units are generally cast in a casting basin or dry dock. After casting the units are sealed with temporary bulkheads and fitted with a range of floatation equipment including ballast tanks. At the same time a portal is constructed ready to receive the first unit.

The next stage is to dredge a trench across the harbour to match the profile of the tunnel. The casting basin is then flooded and the units floated out and manoeuvred into position ready for the immersion equipment to be fitted. Lowering is achieved by controlled flooding of the ballast tanks to induce a slight negative buoyancy so that the unit becomes suspended from cables attached to immersion pontoons. The unit is lowered to with in a few centimetres of the previous unit or portal, and placed onto temporary foundation pads at the bottom of the trench. Hydraulic jacks are engaged to form an initial seal between a steel plate on the perimeter of the portal or previous unit, and a continuous rubber gasket on the unit to be installed. The water trapped between the two bulkheads is then pumped out and the water pressure on the free end of the unit compresses the rubber seal to form a watertight joint.

A layer of sand is pumped into the void space beneath the unit to form the permanent foundation. The trench is back filled to bed level with locking sand, a coarser backfill, and finally rock armour to prevent damage from ship anchors and scour. As the ballast tanks are emptied and removed, additional concrete is placed to prevent floatation.

When all the units are in place the temporary bulkheads are removed and a second permanent joint is constructed. The tunnel is now ready for fitting out.

6. Tunnel unit cross section design

Each tunnel unit has to have sufficient buoyancy to enable controlled floatation and structural strength. Although these are details for final design, enough details at this stage of outline design should be known to establish cost estimates. The client dictates the internal functional areas which depend on the future SHRT network, safety in the event of fire and maximisation of the tunnel's revenue generating potential.

SHRT, Phase 1 has been developed on a 2.4m wide LRV. Future phases of the network may use the wider standard size of LRV at 2.65m and include rubber tyre vehicles with a different guidance system. The tunnel has, therefore, been designed to cater for the largest developed kinematic envelope and the possible mix of LRV types.

This approach allows sufficient room for emergency vehicle access to accidents in the tunnel. Bearing in mind the fire incident in the Channel Tunnel, the smoke control strategy plays an important part in the cross section design. It is usual to arrange for the evacuation of tunnel occupants to a safe haven in the event of fire, which naturally leads to single track tunnels segregated by a fire rated partition with escape doors at regular intervals. Jet fans are proposed for smoke control. The size and number is currently based on 15Mw fuel load, sufficient to allow the future operational use of the tunnel by an electrically powered guided LRV which also has a volatile alternative fuel load on board.

The tunnel is the key to the project viability and has an estimated capital cost of £40M. Revenue streams are being explored from the development of this cross harbour link. Already a number of Statutory Undertakers have approached the project to use the tunnel as a conduit for their apparatus. Taking the above factors into account the likely minimum cross section is 11.5m wide by 7.5m high.

7. Outline construction sequence

The tunnel is 1km long although the length of the immersed tube portion is approximately 670m. It is extended as far as possible to allow the float in of the pre-cast units and provide sufficient depth of cover to guard against uplift due to tidal movement. The optimum length of the individual tunnel units is a combination of the available casting facilities and, for Portsmouth Harbour, the requirement to maintain navigation.

In a similar way to traffic diversion for carriage way repairs, the marine traffic must be kept free flowing and at a safe distance from the works. Extensive ship simulation trials have been necessary to find suitable diversions, in the narrow fast flowing harbour entrance, acceptable for construction and marine safety. As the navigation channel is skewed to the Gosport side of the harbour the optimum solution envisaged is for six tunnel elements, three on the Gosport side of 107m in length and three on the Portsmouth side of 116m in length.

No vessel movements would be allowed during the operation of lowering each element into place, which takes eight hours. Fortunately there is a period of neap tides every two weeks with a cycle that occurs at the quiet period of harbour activity from

11.00pm to 7.00am. All the elements would have to be placed on one side of the harbour before they could be placed on the other.

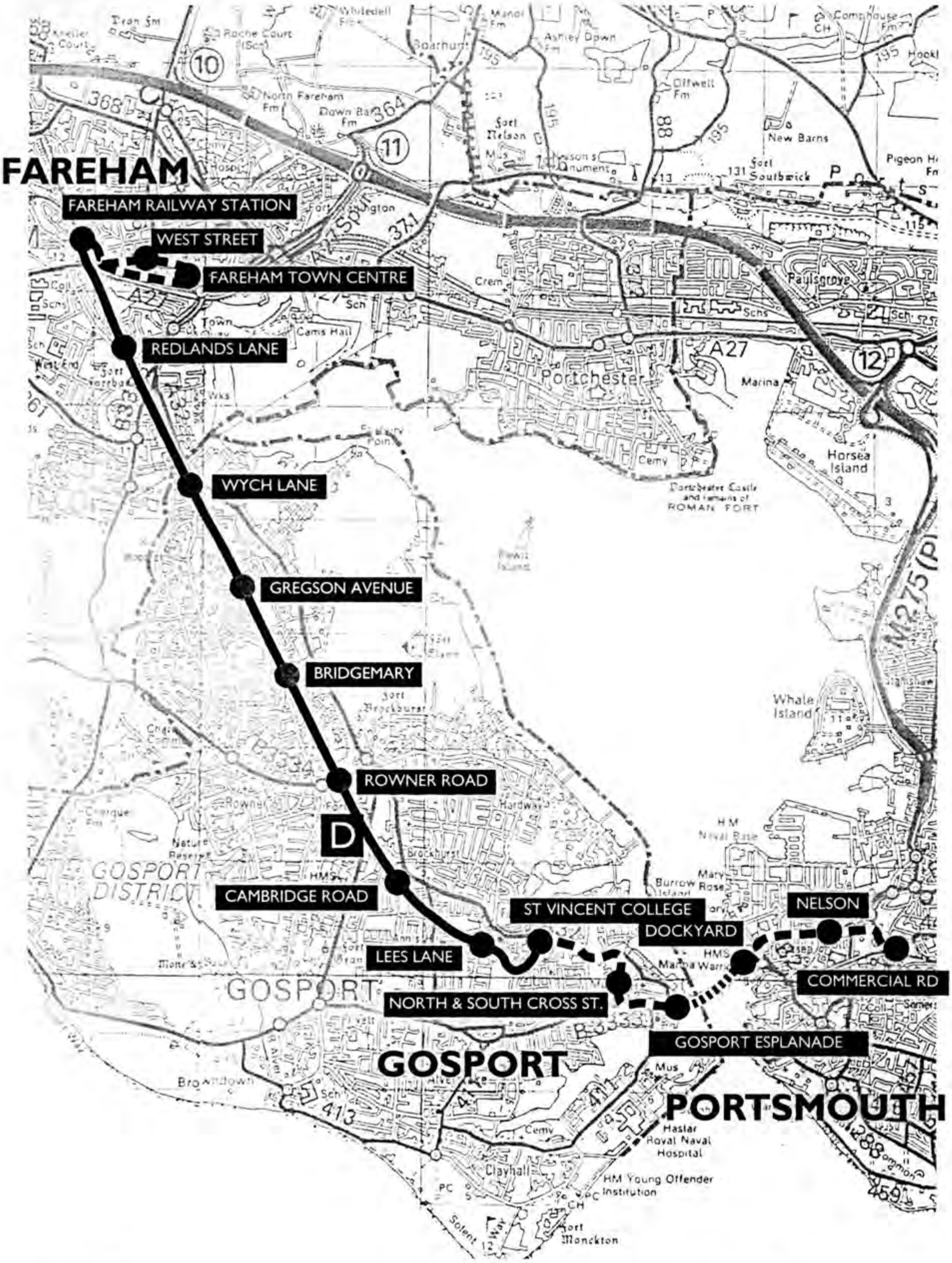
8. Summary

The case for SHRT to connect the Gosport peninsula with the centre of Portsmouth has been proven to bring significant environmental and economic benefits to the area. The immersed tube crossing enables significant patronage to be captured with minimum impact on the densely packed hinterland. Through out a three year construction period for the tunnel it is expected that the harbour will only be completely closed for the placing of the six tunnel elements. As part of the TWA process the last 18 months has seen exhaustive consultation with the many harbour interests. Perhaps a measure of the our success, in establishing an achievable method of construction, is that the objections received from those parties consulted in the harbour were smaller as a percentage than any other group.

Author: M A Gannon

Date: September 1998

Phase 1 Fareham - Gosport - Portsmouth



●	Stop	utilising disused railway line	Segregated Route
●	Interchange Stop	▬ ▬ ▬	Street Route
D	Depot	▮▮▮▮▮	Tunnel

HAMPSHIRE COUNTY SURVEYOR'S DEPARTMENT

September 1996

Lewisham Extension to DLR

Infrarail 98 - 1 October 1998

<u>Bridge Structures, Stations & Tunnels</u>

N Gray - Docklands Light Railway Ltd
W Shepherd - Mowlem Civil Engineering

Lewisham Extension Benefits

- DLR network serves London Docklands area North of the River Thames
- Rapidly expanding market - now 25m passengers p.a.

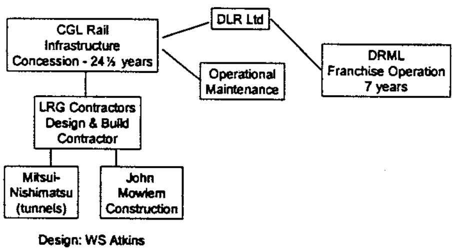
- Lewisham Extension will open up new markets & opportunities by providing a link South of the river
- Key route for local residents, Kent-based commuters and tourists visiting Maritime Greenwich

- Journey times: Lewisham to Canary Wharf 17 mins
- Anticipated passenger levels 12-16m

Procurement

- Procured under the Private Finance Initiative
- Concession awarded to CGL Rail for 24½ years based on a performance/output specification
- Construction phase 1996-2000 with work being undertaken by LRG Contractors
- Operations phase 2000 - 2021
- In the operating phase CGL Rail will:
  - make extension available for train operations
  - maintain, repair and clean the infrastructure
- DLR Ltd will provide train service (via franchisee)

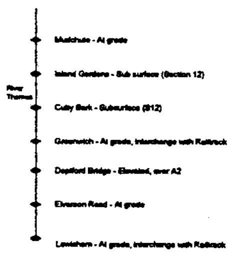
The Contractual Matrix



Overview of Construction

- 4.2 km extension to existing 22 km light rail network

- Heavy civils content
  - 1.1 km in twin bored tunnels
  - 0.6km cut & cover tunnels
  - 0.8km 20 span viaduct
  - 7 stations incl 2 interchanges
- Systems
- Integrating into Existing Railway



Tunnel Layout

- 40% (1.7 km) of Extension is in tunnel
- Combination of cut & cover tunnels at each end with 1.1 km twin bored tunnels under the Thames and Greenwich town centre
- Two subsurface stations
- Single cross passage & sump
- Side walkway at train floor level plus fire brigade squeezeway on the opposite side
- Tunnel ventilation supplied by 4 banks of 3 fans at each sub surface station
- Configured to clear smoke from incident tunnel and keep non-incident tunnel free of smoke

Bored Tunnels

- Method & Geology
- Geology: Terrace Gravels, Woolwich & Reading Beds (sands, clay & limestone bands), Thanet Sands
- Closed face slurry type shield
- 5.85 OD, articulated shield, 200m min radius
- Manufactured by Kawasaki & Markhams
- Constructed by Mitsui-Nishimatsu
- Precast concrete segmental lining, 1200mmW x 250mmT, 5 ordinary + 1 key, by Buchans

- Facts & Figures
- Length 1080m x 2
- Max depth 20m
- Spoil: 58,000m³ deposited on local park to overcome flooding problem
- First bore:May-Oct 1997, Second bore Nov to Apr 1998
- Drive rates: 1 day = 22.8m, 1 week = 104m, 1 mth = 340m
- 1 cross passage dug under dewatering & compressed air (<1 Bar)

Cut & Cover Tunnels

- North Side

- 420m long
- twin single track tunnels
- Routed under public park
- Local road diverted to run over tunnel
- Constructed utilising diaphragm walling

- South Side

- 160m long
- mostly twin single track tunnels
- severe geometric constraints through Greenwich station leads to short section of double track tunnel
- Combination of insitu RC, diaphragm walling and contiguous bored piling

Cutty Sark Station

- Sub surface station alongside historic town centre
- Local authority, in conjunction with English Partnerships, are co-operating to assemble land and promote a property development over the station
- 6,500 sq m mixed residential & retail 3 storey development over 3 storeys
- Station box nearly complete and fit-out underway
- Development construction start Jan 1999

Cutty Sark Station - Structure

- 1.2m thick 27m deep diaphragm walls
- O/A size 62.4m long x 24.5m wide x 23m deep
- Excavated 35,100m³ of sands & gravels, Woolwich & Reading clays & Thanet Sands
- Well point de-watering system during construction
- In permanent state resists floatation by dead weight
- Island platform 18 m below ground

Greenwich Station Blockade

- Shoe-horning DLR into existing Railtrack/Connex SE station
- 8 week blockade completed on time during summer 1997
- Single line reversible working for Connex services
- Existing listed station building underpinned
- New DLR cut & cover tunnel built between building & re-aligned Connex tracks
- Roof of tunnel forms new Connex Up Platform
- DLR on steep uphill gradient to allow same level cross platform interchange at London end of station

Deptford Viaduct

- 800m long 20 span viaduct, crossing Deptford Creek 5 times
- Post-tensioned
- Over-water spans incrementally cast
- Piers founded on bored piles
- Reinforced earth approaches
- Spans 26m to 62.5m
- Headroom approx 5.6m
- Construction start April 1997, completed July 1998

River Diversion

- River Ravensbourne diverted over 415m length to allow railway to follow old river channel
- River diverted into a 450m long environmentally sensitive channel meandering through adjacent park
- New river alignment has vegetated sloping banks replacing concrete channel
- New alignment designed to cope with 69 cumec flood

Box Jacking

- Running tunnel under Railtrack embankment at Lewisham
- Min cover 1.7m
- 5,000t pushed with 24 300t jacks
- 48m long x 6.2m high x 17m wide

- 3 pedestrian subways at Greenwich & Lewisham
- 14m to 31m long

- By Edmund Nuttall/John Ropkins Dec 1996 to Feb 1998

Stations

- 5 new stations south of the Thames
  - two interchange stations: Lewisham & Greenwich
  - Deptford Bridge straddles busy trunk road (A2)
- 2 replacement stations north of river
- 2 of the 7 are staffed sub surface stations
- Rest unstaffed but linked back to central control with CCTV, public address and alarm points
- Full accessibility for mobility impaired passengers
- All being built for two car trains (56m platforms) with passive provision for extending

- Next few slides provide information on the systems elements of the project and are included for background information
- Not part of the Infrarail presentation

Trackwork

- 720t of BS80A flat bottomed rail by BSC
- Min radius 96 m (cf Existing Railway 40m)
- 0.95 km on ballast, 2.7 km on slab track
- 3 scissors crossovers & 1 siding
- GERB floating track used in tunnels under Greenwich (0.45 km)
- Extensive use of Getzner resilient pads under baseplates
- Extensive noise barriers: 850m of barriers on both sides plus 300m with barriers on one side
- Tracklaying commenced July 1998

M&E Systems

- Power supply: 3 intakes providing duplicated supply
- Rated at 9MVA with 8MW for 750vDC traction supply
- Power supply & building services by London Electricity Contracting

- 4 hydraulic lifts and 2 electric lifts being built by Elite
- Cutty Sark has 2 banks of 2 public service rated compact escalators with rises of 11.5m & 6.9m being manufactured by O&K

Signalling

- New route to be covered by an extension of the SELTRAC system used on the Existing Railway
- Alcatel SELTRAC is a transmission based automatic train control (ATC) system based on the moving block principle
- Moving block allows shorter headways than traditional fixed block systems
- ATC incorporates
  - automatic train protection (ATP): vital checked-redundant ("2 out of 3") computers
  - automatic train operation (ATO): non-vital
  - automatic train supervision (ATS): non-vital

Communication Systems

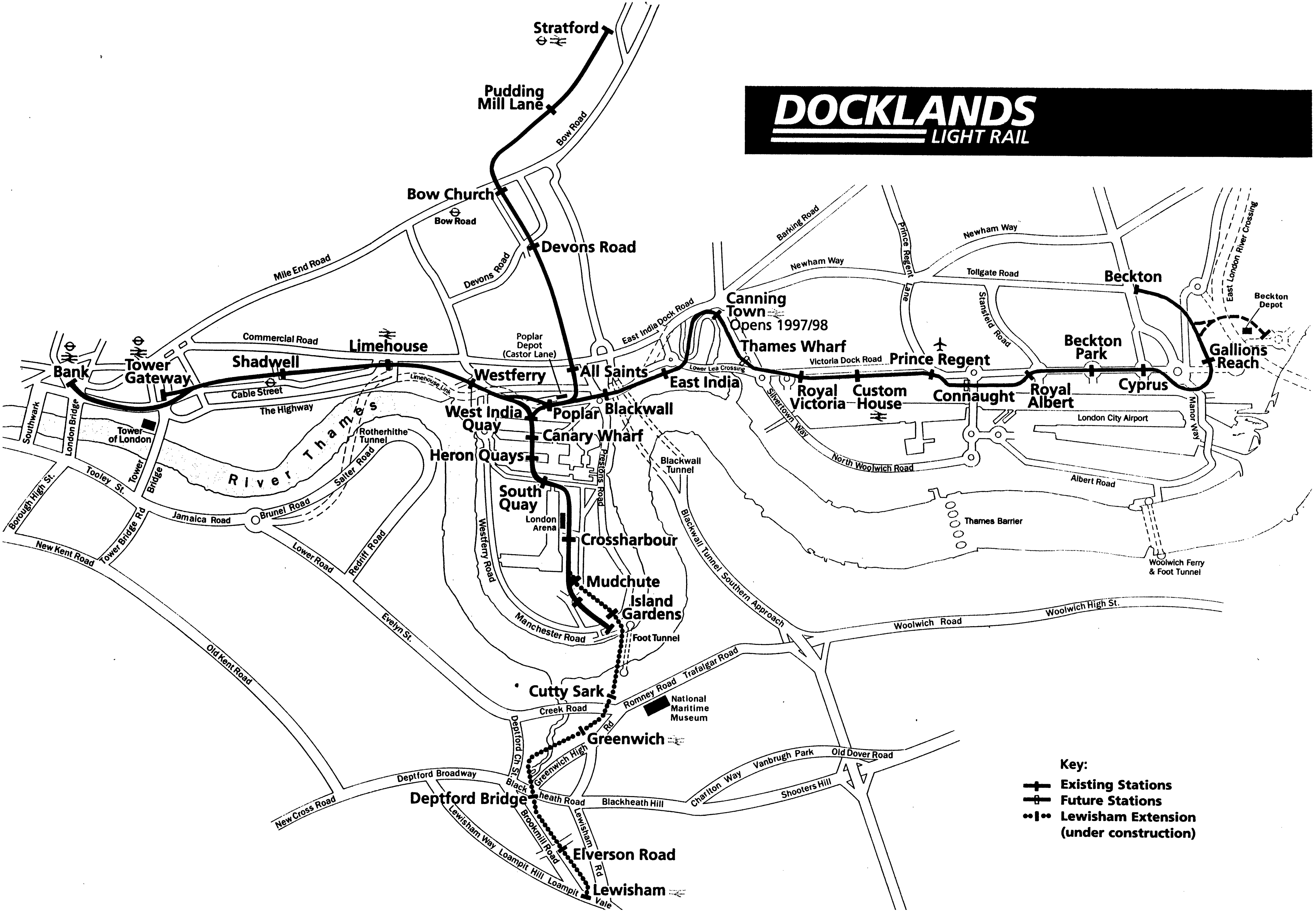
- CCTV: 60 camera add-on to existing 112 camera system by Optical Networks Ltd. Includes video recording & link to BT Police
- Radio: extension to existing 2 channel UHF system plus tunnel & sub surface station leaky feeders all by Simoco
- New Hicom 300 PABX by Siemens plus 75 phones
- Optical Fibre Backbone utilising 28 fibre cables in a dual redundant ring & 9 node topology
- Add-on to Long Line Public Address plus passenger alarms
- SCADA: New Transmitton Cromos 2000 dual redundant warm standby system covering Existing Railway & Extension with 28 existing & 8 new outstations
- Ticketing: 23 new Cubic Transport Systems touchscreen ticket vending machines
- Infra-red automatic passenger counting system by Acorel

History of Project

- 11 years from initiation to start of construction
- 1985: Suggested by London Borough of Lewisham to aid regeneration of Borough
- 1988-90: Feasibility studies, Environmental Impact Assessment, Final Route
- 1990-93: Parliamentary phase, one of the last Private Bills before T&W Order procedure introduced
- 1994-96: Bidding phase
- 1996: Concession awarded

Project Partners

- CGL Rail shareholders:
  - John Mowlem & Co
  - Hyder Investments Ltd
  - Mitsui & Co UK plc
  - London Electricity plc
- LRG Contractors:
  - Joint venture
  - John Mowlem & Co
  - Mitsui-Nishimatsu
  - Design sub contracted to WS Atkins
- DLR Ltd:
  - publicly owned holding company under DETR
- DRML:
  - subsidiary of Serco plc


DOCKLANDS
LIGHT RAIL
Stratford
Pudding Mill Lane
Bow Road
Bow Church
Bow Road
Devons Road
Devons Road
Mile End Road
Barking Road
Prince Regent Lane
Newham Way
Newham Way
Tollgate Road
Stansfeld Road
East London River Crossing
Beckton
Beckton Depot
Canning Town
Opens 1997/98
East India Dock Road
Commercial Road
Limehouse
Poplar Depot (Castor Lane)
Thames Wharf
Victoria Dock Road
Prince Regent
Beckton Park
Gallions Reach
Bank
Tower Gateway
Shadwell
Westferry
All Saints
Lower Lea Crossing
East India
Cable Street
Limehouse Link
Royal Victoria
Custom House
Connaught
Royal Albert
Cyprus
The Highway
West India Quay
Poplar
Blackwall
Silvertown Way
London City Airport
Manor Way
Tower of London
Canary Wharf
Southwark
London Bridge
Rotherhithe Tunnel
River Thames
Heron Quays
Prestons Road
Blackwall Tunnel
North Woolwich Road
Albert Road
Tooley St.
Tower Bridge
Salter Road
South Quay
Borough High St.
Jamaica Road
Brunel Road
London Arena
Thames Barrier
Westferry Road
Crossharbour
Blackwall Tunnel Southern Approach
New Kent Road
Tower Bridge Rd
Lower Road
Redriff Road
Woolwich Ferry & Foot Tunnel
Mudchute
Island Gardens
Woolwich High St.
Woolwich Road
Manchester Road
Evelyn St.
Foot Tunnel
Old Kent Road
Trafalgar Road
Romney Road
Cutty Sark
National Maritime Museum
Creek Road
Greenwich
Greenwich High Rd
Deptford Ch St.
Vanbrugh Park
Old Dover Road
Charlton Way
Shooters Hill
Deptford Broadway
Blackheath Road
Blackheath Hill
New Cross Road
Deptford Bridge
Lewisham Way
Brookmill Road
Lewisham Rd
Loampit Hill
Elverson Road
Lewisham
Loampit Vale
Key:
Existing Stations
Future Stations
Lewisham Extension (under construction)

Practical Application and Operation of Light Rail Signalling

H SAFFER AND P J GROSS
Sheffield Design and Property and Symonds Travers Morgan

Introduction - Sheffield Supertram

The Sheffield Supertram system is the third new Light Rail Transit system (LRT) in the UK in recent times. Dominantly a modern tramway system, it comprises about 29 kilometres of new track formation with about 50% in segregated sections and 50% on-street in mixed running traffic in tram only or tram/bus lanes. The system commenced operation from the city centre to Meadowhall in Spring 1993 and the full system opened in October 1995. The system has now been fully operation for over two and a half years without any significant technical problems. This paper seeks to review experience of system operation and control in the light of both Operator and Highway Authority viewpoints.

LRT Signalling - Design Principles and Requirements

Safety Considerations

In addition to the normal safety related facilities available on TR 0141 traffic signal controllers, which are also available for LRT use, special intergreen extensions are employed which only operate following the passage of a tram through a junction. These timings are controlled through tram detector loops.

Maximising LRT Priority

A multi-loop tram detection arrangement on each approach allows tram phases to be called early to provide maximum priority. In UTC areas and at closely spaced junctions, linking cables between junctions provide advanced indication of a tram approaching a series of junctions so that all the signals can respond quickly.

Minimising Delay to other Traffic

The same tram detection technique which allows the early call of a tram phase on an approach also ensures that the tram phase (and where possible the following extendible intergreen) is terminated as quickly as possible as the tram passes into the junction. This reduces delays to other traffic.

Method of Implementation

Detailed consideration was given to the LRT specification of the signal controller facilities at the design stage of the project; both to maximise priority and to ease setting up, adjustments and maintenance of the system. As a result, most of the signal configurations use standardised LRT facilities with little additional programming. Additionally special handset facilities were provided on signal controllers to simplify LRT timing adjustments and the diagnosis of potential LRT faults, in particular from LRT lamps and detectors.

Signalling Systems

The LRT signalling system employed in Sheffield is shown in Figure 1

The signal controllers are Microsense MTCs, with LRT control and monitoring facilities and integral lamp and LRT detector monitoring was developed especially for the Supertram contract. The LRT signals were produced by GEC(now PEEK) to comply with DoT, Railway Inspectorate and Supertram requirements. The tram detection system, VIS(Vehicle Identification System), was provided as part of the main Supertram contract by Siemens and was based on a similar system used in Tuen Mun. AVL(Automatic Vehicle Location) facilities to monitor tram movement were added to the VIS system part-way through the installation process.

The existing Sheffield City Council PEEK TMS UTC system was extended with the addition of another UTC VAX cell and a number of LRT and other UTC software developments relating to new facilities provided on the traffic controllers. Several new CCTV cameras were also added to the UTC system to help monitor and control potential problems where trams pass through congested areas.

Highway Authority Perspective

Operation of the System

Generally it is felt that the attention paid to the detailed specification of the signalling system at the design stage has minimised the time required to maintain and operate the facilities. The signal timings in particular are quite robust. as the tram ' proceed' and the following intergreen periods automatically respond to the speed of trams passing through the junction. This means that few adjustments have been necessary to set precise green and intergreen periods solely to match the average tram running speeds. At the same time, the signalling system provides a high degree of confidence to tram drivers that their priority is being maintained as they cross the junction, even at quite variable speeds on an approach.

Extent of Priority - a Changing Viewpoint

Initially, prior to the installation of the Supertram System, the Highway Authority's view on tram priority was fairly conservative and it was anticipated that a high degree of priority would only be given at a limited number of sites. Over a period of time this position has changed considerably. This reflects both local pressures in relation to improving the operation and viability of Supertram, and the changing view nationally where greater emphasis is now being given to the implementation of integrated transport systems and improvements in public transport in general. As a result, the signals have been adjusted at many sites to provide a very high degree of tram priority. This work, in addition to the resolution of some early problems with the VIS detection equipment has considerably reduced tram delays at signals.

Operational Changes and Adjustments

Where changes to the LRT signal control has been required, normally to improve tram priority, it has normally been possible to carry this out by simple timing adjustments to LRT operation within the traffic controller on site, or in the UTC plan. However in some circumstances, signal reconfigurations have also been carried out, occasionally introducing some special conditioning to enable special facilities to be introduced. A high level of cooperation between UTC and Supertram staff has enabled progressive priority improvements to be made on a continuing basis. Supertram AVL data is frequently analysed to assess the effectiveness of any changes implemented. There was a considerable amount of signal development and 'tweaking' initially but recent modifications have been relatively minor.

Use of Monitoring Facilities

In operating the UTC system, considerable use is made of CCTV screens in the UTC control room. The new UTC cameras have been very useful to staff monitoring key Supertram junctions. UTC staff liaise closely with Supertram personnel at the LRT control room and with the Police, assisting the efficiency of tramway operation especially when there is an obstruction or other incident.

Equipment Maintenance

The Supertram signal controllers and most of the street equipment is maintained under the Highway Authority's overall contract for signalled installations. The LRT signal heads(and lamps) and VIS tram detection loops are maintained directly by Supertram fixed equipment staff and contractors.

From the start of Supertram operations, the hours of signal maintenance were extended from the normal 08.00 to 20.00 to cover the full tramway operational hours, 06.00 to 24.00 at all appropriate junctions. However these hours now apply to all signals in the Sheffield area. More recently, key complex junctions have been identified for faster initial response with 45 mins of call-out.

LRT Operator's Perspective

Key Objectives

Whilst appreciating the role of the Highway Authority in managing the safe and free flow of all traffic, the financial criteria for Section 56 grant required the Supertram operator to cover at least the operation and maintenance costs of the system and ideally a percentage of the capital cost. The aim of maximising revenue and patronage is therefore a key consideration. A competitive travel offer must therefore be made to potential passengers which includes reliable, regular headways and competitive journey times, particularly at peak periods, when contrasted with other transport modes, for which a premium fare can be obtained. That at least is the theory.

Approach to Priority

During the planning stage in the early 1990s, it was decided to provide the tram service with large 250 person design capacity vehicles at 6 minute headways rather than adopt smaller vehicles at closer headways which would impose greater delays at junctions through increased demands for priority. Given the extended passenger waiting times at stops and park and ride sites with the current 10 minute headways, it is essential that the service pattern ensures minimum journey times and reliable headways through out the day. The vertical and horizontal alignment design constrains tram speeds but are essentially fixed. Therefore minimising delays on on-strret links and at junctions has been the focus for performance improvement.

The Operator has always expected a high degree of priority at junctions although the Highway Authority was initially concerned about the impact on other road users. However early experience indicated the need to increase tram priority at key junctions and to implement both an AVL monitoring system for efficient service operation to maintain headway and to establish a close working relationship with Sheffield UTC control staff. Amendments to signal settings and configeration was therefore a joint effort which has created significant run time benefits

Operational Control

Safe traffic control practise is essential on any LRT system. All tram drivers and control staff must fully understand the user end of LRT signal control and be confident that there is a consistent approach throughout the alignment. Detailed training is provided to drivers and control room supervisors, with the assistance of UTC staff, to ensure safe but assertive driving and control techniques which will still maximise the likelihood of maintaining timetable operation. The use of AVL combined with radio communication has ensured that the LRT control are aware of tram locations and can amend driver operation if required by a blockage or incident. This is backed up by coordination with UTC staff and the recent implementation of a direct link from UTC to LRT control to allow the input of tram demands at junctions when equipment fails.

The Potential for Future Improvement

The programme for amending signal control is now virtually complete. Further improvement must rely on the increased segregation of trams from other traffic. This possibility has already been progressed in the implementation of tram/bus gates and the diversion of conflicting traffic movements. However these measures must be largely self-enforcing to produce real benefits in delay reduction. The impetus to extend these measures is supported by government policy to pursue modal transfer The implications of traffic diversion can be area-wide and require holistic traffic management strategies to balance public transport priority with local access requirements

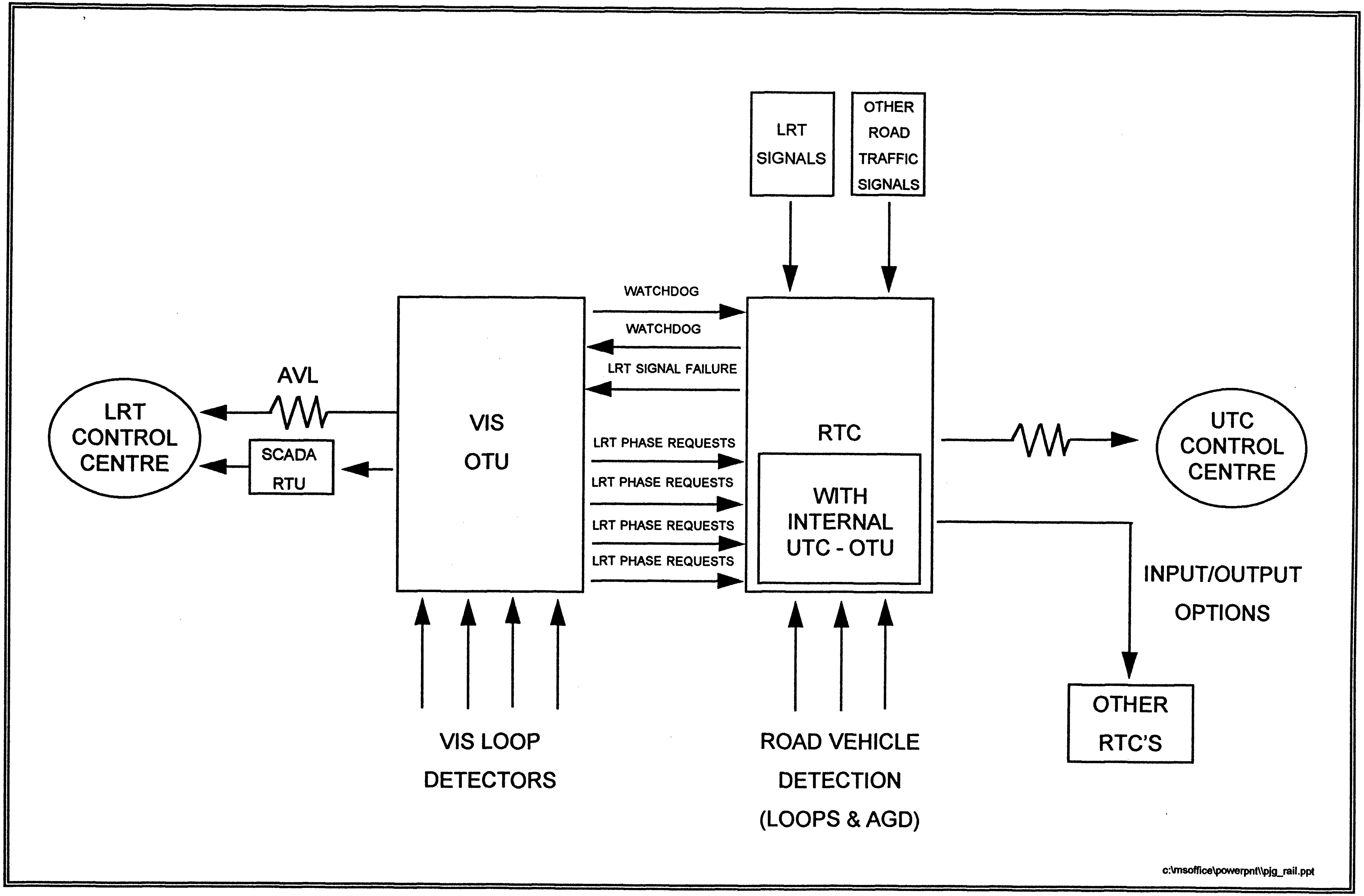


Figure 1 - Supertram signalling system diagram

17 YEARS EXPERIENCE OF TYNE & WEAR OPERATION ON METRO TRACKS

MR IAN CLAYTON
MR PETER JOHNSON
Nexus, Newcastle Upon Tyne, England

BACKGROUND

Metro consists of some 59 route kilometres, 43 of which are ex British Rail, 16km are new construction with 5km of this in tunnels. Existing routes were taken mostly from the North Tyne Loop which was a passenger line, Kenton Bank Foot from South Gosforth which was a single freight line and Gateshead to Tyne Dock where use was made of freight lines. New construction of lines was from Tyne Dock to South Shields and in the centre of Newcastle. At Jesmond to the north of the River Tyne the Metro diverged from the old North Tyne Loop under the centre of Newcastle over the River on a new bridge, under Gateshead and rejoined the old British Rail freight line. In the east of the City Centre the Metro diverged from the North Tyne Loop at Chillingham Road and the alignment passed closer the Centre of Byker before passing under the City Centre to terminate at St James.

Major construction works included Byker Viaduct, bridge over the River Tyne, north-south, east-west tunnels and building of 18 new stations of which seven were major works underground in Newcastle Upon Tyne. Accommodation works for British Rail included a new railway line referred to as the Benton-Backworth diversionary route which was constructed to provide a new line for their sole use to replace the traffic facility which had been lost due to the conversion of the North Tyne Loop to Metro.

Major part of the Metro system was designed to make maximum use of the existing suburban railway inherited from British Rail. Consequently in the interests of economy, and after various investigations, it was decided that no radical change needed to be made to the track gauge and other standards for new construction works. This decision was supplemented by the agreement with British Rail who would install the new track whenever possible with their own machinery and labour.

Standards for new track, therefore, were laid down as 113^{A} FB BS 11 rail on F27 concrete sleepers with 300mm of whinstone ballast on the surface alignments. Choice of rail section, was in the main dictated by supplies from the manufacturers to meet delivery dates, and future rolling of non-standard sections could create further problems on supplies in small quantities for track maintenance.

Track in the tunnels south of the river were laid on ballast with conventional standards. This decision was taken because the tunnel drive was large enough to accommodate the depth of ballast required and also future allowances for packing of track in case of minor settlements induced from collapse of old mine workings.

Tunnels north of the river which are all in more stable ground are laid with concrete tied sleeper block tracks. The diameter of the tunnels were kept to a minimum to limit the amount of excavation, therefore depth of construction was more suitable for a concrete bed than ballast. Also account was taken of drainage from water seepage and future maintenance of the track.

Concrete in this respect, being more preferable for future 'maintenance-free' track. Track bed construction consisted of maximum depth of 200mm with minimum of 40mm bottom in-situ concrete reinforced with mesh. The tied sleeper blocks consisted of two precast blocks, one under each rail, basically 550 x 350 x 160mm deep joined together with steel angle iron. These were placed into position on the bottom bed concrete and packed and lined to give the correct alignment and level. Top concrete was then placed reinforced with 10 No 10mm dia bars parallel and 9 No longitudinally between each tied sleeper. Depth of top concrete was placed nearly level to the top of the sleeper blocks to give a maximum of 200mm with a minimum of 40mm below each block. Drainage channels, ducts for cables and pockets for signalling equipment were shuttered out at the concreting stage. Rails are 113^{A} FB rails 18.3m long and site thermit welded to give continuous welded rail throughout the entire tunnels both north and south. All welds were ultrasonically tested for any flaws in the final quality. Rails are seated on rubber pads and held in position with Pandrol clips, nylon insulators, with the pandrol housing cast into the tied sleeper blocks.

At Haymarket and St James Station crossovers are laid in standard CV $9^{1}/_{4}$ 113lb FB vertical rail with jarrah timbers. Timbers and steelwork were laid in position and infilled with in-situ concrete level to the top of the timbers.

Byker viaduct was designed to accommodate concrete slab track as an integral part of the structure. On the viaduct the alignment consists of a reverse curve of 390m radius with 60m long transitions and maximum cant of 100mm. Concrete slab under each track is 2200mm wide with a minimum thickness of 165mm under the rail seat. Track bed was laid using the British Rail/McGregor slip form paver to give the desired profile and the concrete slabs were broken in 18m intervals to provide drainage channels and also to prevent the slab acting with the viaduct deck to resist bending. The slip form paver was used conventionally across the viaduct to give 'in-situ' concrete slab, reinforced with continuous high yield deformed steel bars and pandrol housings. Rails are 113^{A} FB section thermit welded together and seated on 10mm thick rubber pads with Pandrol clips and nylon insulators.

Special rail expansion switches were installed at the expansion joints in the viaduct deck. These are designed to accommodate 200mm of expansion due to movement of the viaduct which in future years is expected to have creeped and shrinkage and it is expected that the expansion gaps will have to be re-adjusted in a few years time.

Similar expansion switches are installed on the Tyne bridge except they are adapted to accommodate 250mm of movement which includes bridge and track expansion and contraction. These switches have the addition of check rails across the gaps to protect the joints at maximum opening.

Throughout the Metro system particular care has been taken to provide good track drainage which is essential to relieve future maintenance problems and track current leakages. In area of poor formation extensive track blanketing of conventional design has been used to provide drainage. Basics of the track blanketing is bottom fill with graded hardcore, protective membrane linked to drainage pipes and top fill to separate the track ballast.

<u>Appendix 1</u>

Design Parameters

Width of Platforms	3.0m min
Height of Platforms	900.0mm
Length of Platforms	65.0m
Clearance between platform edge and car	100mm
Height of car floor above platform	60mm
Track gauge	1432mm
Minimum radius of curvature - Passenger lines	210.0m
Minimum radius of curvature (Depots)	50.0m
Minimum vertical curve	1600.0m
Maximum gradient	1 in 30
Maximum speed of cars	80km/h
Acceleration	$1m/s^2$
Maximum service braking	$1.3m/s^2$
Emergency braking	$2.32m/s^2$
Tare weight of vehicles	39 tonnes

STANDARDS

Because of joint user with British Rail between Benton and Callerton British Rail standards were adopted in respect of size of rail etc and track maintenance standards. BR had right to inspect our maintenance standards for suitability of running their trains (25 ton axle loads, compared with 10 ton for Metro).

STRUCTURE

All Permanent Way activities are carried out in-house apart from welding. Including track renewals on rolling programme.

3 Permanent Way Inspectors
3 Track Chargemen
4 Patrolmen
7 Machine Operators
28 Trackmen
3 Tamper Operators

Under the Track Group Manager who is responsible for Permanent Way, Signals, Communications and Overhead Line and Power Supplies.

Assisted by Permanent Way Maintenance Engineer and Permanent Way Technical Services Engineer who provide the maintenance and supervision of staff and technical support. They also set standards and competence levels which are audited and monitored on regular basis.

MAINTENANCE

All maintenance apart from small items such as lifting and packing are carried out during track access when there are no trains running.

The maximum period is 5 hours, therefore intensive planning is required to carry out the necessary maintenance programme.

A 08-16M Plasser and Theurer tamping and lining machine is used to maintain the track geometry. This machine has a 6 channel recorder to measure the track geometry and to indicate where future works are required.

This backed up by the Alrian Rider Track Recording System which gives the indication of the track by measuring horizontal and vertical accelerations.

Other plant consist of:

3 battery works locomotives

5 ballast hoppers

4 flat wagons

2 Spoil wagons

PUM relaying system

2 Road/Rail Unimogs with attachments

eg Crane
Flail
Weedkilling Sprays
Tree Cutter
Grinding Machine

1 Road/Rail pickup with Hiab crane

The structure gauge is such that Mainline plant cannot operate on Metro tracks because of the wire height of 3070. Therefore most plant has to be specially adapted for Metro.

DEFERRED MAINTENANCE

When BR knew they were loosing the track, which was eventually to be handed over to Metro, track renewals and maintenance were given low priority in BR's programme for renewal and maintenance and subsequently BR gave Metro £4m for deferred maintenance to be spent on track renewals and extra maintenance to bring the track up to standard for Metro operations.

This inaugurated a track renewal programme from 1979 on an accelerated basis up to 1986 when approximately 25km of track had been renewed. Since that time on average 2km of track are renewed every year on a rolling programme.

SIDE WEAR

After approximately 6 months of operations side wear of the rails on the sharper curve (down to 200m radius) was causing concern, we were using BS II rail as specified in the contracts for new build.

The trains have on board lubrication, but this did not stop the side wear as the lubricating oil was too light and also the problem of maintaining the on board lubrication system. Track lubrication were installed on all curves of radius less than 1000m. A total of 28 track lubricators were installed.

The rail specification was changed to 1% chrome for the high leg of curves of less than 1000m radius. This increased the life expectancy of the rail to a minimum of 10 years depending upon the radius of the curve.

We are now using MHT (Mill Heat Treated) rail which has a harder head to the rail. One of trade-offs of using track to steel to reduce side wear was the effect on the Metrocar tyres which started to wear prematurely, but this has now been addressed by having harder steel in the tyres.

CORRUGATIONS

As in common with all railways. Corrugation appears on the head of the rail. This phenomena can occur at almost any location and occurs on all type of track construction, ie concrete or wood sleepers, curves and straight, steep gradients and level tracks.

This is being controlled by grinding the rails with our own grinding machine which was purchased in 1989 basic machine but does the job.

DRAINAGE

As on most railways this is one of the most important factors in the construction of the formation and one that is most often neglected in track maintenance when resources and other factors are limited.

This was noticeable on the track inherited from BR and extensive works have been carried out in deep stone blanketing together with new drainage to alleviate the problem.

In the tunnels the drainage channels are very small and shallow and are often blocked by litter and refuse eg crisp packet can block channel. The only remedy is to have a regular programme of channel clearance.

FENCING

In an urban area such as Tyne & Wear, the maintenance and provision of fencing causes concern.

Vandalism is a problem in our area and continuous programme of maintenance and renewal is carried out.

It is our experience that it is more economic in the long term to provide steel palisade fencing in areas of particular concern. Although the cost is high, maintenance and repair costs fall dramatically.

VANDALISM

As with other railways and as identified in the recent Health & Safety Executive report vandalism, is on the increase and is a problem.

This is being addressed by providing better fencing and high profile policing by a dedicated Metro Police force.

Incident such as placing objects on the track, putting ballast in the points still occur, but fortunately no major accidents have occurred.

Also the problem of fly tipping is prevalent at certain locations on the system. Environmental Protection Act lays down certain standards that must be maintained and this can be a drain on resources.

We prosecute individuals who are persistent offenders and partnerships with Local Authorities are being investigated to reduce the problem.

NOISE

A very emotive topic at certain locations but it has been proved that Metro is quieter than the original suburban service. Although no special measures have been taken to reduce noise, the levels achieved fall within the accepted range. Probably the greatest cause of noise is badly corrugated rail and this can be reduced by rail grinding.

A particular noisy viaduct at Howdon does cause a problem to neighbours and has resulted in a speed restriction being imposed on the viaduct (40 kph).

LEGISLATION

Over the past 17 years substantial new legislation has been introduced for railways, especially in the field of Health & Safety. The Executive give Health & Safety paramount importance to this subject. Nexus Metro has an Approved Railway Safety Case

Accordingly all staff have the necessary training and supervision to carry out their duties.

It has been a "culture" change for the staff who have accepted that new practices have to be adopted and as a result the work place has become a safer area. The record on the Permanent Way Section is very good and in 17 years of operating, there has not been one derailment attributed to the condition of the permanent way and no staff fatalities.

BYKER VIADUCT

This viaduct was constructed using a slip form paver machine with the pandrol housing installed in situ.

Problems have started to occur with the loosening of the pandrol housings and the subsequent loosenings of the pandrol clips. This has been resolved by diamond drilling the existing housing and inserting new ones in an expoxy mortar cement.

There is still a problem with the pandrol clips becoming loose and investigation is ongoing to resolve this problem.

TRANSITION SLABS

Where the track in the tunnels join the track on ballasted formation, transition slabs were constructed to accommodate the different formation construction.

Generally they have performed as designed but, as usual there is one particular location where a problem in maintaining the alignment occurs. This has been investigated and no solution has been found apart from extra maintenance to correct the alignment.

AIRPORT EXTENSION

Metro was extended by some 4km from Bank Foot to the Airport in 1992. This was a design and build contract worth some £12m. The Specification for the permanent way was such that it has required very little maintenance since it was opened.

The Specification included a geotextile membrane for the full length of the extension together with excellent drainage, all CWR with wear resistant rails on the curves.

PROPOSED SUNDERLAND EXTENSION

If all goes to plan and finance can be obtained it is proposed to extend Metro to Sunderland over Railtrack infrastructure and then continue the University and South Hylton on a new alignment (in fact redundant BR line).

A new company will be formed and the extension will be built using PFI with a hoped for completion by the end of 2001.

Sunderland Metro - Challenge and Opportunity

Ken Mackay
Project Director
Tyne and Wear Passenger Transport Authority
Newcastle upon Tyne
U.K.

PROJECT KEY FACTS

Background

- Metro owned and operated by Nexus (Tyne and Wear Passenger Transport Executive)
- Core network progressively brought into use between 1980 and 1984
- Further extension to Newcastle International Airport in 1991 resulting in completion of the present day 58.5km network
- 35 million passenger journeys in 1997-98 generating total revenue of £22 million
- Most efficient railway in UK in terms of performance against punctuality targets
- Current implementation of efficiency programme and fare increases strategy on track to eliminate need for operating subsidy by 2000

Sunderland Metro

- Extension of the existing Metro network to Sunderland City Centre and beyond to South Hylton
- Sunderland the only district in Tyne and Wear not directly served by Metro
- Significant added value from cross-city and cross-river journeys and allows more intensive use of existing assets (existing Metrocar fleet sufficient to operate extension)
- New solution to track sharing to allow longer distance inter-urban passenger services to share track with light rail and rail freight services over 14.5 km upgrade of existing Railtrack route
- 4.5 km extension is new construction
- 8 new stations (with upgrade of 4 existing Railtrack stations) 10 minute Metro frequency throughout day between South Hylton and Newcastle with 8 trains (6 Metros 2 RRNE) an hour linking the two cities (doubling existing frequency)

Timetable

- Application for Order under the Transport and Works Act submitted May 1997
- Public inquiry held in 1998 - decision expected later in 1998

- Project advertised in OJEC August 1997
- Shortlist of bidders to be drawn up winter 1998
- Concession award end of 1999
- Metro in operation in December 2001

PFI/PPP Proposal

- Extension to be designed, built, financed and maintained (DBFM) by private sector
- Finite concession agreement: 20 to 30 year duration
- Concession agreement to regulate relationship and pre-determine standards
- Operation of services and stations will remain with Nexus in the public sector
- Nexus will carry development and promotion costs and obtain powers to acquire land
- Nexus will obtain revenues from operating services, expected to exceed operating costs, generating funds to pay charges to concessionaire and access charges to Railtrack
- Railtrack recognises commercial investment opportunity
- Approximate cost of £100 million - 50% to be met by private sector, £15 million from ERDF and £35 million from grant funding being sought from UK Government

Economic And Financial Case

- Robust underlying financial case even against improbable downturn
- Public sector financial appraisal demonstrates operating surplus of £51.3m PV leading to a deficit of £16.27m PV after capital and renewal costs
- Restricted Economic Appraisal of Central Case indicates significant non-user benefits of £25.84 m PV and benefit:cost ratio of 1.14:1 leading to eligibility for Section 56 grant
- Full Economic Appraisal of Central Case shows benefit:cost ratio of 3.03:1
- Maximum risk transferred to the private sector within DBFM model

Delivery And Commitment

- Identified as highest priority in Tyne and Wear Package and City of Sunderland TPP
- Local authorities have proven track record in delivering successful partnerships to promote and implement regeneration
- Project supported by key partners including Railtrack and business community

CHALLENGE AND OPPORTUNITY

(i) Statutory Regimes

- Powers to acquire land and provide the infrastructure will be acquired under the Transport and Works Act 1992
- Operational powers will be obtained under the Railways Act 1993

The existing system is authorised by acts obtained under the private bill procedure. Whilst this procedure has been replaced by the Transport and Works Act 1992 for the purposes of constructing and operating railways, the key difference between the existing operation and the Sunderland Metro Project is how it is to be operated. The existing system is vertically integrated i.e. Nexus owns the land, infrastructure and rolling stock assets and operates the Metro service and stations. Nexus has a Rail Safety Case approved by the HMRI. The existing system is exempt from the Railways Act 1993. This is not the case for the extension.

Early agreement was reached with Railtrack that the shared portion of the route between Newcastle and Sunderland would remain part of the national rail network. It will therefore continue to be owned and operated by Railtrack. Furthermore, the existing train and freight operators would continue to enjoy access to the route under the terms of their existing track access agreements – albeit amended where appropriate. Nexus will therefore have to assume a new role i.e. that of a licensed train operator.

This in itself should not be a problem for Nexus which is an experienced operator of some 18 years standing. However it will be required to submit for the approval and agreement of Railtrack, a new rail safety case dealing with that part of its operation which will access the Railtrack network before obtaining its operating licence from the Rail Regulator. This introduces some interesting issues concerned with the compliance to railway group standards which peculiarly, may be more difficult for an established operator to deal with as opposed to a completely new operator.

In the context of the overall project, Nexus will have another important role to play. Under the PFI it intends to procure a special purpose company to provide the extension infrastructure necessary for a fixed period of time. Nexus is currently obtaining the powers to do so under the TWA. The order sought will importantly include the power to transfer to the successful concession, any functions necessary for the complete discharge of its obligations. The concessionaire will receive its income over the life of the project which will be derived from the revenues collected by Nexus. Thus the project will be provided under one regime whilst the ability to earn revenues will be governed by another regime. This clearly will add an extra dimension to the already complex PFI procedure.

(ii) Shared Track Operation

- Identification of key risks
- Quantified risk analysis
- Mitigating measures
- Infrastructure/operational controls
- Joint approach with statutory authorities

Shared track operation is fundamental to the Project – it is not an option. The challenge presented by the necessity of keeping the trains apart is the identification of appropriate mitigating measures which avoid substantial modifications to the Metrocars themselves. If a train is built to UIC standard then a Metrocar is built to ½ UIC standard. It will be immediately appreciated that modifications to such a vehicle would inevitably result in what constituted a virtual rebuild to bring it up to full UIC standard. Therefore, in a joint risk assessment, Nexus and Railtrack have concentrated on identifying infrastructure based solutions.

The preferred option, and the one on which the Project is currently based revolves around the use of two systems namely:

- Metro's own ATP system and;
- Railtrack's TPWS system

The combination of the two, which would be fitted to all signals on the shared section of the route, are anticipated to deliver sufficient safety benefits to meet the requirements of the Railtrack Safety Case. TPWS is still under development by Railtrack and the trials recently undertaken on Thameslink appear encouraging. The green paper has been issued for industry wide consultation.

Physical contact between trains is not the only issue. Metrocars have far superior braking performance to that of their typical heavy rail cousins. Accordingly, the standard signal spacing which is designed for a wide range of heavy rail trains, would give rise to significant overbraking of Metro trains without the addition of measures such as the standard braking marker as used on the existing Metro network.

Allied to this are some other interesting factors such as Metro's use of kph and Railtrack's adherence to mph. The need to keep these conventions is essential as all operator's trains will not be captive to this section of route.

Metro will operate as DOO and therefore communication from control centre(s) to train will have to be provided in such a way as to maintain direct and secure links no matter where the train is.

Nexus will have to go through the vehicle acceptance procedure. Clearly it is not, and will not be compliant in all respects with the various group standards that will apply. However, an enlightened attitude is emerging which recognises that derogations will apply where they can be shown to be practical and safe.

(iii) Development Control

- Design and build
- Environmental impact
- Planning permissions
- Disruption

D&B affords the opportunity of providing cost effective and "fitness for purpose" solutions. Deemed planning permission can be sought under the T&W order. However, certainty as to the finished product cannot be established until the final designs have been drawn up. Absence of designs and the uncertainty that results, does not sit comfortably with local planning authorities nor the public inquiry process. Promoting authorities will prepare their specification in output terms. Therefore effective controls must be introduced.

Certain matters can be reserved for the normal planning application procedures. These could cover for instance, detailed design and appearance, highways and landscaping. Furthermore, formal planning controls, enforceable under development control procedures, can be introduced. Thus the method of construction can be effectively controlled to minimise adverse effects. It is primarily up to the promoter to decide the measures appropriate to the individual needs of a project but typically they might include hours of work, suppression of dust and noise, phasing of road closures and liaison with affected parties.

The trick is to establish the right balance between necessary and effective control during the D&B phase without unduly fettering the ability of the contractor to implement his own solutions. There are no tailor made solutions.

SEMALY

INFRARAIL 98

LIGHT RAPID TRANSIT

Environmental Track Design : Paved and Grass Trackbeds for Dublin

In urban zones with public transport systems such as tramway, respect for, or the creation of, a quality environment is of the utmost importance. The insertion of a steel-wheel tramway trackbed requires that its surroundings are considered from the following points of view:

- the visual impact and appearance involved in structuring public spaces. The putting down of high quality surfacing adaptable to a wide variety of projects so as to personalise the streets and squares is important. It should offer a pleasant journey quality to users of these public spaces by integrating a good drainage system of water flows.
- sound and vibration impact.
- the co-habitation of the roadway by its different users.

1. THE SURFACE COVERINGS

In this presentation we are not going to speak about the ballast type materials which are more adapted to traditional railway projects. In fact this traditional material is not really an option as a surface covering in urban sites. Railway trackbeds involving the use of ballast don't facilitate other road or pedestrian circulation. It is difficult to keep clean because ballast tends to retain litter. The granular materials involved can also act as projectiles which would be easy to use in the case of foul-play or urban violence.
Gluing techniques exist but they are still at the trial stage.

The laying of ballast requires heavy duty compacting. This type of work site is generally not adaptable to dense urban areas.

Some cities, for economic investment reasons, have adopted the solution whereby a tarred or asphalt covering is put over the layer of track ballast. This technique is not adapted to present day urban demands for variety in surface treatment materials.

We will speak about the main types of surface treatment for pedestrian and road spaces which are used in most of today's urban projects. The DUBLIN project involves a certain number of these materials:

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- natural mineral coverings such as stone in the form of slabs or paving stones or in the form of crushed and compacted aggregate (chipping)
- pre-fabricated concrete based coverings: different sizes of modular blocks poured in place followed by treatments to have the surface either smooth or rough or printed.
- black top
- surfacing treatments involving the use of grass.

For all of these surfacings the architect in charge of the surfacing treatment of the road system and the railway trackbed, continuously seeks to minimise the visual impact of the railroad structure. In general only the two fine lines of the rails for each track remain visible. But on the other hand, we are aiming to give the LRT a segregated right of way. In city centre , this is achieved by raising the trackbed by around 5 cm, above the road level. This would allow overtaking but would make permanent use uncomfortable for car drivers. Different coloured surfacings are also used to enhance the visual aspect of the track.

The durability of this fitting out of the surface depends for a great part on the quality of the underlying track system.

2. THE SOUND AND VIBRATION IMPACT

2.1. VIBRATION

The high frequency of passing vehicles rolling on a railway trackbed is a source of sound and vibration emissions. Acceptance of the transport system by the public and residents requires that the level of sound and vibration emissions be kept to a minimum. The choice of track-laying system and the surface coverings adopted are decisive factors.
Track is laid on a foundation of non reinforced concrete. Apart from its railroad stabilising function, the trackbed, when in an urban environment, should filter vibrations and even moreso when the track is close to buildings which are vibration sensitive. This filtering should be compatible with the surfacings in that it should respect their initial appearance and ensure their conservation. It should therefore be invisible and not excessively elastic which could have a destabilising influence.

There are 2 approaches to reduce vibration.

1) absorption of the vibration using an oscillating mass
2) deformation of the track system.

deformation is not appropriate for an LRT. It would lead to damaging of the surface structure.
Therefore, our design is based on the oscillating mass damping approach using a concret slab or a prestressed sole plate.

2.2. NOISE

The principle of noise mitigation is to prevent the vibration of the rail the vehicle moves on. This is achieved by a strong fastening of the rail foot into the concrete.

3. CO-HABITATION OF THE DIFFERENT ROADWAY USERS

In dense urban zones it is often necessary to construct a tramway trackbed which could be shared with local car traffic, cyclists and pedestrians. Surface coverings have to take this factor into account when being chosen but areas where the rails will be crossed also need special treatment.(e.g.junctions)

A concrete slab is used not only as a track foundation but also as a surfacing foundation ensuring good stability of the whole track system. The surfacing is designed so as to be above the rail level everywhere in order to:

1) ensure proper drainage of the surface through the groove,
2) prevent the rail to be an obstacle to,
3) avoid the risks of cars skidding on the rails

4. WHICH TRACK SYSTEM DESIGN CAN MEET ALL THESE DEMANDS ?

4.1. THE DESIGN

4.1.1. Track

The track system chosen for the DUBLIN project allows all these demands to be met: it is the « rigid » track system developed by SEMALY and used with success in several cities in FRANCE as well as in Geneva in SWITZERLAND.

The system requires a minimum ground bearing capacity of 20 Mpa (corresponding to a quite poor soil condition). The thickness of the slab is 30 cm, and the overall thickness of the system is 70 cm.

The concrete allows for even settling of the formation along the line and also for very fine adjustement of the levelling of the rail which is carried out by means of jacks.(The accurrracy of the levelling is +/-1mm).

The space between sleepers is 75 cm but is reduced to 60 cm in curves with radii less than or equal to 150 metres.

The sleepers are embedded in a « blocking » concrete, class C35, having an average thickness of 23 cm. This concrete receives a curing treatment for the initial setting period. This concrete is protected from adverse weather conditions by the surfacing. This is the reason why it does not need to be reinforced.

4.1.2. Drainage.

The quality of the drainage is absolutly essential to keep the urban environment good and to minimize stray currents.
Provided the type of surfacing is adapted to the traffic loads, the design of the drainage is made very easy on a concrete slab support.
Fast water removal is thus guaranteed. The drainage is usually oversized compared to standard carriageway drainage.
This is very important in limiting stray currents as water is the prime current vector especially when stagnant on the surface.

4.1.3. Treatment of Vibrations

Anti-vibration treatment cannot be allowed to absorb vibration energy through deformation because this would adversely affect the durability of the surfacing. It is obtained by oscillating masses (either the total weight of the track system including the resilient material (principle of the floating slab), or by pre-stressing the resilient material under the sole plate of the rail (principle of the ASP track laying)). The quality of this damping in relation to the surfacings is its vertical and horizontal rigidity. This is because the rail twists under the action of the wheel especially in tramway curves where radii are short. A high level of guaranteed vibration reduction with limited deformation could only be given after numerous trials and experiments which allowed a good knowledge of the frequency ranges of the whole light rail vehicle/track system.

4.1.4. Rail insulation

Traction energy current return to the electrical sub-stations is ensured by the rails. For this, an equipotential electrical link between the four rails is set up. In order to minimise losses between sub-stations which are far apart, the best electrical insulation needs to be found. This insulation is also the main interface between the rail and the surfacing. This insulation is subject to both longitudinal and transversal forces. The quality of the materials and of the joints used as well as their installation should allow the insulation to resist deformations caused by both the rail and surfacing systems.
The material used is a foam, with a polyurethane sealant joint on top

4.2. TRACK LAYING IN DUBLIN.

For the Dublin project the track laying is carried out in accordance with the design criteria described hereabove. The choice of surfacing was made by the CIE architects, their design being in accordance with Irish standard but adapted to tramway track constraints provided by SEMALY.
These contraints depend on the type of traffic loads and frequency.
In the system proposed by SEMALY, all surfacing is traditional and therefore is fully adapted to ensure the continuity of the track surfacing with its urban environment.

4.2.1. Track laying using modular blocks :(Either natural or manufactured)

For track laying involving paving we firstly need to respect the minimum dimensions recommended as a function of the expected car traffic flows. Therefore for light traffic, pedestrians and occasional private cars, the thickness of the paving ordinarily doesn't exceed 8 cm. Where traffic is more dense and the thickness must be increased and a specifically designed. From an engeneering point of view, this alteration is not recommanded. We prefer in this type of case, to use a black top surfacing, subject to architectural acceptance. Even for high density traffic at junctions or mixed tram/buse right of ways, a reinforced black top surfacing is proposed.

The bed layer must be properly designed as, its alteration would lead to a loosening of the block laying which would therefore be maintained only by the joints.

The laying of modular blocks in Dublin involves:

- a paving stone, 8 cm thick, which corresponds to the recommendations for heavy lorry road systems with medium traffic flows. This thickness leaves room for an acceptable thickness of the laying bed of the blocks which guarantees an even levelling surface.

- The joint between the blocks should contribute to the rigidity of the whole but it cannot be the main holding element for the paving because it is too vulnerable to external conditions. The joint to be used in Dublin is a non-shrinking mortar for the granite paving stones and sand for the concrete modular blocks.

- The whole rests on a 25 mm bed of mortar for the granite paving stones and gravel with a grain size of 2 to 4 mm for the concrete modular blocks which are adapted for places where space is restricted but which conserve the weight bearing and drainage qualities of this material. This weight bearing capacity is even improved in that the material can be compacted, even with vibrations, without damaging the track system whose design was described hereabove.

- A longitudinal drain between each rail carries water to the transversal water collector boxes, or to the transversal channels located every 50 metres.

4.2.2. Grass laying

Grass track laying in Dublin :

The system consist of :

- a geotextile envelope laid on the concrete slab ensures a good drainage and retains at the sametime enough moisture for the grass.
- The geotextile is flexible enough to fit correctly to the shape the fastening devices of the rails.
- Grass up to the level of the rail, (but not up against the rail), being sufficiently high to allow the passing of a high capacity lawn-mower which collects the cut grass. The top soil doesn't require any special treatment in relation to any other earth used for growing grass of high quality.
  A longitudinal drain between each rail carries water to the transversal water collector boxes, or to the transversal channels located every 50 metres. The transversal channels allow the cleaning of the drains and are sometimes used to give access for repair (after a road vehicle has crushed or bent them due to driving on the grass).
- The laying of a grass covering is similar to that of Strasbourg or Grenoble with the difference that automatic watering doesn't appear indispensable. The drains and the semi-filtering geotextile envelope are the same.

5. TECHNIQUES

For paved surfacings we distinguish between natural stones which are sealed and concrete blocks.

5.1. NATURAL SEALED STONES

The height is adapted depending on its geo-mechanical characteristics which are determined by a series of standardised test. The stones should not possess any smooth faces. To favour the adherence of the mortars the use of sawed blocks is prohibited. The width of the joints will allow easy filing of the mortar and thereby avoid the creation of empty spaces. The joints will be made with resins or with non shrinking mortars. Drainage on the surface of the trackbed will be at the level of the rail grooves.

5.2. CONCRETE MODULAR BLOCKS

Preferably these will be auto-blocking concrete blocks in order to avoid relative movement due to vibrations giving better coherence between them when under vibratory forces. They are laid on an 2 to 4 mm aggregate layer without fines so as to avoid any settling.
With the exception of curves where the pattern of the surfacing requires the cutting of small edging blocks, along the rails in straight alignments, the edging blocks will have as far as possible the same size and shape because of instability risks.

The laying of the blocks is carried out after the putting in place of the surfacing drainage system (PVC drains, 63mm in diameter), the protection of the fastenings and the filling with foam of the fishing surfaces.
The blocks act as lateral supports for the polyurethane joint along the rail. This joint ensures the surface waterproofing along the rail as well as allowing the rail to move freely and thereby limiting the risk of damaging the surfacing.

5.3. GRASS COVERINGS

The construction of a trackbed covered in grass can be done in two ways:
by sowing or by sod laying. Sod laying ensures an immediate result and also better rooting of the shoots.
The wet surroundings, which are favourable to stray currents, imply the need for very careful filling of the surrounding of the rails so as to ensure its insulation.
For this reason the foam filling the fishing chambers will be glued to the rails and the track concrete will drain the water between the rails.

A geotextile of the « SOMDRAIN » type or similar, moulded to the shape of the structure, glued to the foam filling the fish-plating chambers and put in place under the top soil, will protect the railway from muddy infiltrations.

The maintenance of a grass covered trackbed involves the addition of fertilisers and compost and mowing about 25 times per year with equipment which cuts and collects the grass. A renewal of all the grass sods is not necessary. About every 5 years a major rehabilitation should be planned with replanting of grass-seed, as well as aeration, composting and conditioning of the soil.

HISTORIQUE DES MODIFICATIONS

Indice	Établi par	Date	Objet de la modification

Design Of Track For Kerb-Guided And Electronically-Guided Buses

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Introduction

The Government's White Paper on the Future of Transport[1] states that "*Buses are already the workhorse of the public transport system ... Increasingly they will become the focus of an efficient transport system that gets people to where they want to be quickly and comfortably, without having to rely on cars.*" (Para 3.13) and continues (para 3.37 and 3.38): "*The capital costs of light rail systems are ... high - particularly in comparison to bus priority measures and more modest guided bus schemes which may offer a more cost-effective alternative. ... Funding for new major light rail schemes will therefore not be a priority...*" In future therefore, in high flow corridors which would have previously been considered for light rail, we can expect to see much more emphasis on bus-based modes. Indeed, this has already commenced, with projects such as Merseyside Rapid Transit project, the Millennium Transit project (to link the Millennium Dome with Charlton Station), and the "intermediate mode" studies carried out by London Transport for a number of suburban corridors in the London area.

The Advantages of Guidance

The provision of guidance gives a bus a precisely defined path. This has a number of benefits, of which the one of the most often stated is the reduced width required compared with a conventional bus. This factor is not particularly relevant in many cases, and has been somewhat overstated in the past. Other advantages of guidance, which are more important are:

- a defined horizontal and vertical alignment, giving light rail standards of ride quality,
- close tolerance 'docking' at stops allowing level, almost gap-free boarding,
- a precisely defined alignment allowing operation in pedestrianised environments,
- a differentiation in image terms from conventional bus.

Two types of guidance are considered in this paper: kerb guidance and electronic guidance.

Kerb guidance was developed in the 1970s by Mercedes Benz who adopted the name "O-bahn". Kerb-guided bus systems are in operation in Essen (since 1980) and Mannheim (since 1992) in Germany, and in Adelaide in Australia (since 1986). In the UK a trial system was operated in Birmingham from 1984 to 1987, a 175m length of kerb guidance was included in the Superoute 66 project in Ipswich which opened in 1995, and the Leeds Guided

Busway has been in operation since 1995. Kerb guidance is also proposed for the City of Edinburgh Rapid Transit project (CERT).

In a kerb guided system, upstands 180mm high are provided on either side of the track. The width between the upstands is usually 2.6m, giving a clearance of 50mm either side over the bus body. Guidewheels are mounted on support arms fixed to the steering mechanism of the bus (Fig. 1). The guidewheels, which are an interference fit between the upstands, steer the bus within the busway. Apart from the attachment of the guidewheels the steering system is not altered in any way, and the bus is steered manually in the normal way when the bus is not in guidance.

Electronic guidance was initially developed in the 1970s and 1980s and a demonstration system operated in Fürth in Germany in the mid 1980s. Since 1994 the system has operated in the Channel Tunnel Service Tunnel, using specially built multi-function vehicles. The system was demonstrated on a public service vehicle during trials in Newcastle-upon-Tyne in 1996, and is proposed for the Merseyside Rapid Transit project for which a Transport and Works Order application was submitted earlier this year.

For electronic guidance (Fig. 2), two cables are buried under the road surface at a nominal depth of 50 millimetres, spaced 300 millimetres apart. These cables form loops of approximately 2 kilometre length. Each loop carries a precise frequency alternating electric current which sets up a magnetic field which in turn is detected by antennae mounted beneath the front of the vehicle. An on-board computer processes the signals from the antennae and sends the appropriate signal to a hydraulic ram connected to the vehicle's normal steering system.

Implications of Guidance for Track Design

Unguided buses run on a "track" - the conventional road - the design of which has evolved over time to meet the needs of all types of road user. For guided buses there are additional specific design requirements. Firstly, there is the need to include the track elements of the guidance system: upstands for kerb guidance and the guidance cables for electronic guidance. These have to be provided, and maintained, to tolerances appropriate to the required ride quality. Secondly, a consequence of a precisely defined vehicle path is the concentration of loading on a particular wheel track, and hence a tendency to rutting if an inadequate pavement type is used.

These two factors have led to the development of specific track details which are described below.

Kerb Guided Track Forms

In Essen, Adelaide and Ipswich precast reinforced concrete L-shaped units were used to provide both the running surface and the guidance upstand. These units are supported by transverse precast concrete "sleepers". In Essen and Adelaide the ground conditions dictated that the sleepers were supported on piles, giving a rigid trackform. In Ipswich ground bearing sleepers were used. In order to achieve a high quality ride, close tolerances are needed in the manufacture and placing of the precast units, but these have been found to be achievable in practice[2], with good ride quality being achieved at speeds of 100 kph in Adelaide[2].

For the Leeds Guided Busway, which was intended to be more a high grade bus priority scheme than a rapid transit system, a different detail was adopted. In situ concrete was used for the running surface, with the upstands formed by standard bullnose kerb units, backed by a reinforced concrete haunch. The alignment of the guidance system is defined by the edge of the in-situ concrete, and not surprisingly perhaps, it has been reported that the contractor had some difficulty in meeting the specified tolerances.

For the proposed City of Edinburgh Rapid Transit, currently out to tender, the client's reference design for the track comprises two concrete L-shaped units supported on a road-type foundation. The concrete could be precast, in-situ or slip formed. For the latter two, it would be necessary to set up methods of working able to maintain the tolerances on gauge and straightness of the track.

Electronic Guidance Track Forms

The guidance system requires that there should be no ferromagnetic material within 300mm of the guidance wires, otherwise there would be distortion of the magnetic field which would affect guidance. This precludes the use of reinforced concrete within this zone. It is possible to provide reinforced concrete under the wheel tracks on straight track, but on curves, the path of the guidance cables overlaps the wheel tracks.

Other forms of pavement have to be used, and their design has to take into account the increased pavement damage due to repeated tracking of the same wheel path. Unpublished research by the Transport Research Laboratory and design guidance for heavy duty pavements in ports and similar areas[3] suggest that a factor of 2.5 to 3 needs to be allowed for the additional damage caused by repeated tracking of the same path. For the Merseyside Rapid Transit project bituminous and block paved details have been developed. For the former, a high stiffness proprietary wearing course material is proposed to minimise any tendency towards rutting. The latter detail is appropriate for operation in pedestrianised areas.

Entry, Exit and Crossing Details

Entry to kerb guided track is by means of an asymmetric "funnel". The bus can enter at speeds of up to 40 kph, by steering towards the offside guide kerb, and maintaining pressure on the steering to keep the guidewheel in contact until the nearside guidewheel has entered guidance. Symmetrical funnels are used at exits from guidance. Gaps to accommodate pedestrian crossings or minor roads up to about 6 metres wide can be crossed by the use of a pair of symmetrical funnels, providing that the alignment is straight, and that the driver does not attempt to steer while crossing. Larger gaps, or those on curves need full exit and entry funnels.

For electronic guidance no specific entry infrastructure is required. The vehicle is driven towards the guidance wires at a small angle, and when the antennae encounter the magnetic field, guidance is automatically engaged. Demonstrations have shown this to be a very smooth process. To disengage from guidance the driver simply selects manual operation and resumes control of the steering. This enables the vehicle to join or leave guidance at any point, giving the system greater flexibility of operation.

Diverges and Merges

For a kerb guided system "points" are rather impractical, although examples were developed for Essen combined with tramway points where the two follow a common route. It is more usual for route diverges and merges to take place on unguided lengths.

Points can be provided where two electronically guided routes diverge by having two sets of wires operating at different frequencies. The driver selects which he wishes to follow and the system automatically follows the selected route.

Conclusions

Kerb guided and electronically guided buses are likely to feature more prominently in the future, as low cost alternatives to light rail systems. In order to maximise the benefits of such systems it is important that they should be differentiated from ordinary bus operations. Guidance, in itself, provides "image" benefits, and also contributes to the ride quality of the system, itself another differentiating factor. Kerb guidance is limited to lengths segregated from other road traffic, but offers a strong visual impact. A number of track forms have been used, or are proposed, to balance the requirements of alignment tolerance, ride quality and cost. Electronic guidance is more flexible in operation, being capable of use in segregated and shared use situations, and not requiring special treatment at each entry exit or crossing point. It is less visually distinctive. The guidance system precludes the use of reinforced concrete track, and therefore a road pavement type of track is appropriate.

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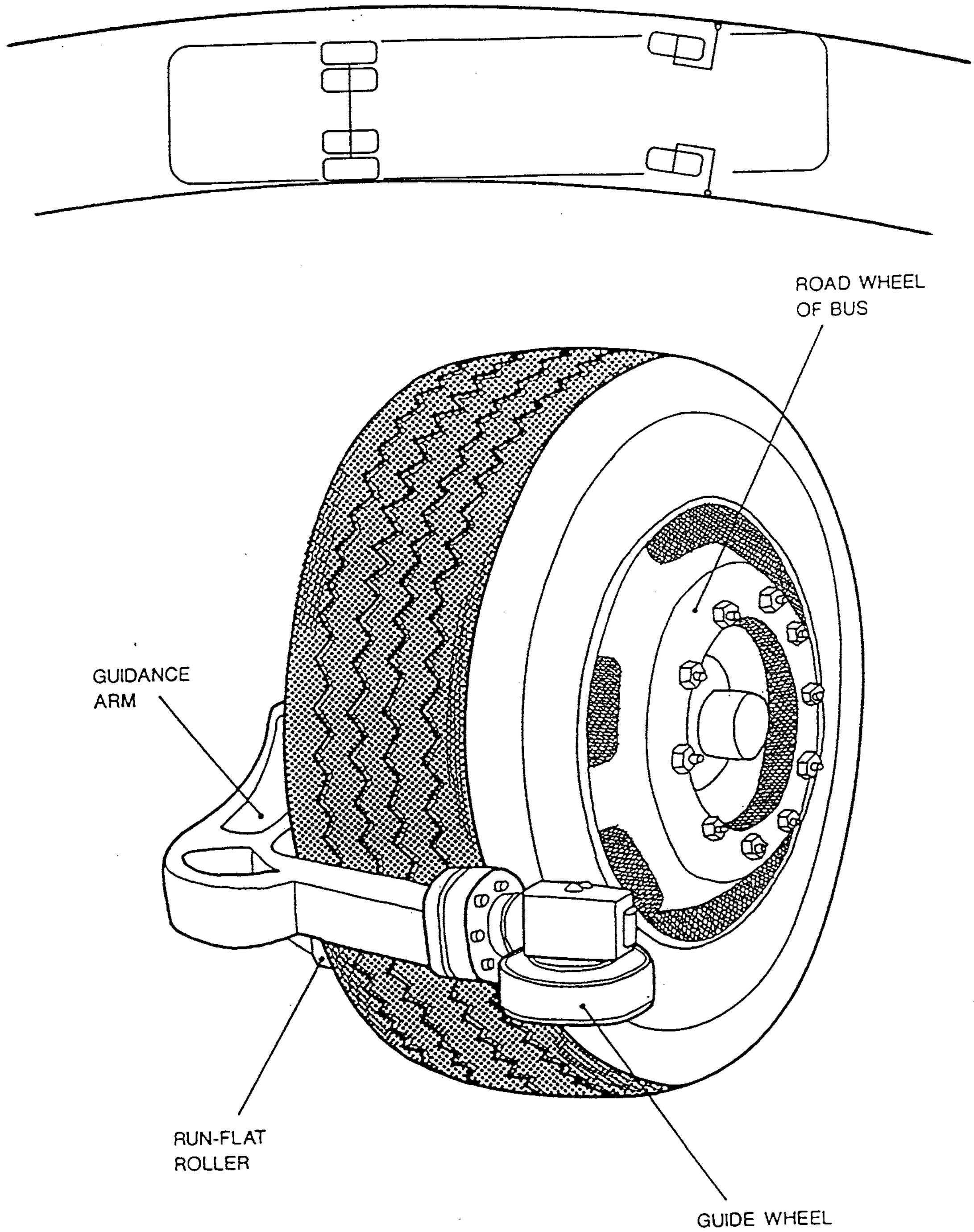
[1] A New Deal for Transport: Better for Everyone The Government's White Paper on the Future of Transport Department of the Environment, Transport and the Regions July 1998

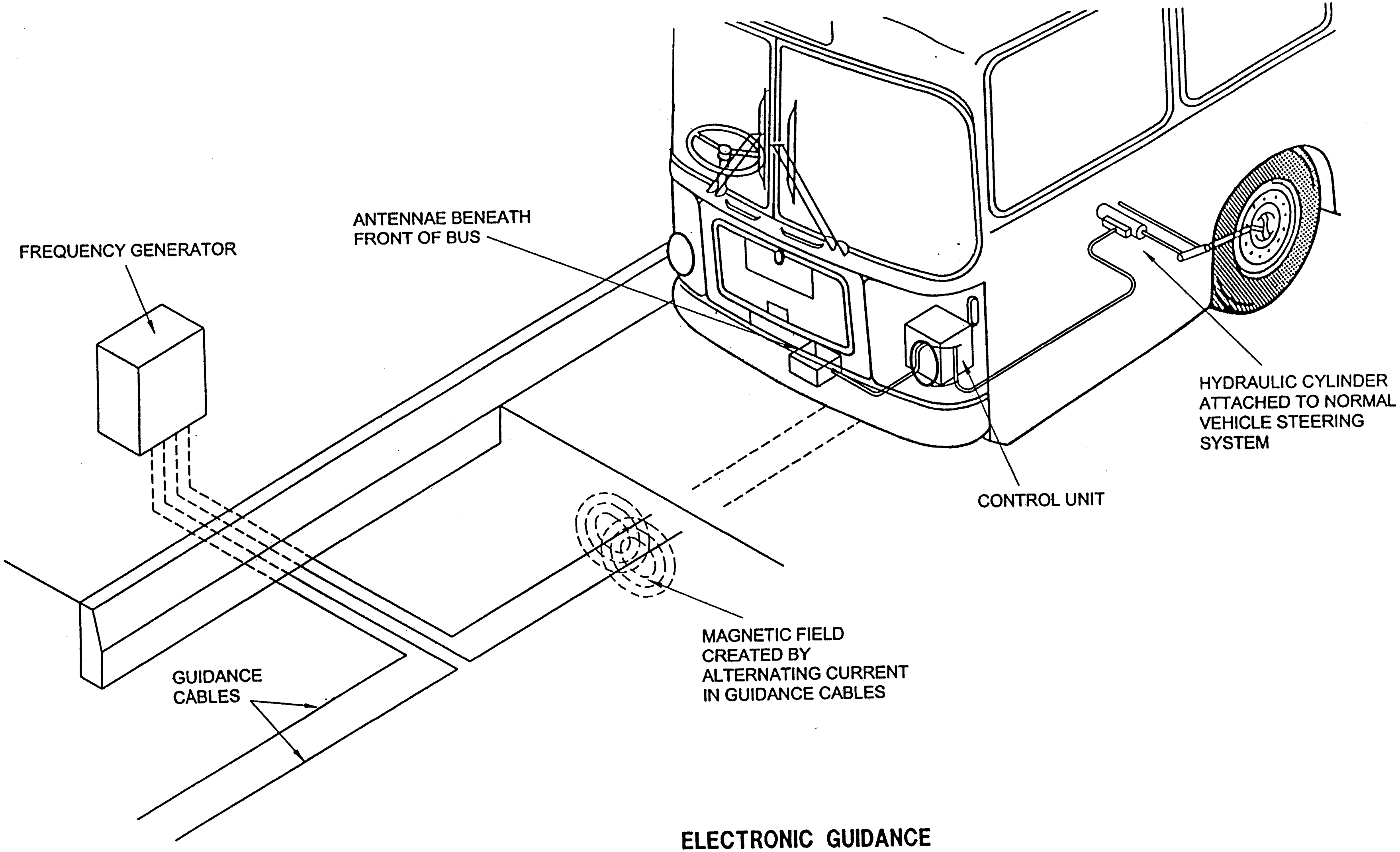
[2] Adelaide's New Rapid Transit Busway Open Alan Wayte Highway Engineering in Australia Feb/March 1986

[3] The Structural Design of Heavy Pavements for Ports and Other Industries British Ports Federation 1988



KERB GUIDANCE

FIGURE 1



ELECTRONIC GUIDANCE

FIGURE 2

Track design, construction and maintenance
- **polymer embedded rail**
- **shallow track**

DAVID BATEMAN
Hyder Consulting, London, England.

1.0 Introduction
So much has been said about the philosophy and methods used for successful rail embedment in the street. If modern light rail is to continue to be seen as a credible alternative to road transport with good whole life cost benefits, designers, manufactures and contractors must work together to deliver an effective whole life scenario. If this is not done then the current systems will in time become no better than their old time predecessors. We have already seen examples of costly repairs to a rail embedment in the street both in Europe and the UK with the image of these systems perceived to be tarnished. We can not afford this to happen with the current systems under construction and or nearly complete. So what are the steps that should be taken to produce good satisfactory performance for in street embedded designs.

2.0 Principles of rail embedment
To understand the nature of rail and track embedment it is necessary to understand some facts about component design, vehicle /track interaction and permanent way philosophy. These can be described as ingredients and like a cooking recipe, get it wrong and its disaster, get it right and there is a sumptuous feast to enjoyed. To get it right manufactures contractors and designers must work along side each other to produce the correct recipe.

To create an embedded track system the final product must be defined and the constraints considered and appreciated. The considerations will include,

- the general environment where track is to be constructed
- the type and use of areas served, (pedestrian shopping areas etc)
- road traffic use of the track pavement
- proximity of buildings
- noise and vibration considerations
- stray current protection

These considerations will enable the system performance to be established. From this embryonic performance will stem generic ideas that will shape the design approach. Some of the considerations will be purely aesthetics, and designed to blend the system into surrounds. The generic approach will need to establish the form of vehicle that is likely to be used. Establishing a high level system philosophy will allow project briefs to be given to a system designer who can develop these concepts into a design and specification for construction

The combination of the system criteria or elements to form a cohesive system design is essential. The part that contributing elements play must be understood and how each combine to give the total performance of the system. Element combination will be a difficult role and will tax the designers skill. The secret if there is one, is to eliminate as many variables as possible, not easy, but possible. The most significant element to eliminate is the vehicle, by establishing its characteristics and the way in which these impact on the track system. The penalty of not establishing the character of the system will be incorrect specification for the track structure.

There are distinct elements used to shape the design of embedment, and like all ingredients, need to be obtained before creative success can be achieved. These are;

- The design philosophy and performance.
- The material element
- The vehicle element
- The construction element
- The cost element

The components used for a specific track system will give a certain holistic performance and is unique. The vehicle and the materials for the track system will combine to determine the performance, a fact which is so often conveniently forgotten or not even understood by designers, manufacturers and contractors alike. Any change to a single item either to the vehicle or the track will alter the performance. Vehicle engineers beware that seemingly small changes to suspension stiffness has been known to cause catastrophic wear to the track system. Conversely a small change to the track system such as a change to the rail pad stiffness has been known to cause excessive vibration in vehicles, corrugation on rails and even clip failures. Simple matters, for example, a small change to the polymer mix will alter the system performance. Thus no single system will perform exactly as another.

2.1 The Design Element

Embedded track can take a number of forms from the traditional bolted fixings to the use of modern polymers. The range of ideas between theses wide extremes can satisfy most needs. A simplistic approach is often used and can provide a cost effective system. This simple bolted system and the bitumastic fill between the road wearing surface and the rail is accepted as being a good traditional system. It is also accepted that maintenance will occur, probably annually, but will be quick and cheap. Many European systems perceived in the UK as show piece' systems use this traditional method with good results.

Most of European systems have used 'modern' polymer materials with some applying considerably more thought to the use of the material as a rail embedment system. In the UK worries about stray electrical currents, has tended to colour our thinking on system designs. This design approach has tended to be considered in haste resulting in the holistic nature of a system forgotten and some aspects of rail embedment given scant consideration, including such matters as water ingress prevention.

The range of design concepts are increasing and included;

- Traditional fixing rail by bolts directly on a sub-base
- The uses of separate baseplates to support the rail on a sub-base
- Total of embedment rail by polymers
- Coated embedment of rail be polymers

- Embedment of rail foot by polymers
- And a number of variations and combinations of these

To establish a successful system specification, the characteristics of components will need to be established and used to determine the required performance of the embedment system, as a complete entity. Factors to be assessed and determined must included;

Support mechanism,	System fixing details,
The vehicle performance	Type of rail and shape,
Stray current requirements,	Type of rail clip and track fixing
Load capability of the materials,	Rail pad if fitted,
Deflections of materials,	Drainage methods,
Frequency of the materials	Method of rail and road sealing,
System dynamics and frequencies,	Wearing surfaces
Deflection required from the system,	Skid resistance
Polymer requirements, if used,	Component availability
	Cost

2.2 The Material Element

The material list for a track system includes, the rail, the rail pad (if required), the rail clip (if required), rail support medium (may be a polymer), the system supporting mechanism (may be just sand or a concrete base), void fillers, sealing materials and the ground itself. All materials have their own individual characteristics which will be modified when combined in to the system.

The material which generates the most concern and debate is the use of polymer based materials. The manufactures of polymer materials have arrived at their 'in-street' embedment products from very different backgrounds. None are the same and their use, whilst intended to be the same need different considerations by the designer. The understanding of the performance of these materials generates the largest debate, except for vehicle colour. It is the one material that requires considerable input and contains the largest number of variable parameters. These parameters can only be fixed once the vehicle parameters are known. If the system vehicle is not known, it becomes a dangerous exercise to fix the polymer characters as this inevitably leads to other system problems for example, corrugation, rapid wheel/rail wear, noise and vibration transmission.

The parameters that impact on system performance and designs are; material natural frequency, deflections under load, recovery rates and frequencies that are transmitted through the system to the adjacent structures. It should be remembered that a system performance is quite separate from the material performance and in particular polymers will have their own set of characteristics that are separate from the system, but will determine the track system characteristics (including their own defection rates, carrying capacity, and frequencies). Natural frequency of a polymer is around 17/20 Hz with track clipping systems tending to be between 50 and 70 Hz. Thus any vehicle generated frequency close to these will pass through the material unchanged. It should be borne in mind that should the track system, be subjected to these frequencies, accelerated fatigue failure of the certain component will occur.

2.3 The Vehicle Element

The civil engineer tends to ignore the difficult subject of the tram running on the track system in the street. The type of vehicle will generate a set of characteristics which will be imparted into the track system. They are generated by the vehicle weight, wheel size and type (i.e. solid or resilient), suspension type and frequency, actual physical wheel spacing and bogie centres, and motor type and characteristics, vehicle body characteristics. The vehicle suspension system plays a crucial part in determining the frequency imparted to the track system and the reflected frequency back from the track system into the vehicle. These are typically from the vehicle components around 1 to 2 Hz but could be lower (heavy rail starts lower typically 0.3 Hz to 1 Hz) which generate harmonics and amplify typically up to 80 Hz and in some cases 200 Hz. It is important to understand the frequencies that are generated as this will and must influence the selection of components. It is no use selecting a track fixing clipping system that has a natural frequency of 60 to 70 Hz if the vehicle and track system combine to give the same frequency. The rail clip will fatigue and fail long before any life expectancy has expired.

2.4 The Construction Element

It is of little use for us as designers to establish a system which is not practical or constructable, or is to expensive. It is said so many times by contractors that the designers can not and do not understand how to build track systems. The 'build-ability' must not be confused with high construction costs. The ease of construction must influence a design. The contractor must understand that specification are not written lightly and there are reasons for using certain products and types of components. The designer for his part must carefully consider the construction, for example it is of no use to specify a material which is moisture sensitive for example polymers, if the track system is to be fixed into a water environment such as Madrid Metro which has a water course that drains along the track. If this is to be the answer then the designer must understand how the de-watering is to be completed and include this in the specification so that a contractor fully understands the requirements and liabilities. The harmonisation of the design and construction is paramount if performance is to be met. We as designers must not be impervious to construction issues. Very often in-street construction can be kept simple which offers usually the best and cheapest solution.

2.5 The Cost Element

The cost of the design is measured in terms of contract price. Often costs are too competitive and a contractor is squeezed to the last penny. Faced with this a contractor will understandably look for savings and changes to the specification to provide a cheaper alternative solution to the contractor. Clients should be aware of this. Manufacturers and contractors can give convincing reasons why changes do not alter track system performance. The changes are not usually controlled by the designer, and is left with no say as to the final outcome. Major contracts are currently proceeding this way where two consultants are advising their respective masters; one advising the contractor and his interests, and the other the client who had written the specification but now can only advise, as the contract is between the client and contractor. So now, who has the project's interest in mind? The contractor has to make his money which is understood, but clients should remember changes in materials rarely, if ever give the same track system performance. This fact must be not forgotten when agreeing to the change.

3.0 Principles of shallow depth construction

A major concern for new light rail systems is the construction cost of the in-street sections. The largest contributor to the cost is the moving of utilities companies services and the need to provide stray current protection which could be as much as 50% or more of the total project cost. A number of recent initiatives to reduce this cost and ease construction issues of rail embedment in the street have been designed and trialled. The principle behind these is to construct the track system in the top 100mm of a road surface so that the road sub-formation and utility services are not disturbed. To achieve success the system must also satisfy the design conditions of more usual construction methods.

Current thoughts and proposals are; LR55; a modified form of track construction which is suitable for ultra light rail systems using new technology vehicles; and modular form of construction that can be placed on the top of any road sub base.

The systems that have been designed have yet to gain recognition in the world. The LR55 has a short trail length installed in the Sheffield Supertram system and has been giving satisfactory service. The system uses a concrete trough to retain the construction and the rail is encapsulated in the trough with a polymer material. The rail itself is a different section and resembles a top hat. Currently no rail manufacture has signed up the ideas for the rail shape. The top of the rail has been treated to increase the skid resistance potential for in-street scenarios. The other type of construction takes a more traditional approach. This uses conventional components for its construction, but is contained in the top wearing course of the road surface. The type of system is primarily suited to ultra light construction especially where stray currents are not an issue. The rails are normally 30lb per yard or similar. The main load criteria will be road traffic.

This type of construction must be given a chance if light rail is to succeed. It is a difficult balance between new ideas and ideas using proven materials. There should be scope for clients to use these materials, however the unknown aspects of different designs will always be a hurdle to over come. we must allow these systems a chance. The proving ground for these should be the ultra lightweight systems ideas such as Parry and Pullman.

4.0 Summary

This short paper has given an overview of track embedment and shallow track principles to be followed. For ideas to be successfully executed, the contractors should allow the designers to design, and manufacturers must refraining from exaggerated claims of products. The manufacturers should allow the designers some credit as to how best to use materials for particular applications. Conversely designers must also be mindful of 'build-ability' and costs. Lessons should be learnt if further expensive mistakes are not to be made. All engineers must work together so that short term financial gain is not at the expense of long term success of a scheme or project. The eventual looser will be the industry, as potential clients will not invest in more systems that cannot demonstrate to operate economically and successful.

For my own preference in design, I prefer polymers which surround and support the foot only with polymers not to be used as a void filler, unless a mechanism of maintaining water seal has been carefully considered and can be guaranteed to remain secure. For the future, shallow depth type construction must be given a chance particular if low cost ultra light rail schemes are to proceed, however development of the form is required with a radical approach to rail shape. The challenge is to use modified existing technology and philosophy to give confidence and credence to the industry.

Notepaper

DESIGN ISSUES FOR GUIDED BUS AS A RAPID TRANSIT SYSTEM: EXPERIENCE FROM DEVELOPING SYSTEMS IN THE UK

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There has been extended debate in the UK over a period of some ten years as to the suitability of guided bus as a weapon in the transport planners armoury. During a period when public transport usage has continued to decline much of this has been inward looking and rather sterile, focusing on unproductive image comparisons between steel wheels and rubber tyres. With the introduction of Superoute 66 and Leeds Superbus, however, guided bus has now arrived in the UK (or more correctly returned) and this debate should be over. Transport planners must now concentrate their energies on how to promote the use of public transport using all the weapons at their disposal.

The Leeds and Ipswich guideways may be considered Jam-buster schemes, where short sections of guided busway allow buses to bypass congested sections of the road network. The next generation of guided bus schemes represent more extensive systems: in Edinburgh, the City of Edinburgh Transit (CERT) scheme now has statutory authorisation and four shortlisted consortia are currently bidding to build and operate the system which includes a 9km segregated guided busway. A preferred bidder has been selected for the 12km Liverpool scheme whose Transport and Works Act application is due to be heard at public inquiry in November. These more extensive systems raise additional design issues yet to be tackled in a UK context.

Four main areas exercise transport planners and engineers in the development of these larger schemes; the choice of guidance technology for the system and the effects of the image, both of that technology and the system, upon patronage. In addition, the level of access to the system in a deregulated bus market and the engineering details continue to be considered. This paper seeks to outline these additional considerations arising from Guided Bus's transition from Jam-buster to Light Rapid Transit.

GUIDANCE TECHNOLOGY

The historical development of guided bus is well documented [1],[2]; with the O-Bahn kerb guidance technology being developed in Germany in the late 70's largely as a means of allowing buses to take advantage of existing tram tunnels. The development of operational systems in Essen and Adelaide in the mid 80's allowed kerb guidance technology to be proved under a variety of operating conditions, while the Tracline 65 experiment by West Midlands PTE in 1984 ran for three years and left several test tracks in operation in the UK. Kerb guided buses were reintroduced in the UK in 1994 with the completion of a 200m section of guideway in Ipswich as part of a wider package of bus priority measures on Superoute 66. Yorkshire Rider introduced Superbus to Leeds in 1995 as the first phase of the Scott Hall Road corridor scheme. Further phases have followed, and the final phase, including a Park & Ride facility at Alwoodley, is currently under construction.

Other guidance technologies were being developed over this time; electromagnetic guidance being tested in Furth, Germany and central rail forms in Belgium. There is now the possibility of optical guidance with the development of the 'Visee' system by Renault.

Electromagnetic guidance grew out of factory production techniques for moving materials around the factory floor on automated pallets, but early demonstrations of its application to buses proved less popular than kerb guidance. The adoption of the AEG electromagnetic guidance system for the Channel Tunnel Service Fleet [3] elevated electromagnetic guidance to a 'serious' system. In 1995, Ove Arup & Partners designed and procured the test track for trials of electromagnetic guidance for passenger transport operation on behalf of Tyne & Wear Development Corporation and NEXUS at Newcastle Quayside. These trials were so successful that the technology was accepted as part of the preferred bid for the Merseyside Rapid Transit scheme, and forms one of the bids for the CERT system.

Systems using a central rail to guide vehicles was developed in Belgium by Bombardier, and a demonstration track created in Rochefort. These vehicles have the appearance of a tram on wheels and were the first of a type to be dubbed 'tramalikes'. The technology is being considered for a number of schemes in France, foremost amongst which is Caen, where the system has been renamed TVR (Transport sur Voie Reservee).

There are a large number of guided bus schemes under consideration in the UK, and the variety of guidance technologies contributes to reiteration of the arguments in favour of competing technologies in each scheme. The argument that guided bus needs to be viewed as technologically advanced to ensure its success inevitably links the operating technology to the overall image of the system. While this debate continues, public transport patronage continues to decline.

IMAGE

Supporters of the Leeds and Ipswich guideways claim that improved service perception is an important part of the success of these schemes: most transport planners would agree that countering the poor public perception of bus transit in general is essential to the long term success of promoting public transport. Guided bus LRT systems are promoted as offering something different to the travelling customer, and therefore must address image to an extent which sets them apart from traditional buses.

The public's long held assumption that trams have an in-built advantage over buses has led to higher patronage forecasts and better economic performance when comparing the two; going some way towards offsetting the higher capital cost of trams and their infrastructure. Forecasting models therefore have built-in attractiveness factors in favour of tram or light rail systems. It has become the received wisdom that buses are less attractive than trams, and that this effect is an inherent attribute of each.

Some perceptions of poor quality can be readily quantified, including reliability and journey speed, but there are many additional factors influencing the public perception of bus travel. A successful bus LRT system needs to recognise these factors and to develop measures which address such perceived weaknesses. One "permanent" method of improving bus service reliability and journey times is through the reduction of bus interaction with general traffic flows. Bus lanes contribute some way to this, but may only be effectively addressed by a segregated bus only road: a Busway.

Dedicated roads for buses are used extensively throughout the world, but generally only involve short links for access to specific facilities such as bus stations; there are relatively few busway networks. The most systematic and extensive segregated existing systems are those in Sao Paulo, Curitiba, Pittsburgh, Adelaide and Liege. The proposed Paris busways will, if implemented, be similar in length to Sao Paulo. In contrast, the Leeds Superbus system includes some 1.25km of discontinuous guided busway, the remainder being on-street and relying on traditional bus priority measures at specific locations. Clearly, continuous segregated busways provide buses with the greatest protection from traffic delays and are therefore more likely to exhibit a high quality image than the discontinuous systems currently operating in the UK.

Stated preference research(5) into the Essen system image found that, while public transport users displayed a statistically significant response to journey time and journey cost, the introduction of kerb guided buses did not produce a significantly higher level of preference to that attributable to a conventional bus. Significantly however, this research suggested the same indifference to system type when considering conventional trams. This suggests that system type has much less effect on public attitudes than issues such as journey times and fares.

This contrasts with research elsewhere (6),(7), which suggests that where new urban transport systems are introduced, rail based systems do confer an image advantage over bus systems and will be reflected in higher forecast demand assuming all other factors remain equal. One hypothesis proposed to explain the Essen result is that in urban areas where the travellers have become familiar with trams and guided busways over a long period and where, in the case of the busway, it is discontinuous and not heavily marketed as being distinct from conventional buses, any "image"effect will wear off. Customers then base their travel mode choices on attributes such as service reliability, journey times and costs.

The Leeds Superbus system was initially promoted as a means of protecting buses from the effects of traffic congestion, while improving the quality and image of bus services in the city. Research(8),(9) into the undoubted success of the system suggests that service quality and image was significantly less

influential in people's decision to use Superbus than lifestyle changes such as relocation of house or place of employment. The work also suggests that only a small proportion of new Superbus users had switched from car: the majority of new users switching from other bus services (either on the corridor or elsewhere) or making additional journeys. Service frequency was confirmed as being significantly more important than other variables [10], but when users were asked to describe "Superbuses to someone who had never heard of them", the most frequent answers given were:

- guideway aspects (19% of responses);
- fast/speed (19% of responses).

Such findings may imply that passengers perceive a greater correlation between a permanent busway and journey time benefits than those which accrue from traditional unsegregated and possibly poorly enforced bus lanes. However, additional research is required to confirm this.

Regardless of whether a case can be established for improved perception of guided bus, the emergence of various "tramalike" vehicles in recent years must further blur the assumed image distinction between bus and tram. The Bombardier Eurorail TVR vehicles proposed for use on the Caen system have a distinctly tram-like appearance. Similarly, the emerging family of "Translohr" vehicles, some of which are capable of guided operation, and the Renault designed "Civis", previewed at the 1997 UITP Conference, all have the hybrid appearance. There is therefore every reason to assume that a well designed guided bus LRT will benefit, at least initially, from the same 'soft' quality attributes as have hitherto been assumed to be applicable only to rail based systems.

ACCESS

The sections of guideway constructed in Ipswich and Leeds are classed as demonstration projects and are part of the public highway. They are therefore open to other operators to register competing services on these routes, although none yet have. For the larger schemes now in the pipeline, the size of the necessary investment has so far meant that a substantial element of private investment is required. This, combined with the fact that these schemes also tend to have a greater degree of segregation and therefore, potentially, a greater competitive advantage, means that the question of competing services and busway use require revisiting.

One of the key benefits of a bus transit system is the opportunity to develop an extensive network with a wide range of potential origins and destination. Guided busways seek to combine the best features of bus and rail systems; fast, high quality trunk services with flexible routeing and a high level of accessibility. In Essen, the busway transit system shares city centre alignments with trams. This allows different systems to be chosen for different corridors but enabling shared infrastructure in the central area, thereby reducing capital costs and allowing easy interchange.

It is this very flexibility which may threaten the application of the introduction of buses within a deregulated bus market. The promotion of schemes either as open access, where any operator may provide a service, or as toll-roads, open to any operator willing to pay the toll, may lead to "bus wars" seen in parts of the UK. Restricting access through quality requirements is under consideration, but its suitability has yet to be finally tested.

Bus LRT potentially offers the development of a denser and more flexible network than light rail reducing the need for mode interchange. In the case of a kerb-guided system the busway cannot easily penetrate central areas and buses must revert to the general highway. However, extensive bus priority measures including bus only streets are becoming commonplace in many of our cities and, therefore, the need for a guided system is less important. Electronic or slot guidance systems potentially enable guidance in central areas as these do not introduce significant physical obstructions.

Careful planning of the network is crucial to the success of the system and, the extent of the busway network and how it relates to other transport modes will be largely dependent on size of the town or city it serves. For example, busway transit project in Leeds, Leeds Superbus, is only one type of public transport system planned for the city. The Leeds Transport Strategy published in 1992 identifies four key public transport modes for serving the city in the future; heavy rail, light rail, busway transit, and enhanced bus. In addition, the City Council recently introduced a High Occupancy Vehicle (HOV) lane that can be used by buses, taxis, and cars carrying three or more passengers.

CERT is designed around a segregated arterial section running from near Edinburgh Airport to beyond Murrayfield stadium. There is provision for feeder services to join at several intermediate access points, including dedicated Park & Ride services from two sites to the west of the city at Ingliston and Hermiston. Interchange is planned with mainline rail services at Edinburgh Park (Edinburgh-Glasgow) and the possibility of linking to a future station at Gogar (Edinburgh-Fife) has been preserved. Access to CERT is dealt with by seeking a disapplication of the 1985 Transport Act.

ENGINEERING DETAILS

The responsibility for safety on guided busways falls within the remit of HM Railway Inspectorate and the Railways and Other Transport Systems (Approval of Works, Plant and Equipment) Regulations 1994 require that approvals for any new or altered railway, etc must be sought from HMRI. Regulation 3 of the Regulations defines "other guided transport systems" include:

Road-based with cable guidance;
Road-based with rail guidance;
Road-based with side guidance;
Track-based with side guidance.

Such definitions clearly place most systems under the remit of the RI, and they have undertaken considerable work has been undertaken to consider the safety of guided systems. There are many questions which affect safety including those surrounding the form of signalling and the level of physical separation of the system.

Since the RI is responsible for authorisation of the safety of the system, it may be argued that rail design parameters should be used in its design. The fundamental principle of a guided busway is, however, that the service may use both the busway and existing roads. Therefore it is argued that road design parameters should be used. Similarly when considering signing and signals, the use of road signs is proposed. This would simplify the training required for drivers to use the guided sections of their routes, but does not fit with the image of traditional LRT.

Design speeds are appropriate in a number of instances along a guided rapid transit route: at the point where guidance is first entered, at subsequent breaks in guidance and when leaving the system. Additionally the design speed of a segregated route must consider the passenger safety and comfort, while those using existing roads must consider the 'break-out' speed of the system, and its possible implications for road safety.

Kluge[11] identified a number of issues to be considered when designing curved guided tracks with kerb guidance. These included the balance between the speed of cornering, the superelevation and the comfort of passengers. When an equilibrium is set up between centrifugal forces and superelevation the vehicle will tend to steer towards the centre of the curve; to overcome this problem, and to limit lateral acceleration to passengers to $1 m/s^2$ (note that this is significantly higher than that accepted for car passengers in road design) a "speed window" is derived. This results in a situation where a minimum speed is also applicable for a particular curve radius and superelevation. Such a concept is alien to the general road user, and additional signing may be required to address it.

Together with mechanical implications of speed are the personal implications: how do the seats of the vehicle accommodate passengers? Are passengers to be allowed to stand and, if so, do they have grab handles or perches to provide some form of lateral restraint? Not the least important will also be the driver behaviour during the operation of the system: harsh acceleration and sudden braking not only may be unpleasant, but can cause severe personal injury accidents within a vehicle.

Good road design practice dictates that a carriageway be widened when turning through small radii to ensure that the swept path of the vehicle does not impinge into the oncoming carriageway or impact upon the kerb. Since the vehicles used in a guided rapid transit system are generally built to conform to Construction and Use Regulations, they must exhibit the same characteristics. The issue of curve widening is addressed by Bob Tebb[2], with his direct analogy to road alignments.

The drainage of a track based system associated with kerb guidance may present particular difficulties, including issues of the location of the drains, and whether use is made of a central cess. In an external restraint system where the tyre path is well defined, the issue and consequences of puddles forming, for example, may become important. In this case the issues of passenger comfort, skidding resistance, spray and splashing require consideration together with the means of dealing with the run-off.

Pavement design in guided busways is important, the very definition of a guided busway means that the vehicle path is fixed and the vehicle wheels will therefore always load the same area of road surface. This has implications for the durability of that surface, and the maintenance regime to ensure the quality of ride: pavements do not suddenly fail but gradually deteriorate to a level which may be described as failure. Such failure may be an unacceptable level of rutting or loss of skidding resistance. The long term design of the busway and the maintenance strategy should be considered: is the road designed for full 25 or 40 year life (plus some residual for hand back) or is a higher level of maintenance and reconstruction to be accepted? In this case the potential disruption caused by such maintenance and reconstruction will become important in an economic assessment of the guided way.

The form of construction of a segregated busway is most commonly concrete running surfaces. The long term maintenance of joints, and the method of construction together with maintenance to maintain macro and microtexture while ensuring safe skidding resistance should be considered.

CONCLUSIONS

With the publication of the publication of the Government's white paper on transport[12], there is a sense amongst transport planners that the message is finally getting through. If we are indeed at the turning point in relation to a more sustainable transport policy, then the challenge to provide attractive and efficient public transport alternatives is already with us. If our response is the habitual internecine warfare which has characterised the debate over the last ten years then we will have missed the bigger picture.

If we are to respond effectively to the challenge, we will need all the means at our disposal, and guided bus is now part of our arsenal, either in jam-busting or in LRT form. It may well be that what is developing in Leeds is the model for the future, with the most appropriate mode serving different corridors as part of one overall coordinated public transport system. Alternatively, different systems may be adopted in different towns. The historical distinction between modes is anyway becoming increasingly irrelevant as new prototype vehicles emerge.

The design issues relating to the use of guided bus as an LRT system are not new, except to the UK, and the next generation of schemes will benefit from some twenty years of development in Europe and elsewhere.

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