Leaning towards the future....

Countrylink's *X2000* Tilt Train Trial

By David Foldi - Project Manager, Tilt Train Trial

Introduction

In November 1994, Countrylink committed to an agreement with Statens Järnvägar, the Swedish State Railways (or "SJ" as they are known) and ABB Traction AB for a ten month lease of three X2000 Tilt Train cars for trial in NSW. The purpose of the trial was to evaluate tilting technology (as opposed to the X2000 itself) under local conditions.

This paper provides a brief introduction to the X2000 and an overview of the trials.

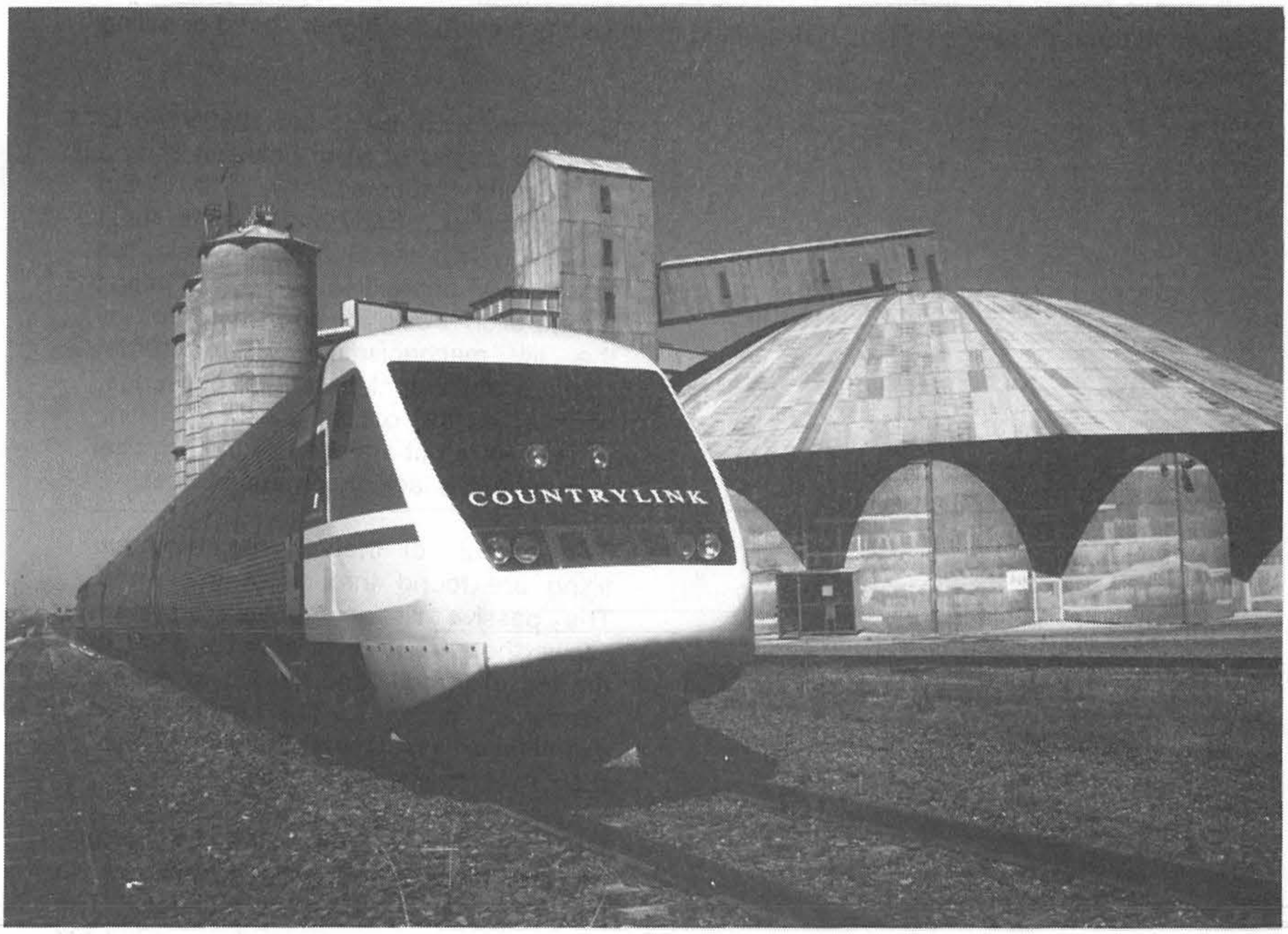
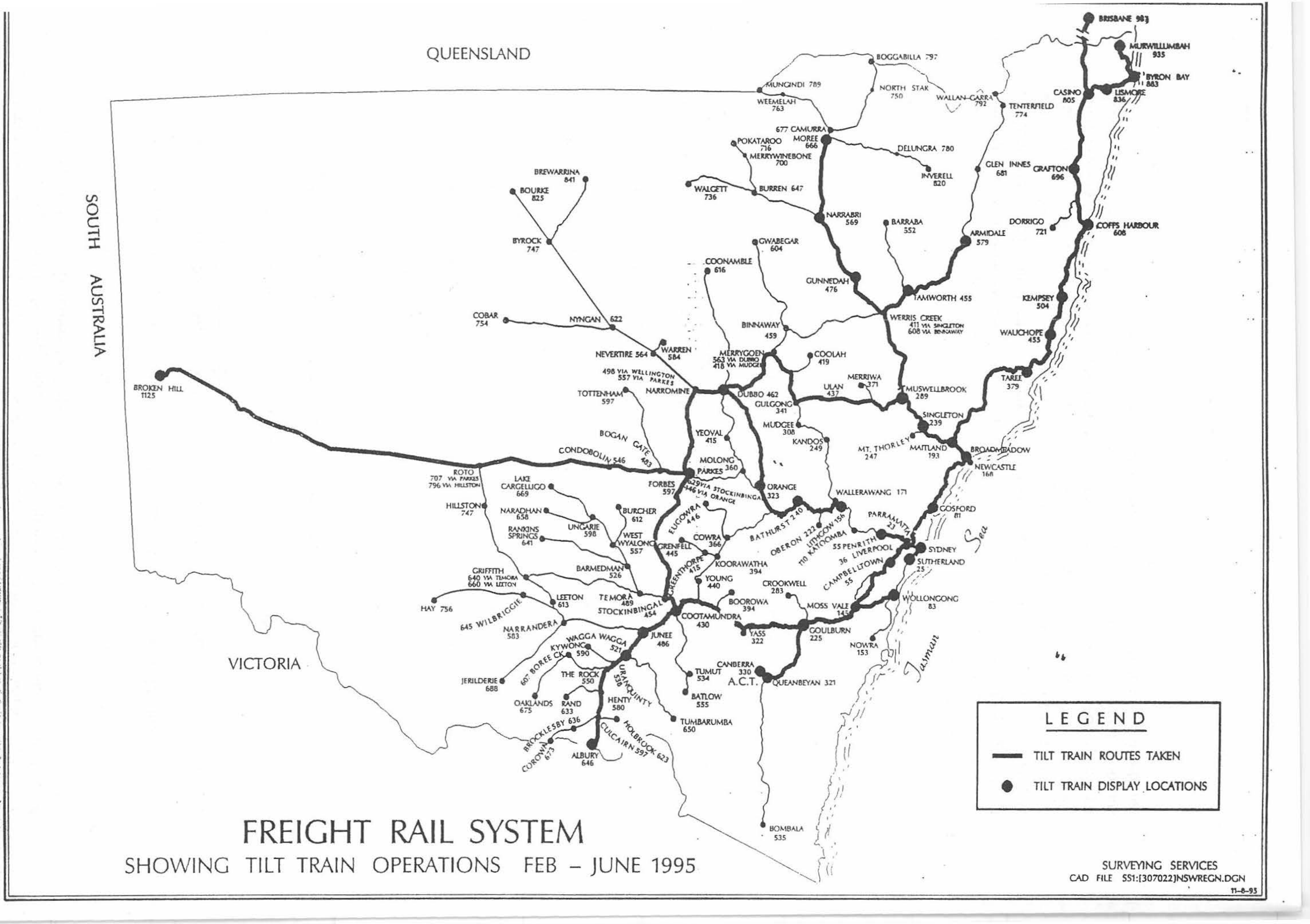


Fig 1. The X2000 Tilt Train near Bellata during the March 1995 State Tour. For demonstration purposes, a single XPT Power Car was used to pull the consist, allowing display of the X2000 nose. The second Power Car was coupled to the X2000 for the return journeys.


FREIGHT RAIL SYSTEM
SHOWING TILT TRAIN OPERATIONS FEB – JUNE 1995
QUEENSLAND
SOUTH AUSTRALIA
VICTORIA
A.C.T.
Tasman Sea
LEGEND
TILT TRAIN ROUTES TAKEN
TILT TRAIN DISPLAY LOCATIONS
BRISBANE 983
MURWILLUMBAH 935
BYRON BAY 883
CASINO 805
LISMORE 836
BOGGABILLA 797
MUNGINDI 789
NORTH STAR 750
WALLANGARRA 792
TENTERFIELD 774
WEEMELAH 763
677 CAMURRA
MOREE 666
POKATAROO 716
MERRYWINEBONE 700
DELUNGRA 780
INVERELL 820
GLEN INNES 681
GRAFTON 696
BREWARRINA 841
BOURKE 825
WALGETT 736
BURREN 647
NARRABRI 569
BARRABA 552
DORRIGO 721
COFFS HARBOUR 608
ARMIDALE 579
BYROCK 747
GWABEGAR 604
COONAMBLE 616
GUNNEDAH 476
TAMWORTH 455
KEMPSEY 504
WERRIS CREEK
411 VIA SINGLETON
608 VIA BINNAWAY
COBAR 754
NYNGAN 622
BINNAWAY 459
WAUCHOPE 455
NEVERTIRE 564
WARREN 584
MERRYGOEN
563 VIA DUBBO
418 VIA MUDGEE
COOLAH 419
BROKEN HILL 1125
498 VIA WELLINGTON
557 VIA PARKES
NARROMINE
DUBBO 462
MERRIWA 371
TAREE 379
TOTTENHAM 597
ULAN 437
GULGONG 341
MUSWELLBROOK 289
MUDGEE 308
SINGLETON 239
YEOVAL 415
KANDOS 249
BOGAN GATE 483
MT. THORLEY 247
MAITLAND 193
BROADMEADOW
CONDOBOLIN 546
MOLONG 360
PARKES
NEWCASTLE 168
ROTO
707 VIA PARKES
796 VIA HILLSTON
LAKE CARGELLIGO 669
FORBES 597
629 VIA STOCKINBINGAL
646 VIA ORANGE
ORANGE 323
WALLERAWANG 171
HILLSTON 747
NARADHAN 658
BURCHER 612
EUGOWRA 446
BATHURST 240
LITHGOW 156
PARRAMATTA 23
GOSFORD 81
RANKINS SPRINGS 641
UNGARIE 598
WEST WYALONG 557
GRENFELL 445
COWRA 366
OBERON 222
110 KATOOMBA
55 PENRITH
SYDNEY
36 LIVERPOOL
SUTHERLAND 25
GREENTHORPE 415
KOORAWATHA 394
CAMPBELLTOWN 55
GRIFFITH
640 VIA TEMORA
660 VIA LEETON
BARMEDMAN 526
YOUNG 440
CROOKWELL 283
WOLLONGONG 83
HAY 756
LEETON 613
TEMORA 489
BOOROWA 394
MOSS VALE 145
645 WILBRIGGIE
STOCKINBINGAL 454
COOTAMUNDRA 430
NARRANDERA 583
JUNEE 486
YASS 322
GOULBURN 225
NOWRA 153
WAGGA WAGGA 521
KYWONG 590
60? BOREE CK
CANBERRA 330
THE ROCK 550
URANQUINTY 536
TUMUT 534
QUEANBEYAN 321
JERILDERIE 688
BATLOW 555
OAKLANDS 675
RAND 633
HENTY 580
TUMBARUMBA 650
BROCKLESBY 636
HOLBROOK 623
CULCAIRN 597
COROWA 673
ALBURY 646
BOMBALA 535
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Tilt Technology

The principles of Tilt Train design developed from research carried out during the 1960's and 70's. As a number of countries in the developed world investigated the feasibility of high speed rail systems, it became apparent that in areas where topography, population or government priorities prohibited, the investment in new, dedicated high speed infrastructure was not possible.

Tilt Trains were developed as a means of improving journey times by increasing average speeds over existing track alignments.

This is achieved more by increasing speeds through curves than by increasing absolute top speed. Car tilting reduces the effects of centrifugal force on passengers, by simulating an increase in curve superelevation or cant. This allows a significant increase in the "balancing" speed, or the speed at which the resultant force between lateral acceleration (due to centrifugal force) and vertical acceleration (due to gravity) is perpendicular to the car floor.

It should be stressed that tilting of the cars serves only to increase the level of passenger comfort through curves. Tilting has nothing to do with achieving the higher speed of rolling stock.

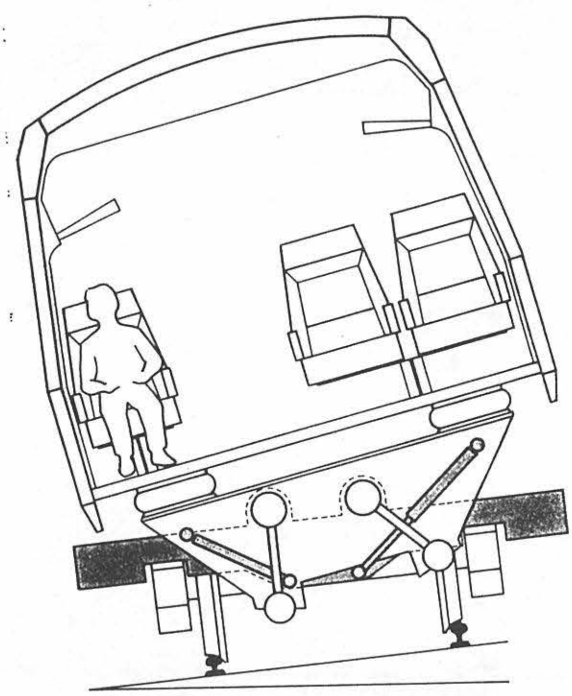

Fig 2. Cross section of X2000 car showing tilt mechanism. A maximum tilt angle of 8 degrees is achieved with all tilt equipment fitted beneath the floor to otimise passenger space.

Experimentation during the 1980's led to optimum angles of tilt of between 8° and 10° being adopted by Tilt Train manufacturers. Early poor results, most noticeably with the British APT train, led to a level of approximately 70% of lateral acceleration being compensated for by the tilt mechanisms. Full (100%) compensation contributed to passenger nausea, as the optical cues of a tilting horizon were not matched by the physical sensation of a lack of cornering forces.

Two schools of thought regarding car tilting are found throughout the world. The passive tilt or "pendular" system allows the cars to pivot about a point at the top of the car and tilt due to natural pendulum action. The most noted example of this is the Spanish "Talgo" train.

More common is the active tilt system, whereby tilting is initiated mechanically via hydraulic or compressed air cylinders. The cars tilt about a point lower down in the car body (usually the centre of gravity) and tilt is induced either by accelerometers mounted in the leading bogie of the first car, or by signals from track side transponders.

Active tilt systems are featured in the Italian "Pendolino" ETR 450 and 460's, the German VT610 DMU's, the Japanese TSE2000, and the Swedish X2000 (or more correctly known as the "X2") Tilt Trains.

The X2000 Tilt Train

The X2000 was introduced to revenue service in Sweden during 1990. The decision to introduce a tilt service, rather than conventional high speed trains on new infrastructure, was influenced by the spread of the sparse population over relatively large distances.

The X2000 was an immediate success. Traveling at service speeds of up to and exceeding 200kph, it cut the 457km trip between Stockholm and the major centre of Gothenburg from 4 hours for locomotive hauled trains to 2hrs 55mins. Further improvements are continually being gained through progressive infrastructure upgrading.

Some 60% of X2000 passengers were captured directly from the airline market. Aggressive marketing of both the X2000 trains and the service concept has resulted in a high percentage of this market being retained.

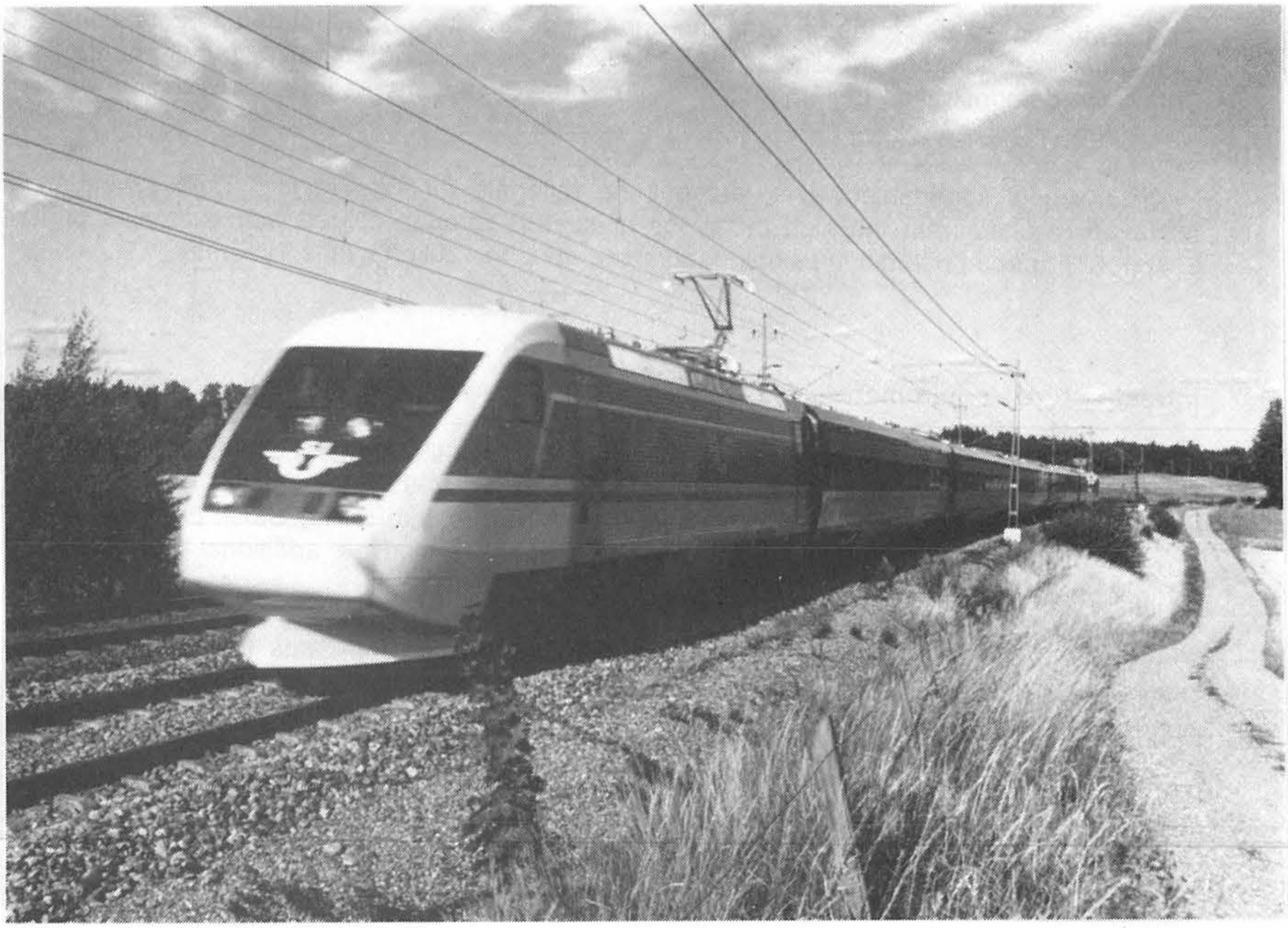

Fig 3: The X2000 operating in its native Sweden. The tilt angle of the Trailer Cars is evident when compared to the leading, non- tilting, Power Car.

The Swedish trains are electrically powered from line Voltage of 15KV-AC. Maximum rating of the power cars is 4.0MW. Trains consist of 1 power car, up to 5 passenger cars and the driving trailer or up to 12 intermediate passenger cars with 2 power cars.

The X2000's feature self steering bogies and active carriage tilting of up to 8° with tilting information derived from accelerometers on the bogies.

The X2000 in NSW

Three cars were leased to Countrylink; a driver trailer, a Bistro and a First Class car. The consist was propelled by two XPT power cars modified to include a generator set for train hotel supply, a drivers control panel, and stiffened suspensions.

Countrylink's Tilt Train featured seating for 100 passengers, a conference room , fax machine, public cellular telephone, disabled access and toilet facilities, video and three channels of stereo music. The "bar" like Bistro area also proved extremely popular (especially with Countrylink Staff during our extended state tour).

Top speed was limited to 160kph for Class one track with a 10% higher margin allowed for testing. This limit reflected the need to conserve the XPT Power Cars for the duration of the trial, the demands on the driver in the non-tilt power cars, track speeds and condition, passenger ride comfort, the limitations of level crossings, and signaling requirements. During the demonstration tour speeds in excess of 170kph were recorded between Junee and Albury.

High maximum speeds, however, are not the rationale for Tilt Trains. Time savings achieved resulted from the high increases of speeds through curves with examples of 90kph XPT speed posted curves being traversed at up to 130kph by the Tilt Train.

Infrastructure Requirements

The external dimensions of the Swedish Car were to cause the greatest challenges during the tour. With a width of 3080mm and length of up to 24.95m (17.7m between bogie centres), the cars fell between the Medium and Wide Electric Rolling Stock profiles. A "lower bolster beam" projecting from the bogies centres caused additional clearance infringements.

The FreightRail Out of Gauge Section's Profile Car traveled the State testing and re-testing planned routes for the revenue service and state tour. Infringements were recorded and detailed survey commissioned for design analysis.

This analysis was undertaken by FreightRail's Design Consultancy and the Projects Group (CityRail area). With a few minor exceptions it was found that the only impediments to the Tilt Train's movement would be platforms in the Medium and Narrow Non-Electric areas.

The process of platform analysis represented an enormous feat, not just in attempting to understand the behaviour of a foreign train by communicating with Swedish experts in a different time zone, but also in the huge volume of calculations required to analyse hundreds of platforms in an extremely short time. The skill and dedication shown by members of both design groups was a fundamental element in the projects success.

A strategy for areas of insufficient clearance was developed in consultation with the Design Groups and Division Engineers. For the planned revenue service route, Sydney to Canberra, a program of platform cutbacks and track slews between Glenlee and Canberra was developed and implemented. This was further complicated by the deadline of 5th March for the public demonstration run and the high summer temperatures limiting the option of track slews.

Away from the Sydney to Canberra route, a strategy to minimise infrastructure changes was adopted resulting in speed restrictions on the Tilt Train, or routing of the train via crossing loops or alternative lines to avoid clearance infringements. Work proceeded in this way up to and including the trial with speed profiles and route certification in some areas being completed and faxed to the train on the night before operation in a different corridor.

In addition to platform clearances, track centres in multiple track areas or between main lines and loops had to be checked prior to Tilt Train operation.

The analysis highlighted an interesting aspect of the X2000. As tilting occurs about the centre of gravity of the cars, the centre of tilting varies, resulting in the cars having a narrower profile than would otherwise be the case.

Project Achievements

The X2000 tour of the state and revenue service resulted in the Tilt Train covering a total of approximately 95,000km during its time in Australia. A total of 39 cities and towns were visited within 15 days during the state tour in March 95.

Limited platform clearances prevented operation in only two planned corridors, the Illawarra between Sutherland and Wollongong and the Main West between Penrith and Lithgow. Alternative routes were used to overcome these difficulties, however, namely the Unanderra-Moss Vale line and Ulan Lines respectively. Contrary to press reports at the time, the X2000 passed through a total of 51 tunnels, most of which were single track.

In revenue service, the Tilt Train covered some 75,000km carrying a total of 18,525 passengers in 57 days. A total of 4,944 passengers opted for Countrylink's "Premium Service" which provided meals and to-seat service as a trial for other Countrylink trains. The existing XPLORER timetable of 4hrs 7mins to Canberra was cut to a timetabled 3hrs 25mins and a best time of 3hrs 15mins. Remarkably this fastest time was achieved on 4/3/95, only 15 days after the arrival of the cars in Australia on 17/2/95. Curve speeds increases of up to 44% above XPT speed boards were achieved in regular service between Sydney and Canberra.

It is estimated that some 60,000 people inspected or traveled in the X2000 during the March tour and an estimated 600,000 inspected the cars at either the Royal Easter Show or Maitland Steam Fest, during April.

Project costs were contained within the originally budgeted figure of $7.5M.

Tilt Train Evaluation

Both during the X2000's time in Australia and since, a detailed technical and economic evaluation has been in progress. The aim of the evaluation is to review the information gained during the trial in terms of infrastructure requirements, rolling stock performance, market research, and potential funding sources.

The Steering Committee performing the evaluation has a brief to study high speed options for the Sydney to Canberra corridor, not just tilt trains. It is due to report to Government in late 1995.

Preliminary information gained during the trial indicated a high level of public acceptance of the Tilt Train concept. The features of the X2000 were widely praised by passengers, as was the high quality of service provided for the train.

The X2000 coped well with an environment very different from that of its native Sweden. Ride quality varied however, as expected, from excellent on the concrete sleepered portions of the route which compared well with Swedish standards, to barely acceptable in some areas. Consistent high speeds for a local Tilt Train would appear to require considerable track upgrading for success.

No problems were experienced with the Tilt Train's ability to cope with our transition curves however, which proved to be well within the X2000's capabilities of 4° tilt angle per second. Track studies undertaken early in the tour indicated that the X2000 trailer cars exerted lower track forces than did conventional XPT trailer cars, most likely due to the self steering bogies which are a feature of the cars.

The Future

The Tilt Train Trial indicated that these trains are a technically viable option for NSW conditions. Improved Tilt Train times for Sydney to Canberra are possible with preliminary estimates of times approaching 2-2¼ hours possible for rolling stock and infrastructure (including track upgrading and deviations) investments in the order of $500M.

The question of whether Tilt Trains are commercially viable is still to be answered and is the subject of the ongoing evaluation.

The Steering Committee is currently evaluating Tilt Trains against a range of options including high speed conventional rolling stock. A separate evaluation by the Department of Transport is also continuing into the "SpeedRail" proposal of a TGV type service offering travel times down to as little as 1hr 20mins for the Sydney to Canberra journey.

The future of high speed rail in NSW, while by no means certain, at least should be very interesting.

To achieve this, a formal staged design review process, tied to the quality assurance system, is being implemented. For each design package, at each milestone design stage, the design is to be reviewed against the functional requirements and the major risks associated with the design decisions made. This process is internal to the contractor, but does involve external stake holders in order to provide the assurances and confidence that the designs are appropriate.

The quality control system will hold the design at each of the milestone design points until the design review has confirmed that the design conforms to the requirements.

Currently the contractor does not plan to introduce any significant technology innovations to the end product. The application of tried and proven technologies will assist in the integration of the railway into State Rail as well as minimisation of the technical risks associated with the project.

CONSTRUCTION

The construction methodologies have been dictated by geotechnical conditions along the route, environmental requirements, risk mitigation and accessibility. Tunnel construction utilises three basic construction techniques.

Between Prince Alfred Park to south of Green Square Station at Beaconsfield, the tunnel passes through good quality sandstone with some shale intrusions. For this section, a total distance of 2.4 kilometres, hard rock tunnelling techniques will be used. The rock excavation will involve heading, using road headers and bench excavation methods with the use of canopy tubes (advanced re-inforcing on the roof of the tunnel) and forepoling in low cover areas. Tunnelling will take place from both faces with an access shaft being sunk at the rock/soft ground interface south of Green Square Station.

A special purpose soft ground tunnel boring machine will be used to excavate and construct the tunnel between Tempe Reserve and the access shaft at Green Square. (*Figure 2* provides a typical cross section). The tunnel boring machine will be of a slurry type with an outside diameter of approximately 11 metres and extending 100 metres in length. It will commence excavation from a temporary shaft constructed at Tempe Reserve near the southern end of the line. The tunnel boring machine itself utilises the latest technology. A bentonite slurry is pumped into the face of the machine, the excavated spoil mixes with the slurry and is pumped away from the face to a treatment plant to be located at Tempe Reserve. The treatment plant will separate out the bentonite from the spoil. The bentonite is then recirculated through the tunnel boring machine. The spoil itself is then dried and transported to the spoil disposal land fill site. Spoil transport within the tunnel is thus via sealed pipes with slurry pumping stations along the route. (*Refer figures 3 & 4*)

The slurry machine has been chosen principally because it allows for fine adjustment of the pressure at the face of the machine to ensure excavation stability and minimise settlement. The expected boring rate is 8 metres per day.

The tunnel lining and support is constructed as the machine progresses. Pre-cast concrete lining segments will be erected in the tail of the machine as it moves forward. The segments are manufactured to high tolerances in a pre-casting plant. Joints between segments will be sealed with continuous rubber seals to minimise water seepage into the tunnel. The void between the ground and the outside of the concrete rings is filled with grout injected through the tail of the tunnel boring machine as the excavation proceeds.

Fig 4: The Tilt Train on display at Penrith during the state tour. One of the Modified XPT Power Car used to pull the consist is shown here.

References

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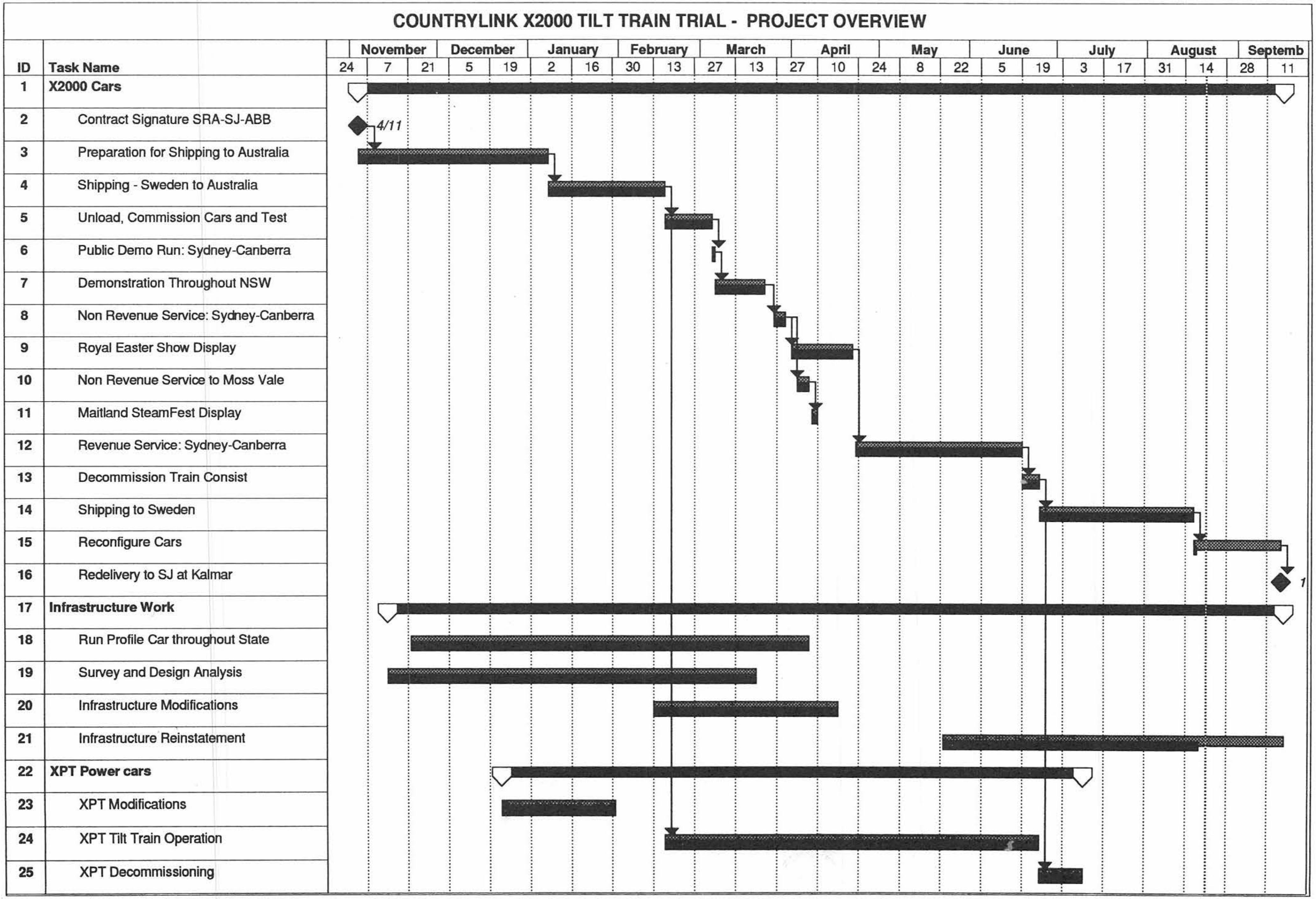
COUNTRYLINK X2000 TILT TRAIN TRIAL - PROJECT OVERVIEW
ID
Task Name
November
December
January
February
March
April
May
June
July
August
Septemb
24 7 21 5 19 2 16 30 13 27 13 27 10 24 8 22 5 19 3 17 31 14 28 11
1 X2000 Cars
2 Contract Signature SRA-SJ-ABB
4/11
3 Preparation for Shipping to Australia
4 Shipping - Sweden to Australia
5 Unload, Commission Cars and Test
6 Public Demo Run: Sydney-Canberra
7 Demonstration Throughout NSW
8 Non Revenue Service: Sydney-Canberra
9 Royal Easter Show Display
10 Non Revenue Service to Moss Vale
11 Maitland SteamFest Display
12 Revenue Service: Sydney-Canberra
13 Decommission Train Consist
14 Shipping to Sweden
15 Reconfigure Cars
16 Redelivery to SJ at Kalmar
17 Infrastructure Work
18 Run Profile Car throughout State
19 Survey and Design Analysis
20 Infrastructure Modifications
21 Infrastructure Reinstatement
22 XPT Power cars
23 XPT Modifications
24 XPT Tilt Train Operation
25 XPT Decommissioning